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ACOUSTIC PARTICLE IMAGE VELOCIMETRY AND SOUND INTENSITY TECHNIQUE IN VISUALISATION OF SOUND FIELDS

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Abstract

The paper describes two modern techniques which might be used in sound field visualisation. Both methods – Sound Intensity and Particle Image Velocimetry are presented, the most important conveniences and inconveniences are described, indicating possible limitations and showing relevant features which might lead to further development of the measurement.

Key words: *laser anemometry, sound intensity, acoustic flow visualisation*

INTRODUCTION

The acoustic field may be described as a spatial distribution of pressure and particle velocity and may be represented by one vector quantity – sound intensity (SI). Sound intensity is an energetic parameter which describes the average flow of acoustic energy (Fahy, 1995) and is extremely useful in many cases where the precise acoustic sound source characterisation is needed. Nowadays classical pressure acoustics methods have become omnipresent but its usage does not guarantee correct results in several cases. In order to obtain reliable results the use of an appropriate sound intensity probe is essential and the sensor has to be equipped with a three component acoustic particle velocity transducers and a pressure condenser microphone. The application of the sound intensity probes made possible to visualise many linear and non-linear effects in acoustic field which had never been seen before in conventional acoustics. Unfortunately this method has got some limitations mainly related to the impact on acoustic field by the introduced probe. This implies the fact that the acoustic research community is looking for a non-invasive method and the most promising seems to be Particle Image Velocimetry.

SOUND INTENSITY MEASUREMENTS BASED ON VIRTUAL INSTRUMENT

Sound intensity measurement with specialised pressure – velocity probe has to be considered as a very complex and time-consuming indirect measurement procedure. The need of translating the probe thorough the measured area and the nature of measured phenomenon makes the process even more complex.

In order to measure correctly the sound intensity a tight integration of probe module with translating unit and processing algorithms is needed. A system which can handle the full procedure of sound intensity has to be equipped with many subsystems responsible for each task. The paper presents the recently developed system which implements full scheme of the procedure. The programming environment chosen for the full integration is LabVIEW. It enables combining the serial communication protocol with data acquisition and processing of acquired data.

The virtual instrument was divided into 2 basic parts. The first consists of full data acquisition module combined with translating stage software drivers. The second part is responsible for the processing algorithms. This division was done in order to adapt the system to specific requirements of the sound intensity measurements. The first part records files with raw data – which protects the data from erroneous processing settings and enables processing it in many ways, even with algorithms which are not known during the acquisition process. Another reason of splitting the procedure into two parts was the optimisation of resources needed to achieve high performance. The acquisition part cannot be shortened, due to the minimal time of data acquisition to fulfil the industrial standards. The processing part has been optimised and it should be run on high speed computers in order to reduce the processing time.

Data acquisition is done with a DAQ card which was specially designed for sound and vibration engineering. The five channel card with 24bit analogue-digital converter which is sampled with 102.4kS/s provides high quality measurements. In order to obtain reliable and comparable results the procedure must follow the standards. According to the formal documents the filtration is done with a set of 100 1/12 octave filters. In order to optimise this process the computation was parallelised thus enables using modern multi-core processors. The virtual instrument based tool enables faster and more accurate measurements. In the fig 2 a fragment of acoustic field was showed. In order to perform correct comparison of reliability of the new system the filed was measured both with the RTA-840 and the new system. The figure shows the convergence between those two systems and thus proves its correctness.

The application of presented system reduces significantly the time needed for complete measurements. In the fig. 1 we can see a sample visualisation of sound intensity distribution in cross-section of a rectangular (15x15 cm) waveguide, the measurement took ~4 h with the new system, while with RTA-840 it would have taken more than 12 h.

