FFT analysis of planar distributions of oscillations in a thermal plasma jet

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Plasma jet optical radiation was recorded by the arrays of optical fibres. The jet was observed from 4 directions in two parallel planes perpendicular to the jet axis. The record lengths and time resolution were