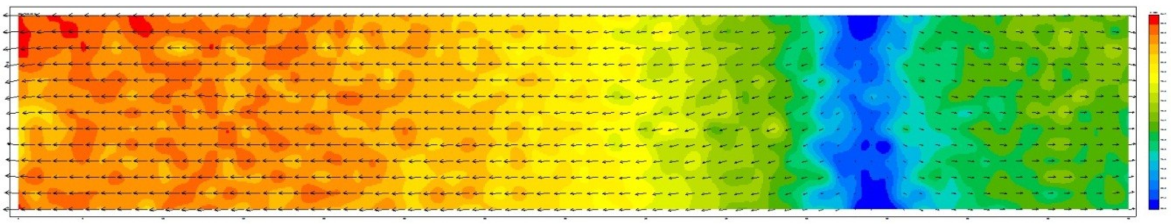

Figure 1: Acoustic waveguide visualisation

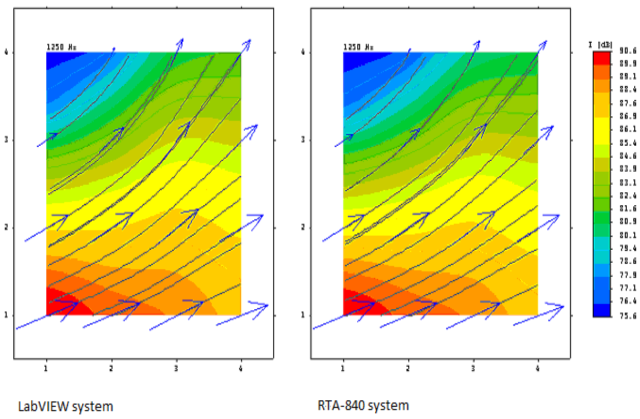

Figure 2: Comparison between results obtained from two systems

The data which comes from the sound intensity probe might be used as reference method of sound field visualisation. The main limitation of the typical probe is its size and the potential impact on the measured field. In case of measuring some low frequency sound fields the probe's impact on the acoustic field might be omitted, but in case of interesting phenomena which is observed on high frequencies the influence of the probe dimensions cannot be neglected. Even using the smallest available on market sound intensity probe (5 mm head of Microflown 3D USP transducer) does not allow reaching some particular areas, e.g. acoustic boundary layer in real flow fields.

PARTICLE IMAGE VELOCIMETRY

Particle Image Velocimetry (PIV) is a non-invasive technique based on particles added to the fluid, which enables recording by taking photos of the movement representing the flow in the field (Markus 2007 et al). The PIV is done with laser as light source and digital cameras as recording element. From the beginning it is obvious to indicate all areas where the laser-based techniques are superior to so-called traditional methods. The most important advantage of using laser based methods is its non-intrusiveness, so crucial in all observations where any external element may disturb the actual distribution of acoustic field. Moreover, the laser sheet with its properties evades another problem related to the size of the sensor.

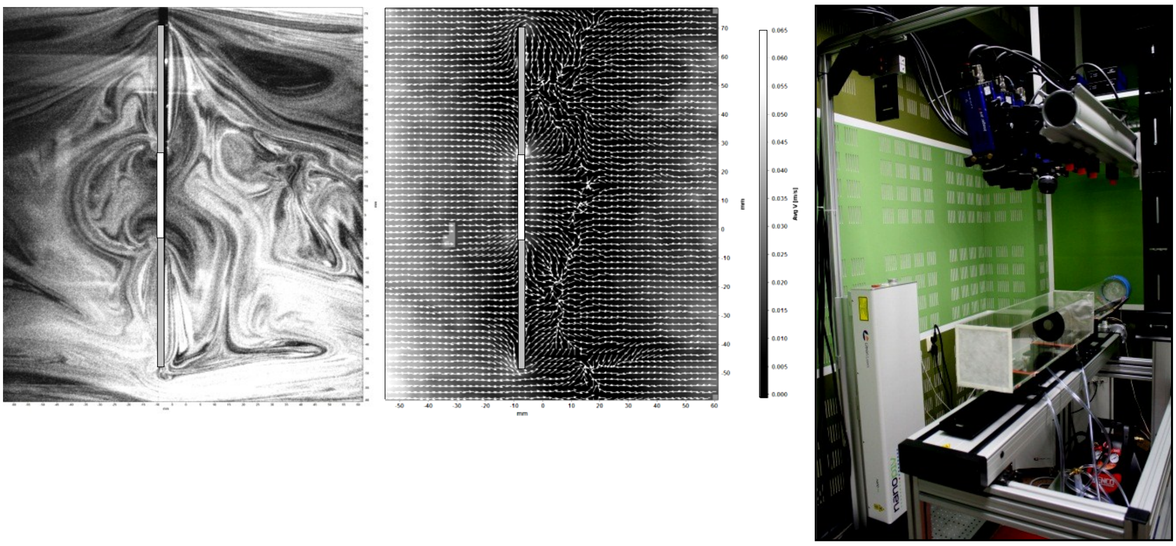

Figure 3: Sample seeding, obtained vector map and experimental setup

This paper presents a PIV set-up, built at our university, dedicated to acoustic flow in the square acoustic waveguide (fig. 3), and its ability to measure the acoustic particle velocity in the flow field. Specific aspects of the acoustic velocity have to be taken into account in order to achieve precise measurements, namely to deal with low levels or high frequency. In these areas some optimisation of the optics, the mechanical support, and the signal processing are required.

Laser based acoustic visualisation system generates different challenges and ideas and concepts taken from the conventional approach cannot be used directly. Different principle of operation disables the usage many procedures which are commonly used in the standard acoustics. These problems are described in the following part of the paper.

The first described procedure is called phase locked particle image velocimetry which is necessary because the observation of the object cannot be done with sufficient sampling frequency. In order to perform such type of measurements is necessary to assume that the observed state is stable and stationary. So far the best results were obtained for stationary single tone input. The period of the excitation is divided into several phases. The PIV system is synchronized with the input generator and the measurement is taken in chosen moment of time. This procedure repeated several times and averaged lets reconstruct the distribution of sound particle instantaneous velocity. In the figure 4 a visualisation (one cross-section) of instantaneous acoustic velocity field around an obstacle (disk with hole) is presented.

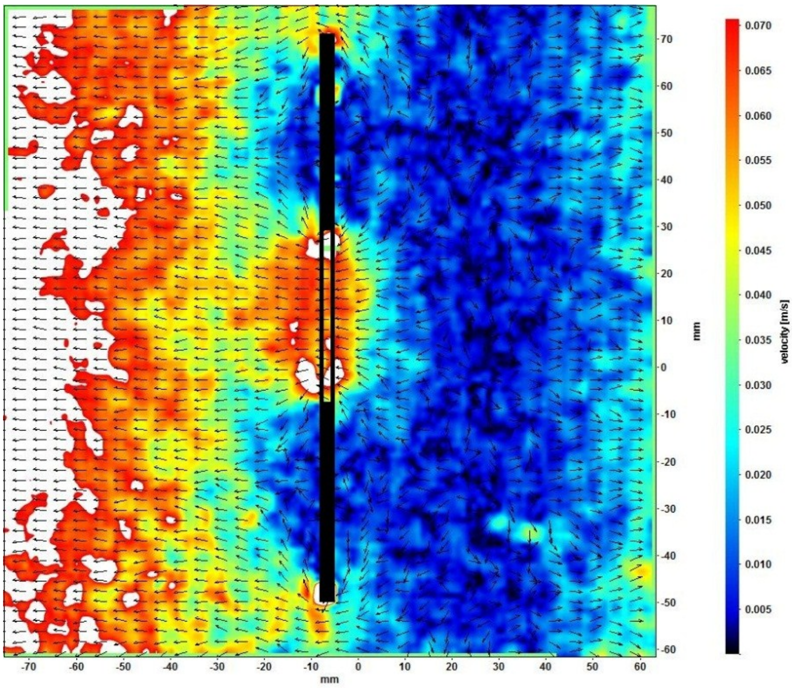

Figure 4: Instantaneous acoustic velocity field around an obstacle

This procedure repeated several times for each phase and averaged lets reconstruct the time-dependent distribution of sound particle velocity. In the figure 5 some chosen phases of propagating sound wave were shown.

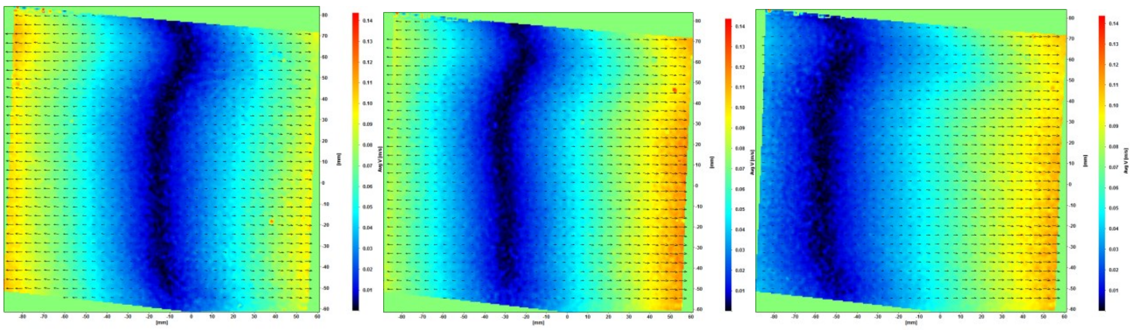

Figure 5: Images of acoustic wave in 3 different phases

So far the PIV technique gives us an opportunity of visualising the acoustic velocity but for sound intensity technique the pressure data is also indispensable. The lack of direct pressure data is a serious inconvenience of the method. The necessity to determine the sound pressure is obvious, due to the fact that the acoustic field is described as a spatial distribution of pressure and particle velocity or as a sound intensity. The problem of applying PIV to acoustics testing lies in the fact we have to calculate the pressure produced by the particle movement.

CHALLENGE

Modern research in acoustic fields and sources has to be based on sound intensity. The simultaneous information about pressure and acoustic velocity distribution give us complete description of phenomena occurring in physical objects. This fact causes our long-time and profound interests in described technique. Unfortunately sound intensity technique has got many limitations which already have been described. Among the list of inconveniences we find the highly time consuming procedure, which can be minimised but not overcome with the recently built system. Another problem with the probe-based system might be the limited spatial resolution of the measurements, which is not a technical problem but the balance between the quality of results and time spent on a single object. We dare to say that the sound intensity technique supported by modern computer solutions has achieved the maturity and no significant progress is expected. The goal of entering to the boundary zone needs to apply of a new and non-intrusive approach. The technique which may guarantee a research progress in that area seems to be PIV. Particle image velocimetry does not possess many inconveniences which are typical for sound intensity probes like the intrusiveness or low spatial resolution but the problem is located in different aspect of the procedure. The essential reason of applying all PIV related techniques like phase-locked or time resolved methods is the inability of homogenous sampling with fulfilling Nyquist criteria for sound issues. We are conscious that the essential assumption we did is that the acoustic flow is stable and deterministic. The matter of fact may change with further development of instrumentation equipment (high speed cameras and lasers). Another fundamental problem is that the PIV is an anemometry technique so is returns only the map of velocity vectors and there is no direct way to measure pressure.

The lack of direct pressure data obliges us to find different methods of getting the pressure information. Pressure as one of the physical parameters might be calculated indirectly – with different models (e.g. Navier-Stokes equation). As it is commonly known the numerical models are built with some simplifications and sometimes describe precisely the reality in macro scale but are not suitable for the micro scale. The success of applying certain models is also the issue of model's reliability and applicability to certain situation. In order to get some reliable pressure approximation the continuous comparison with measured data obtained using the classical sound intensity is still needed. So, the correct command and interpretation of SI technique is crucial for further development of PIV in acoustics.

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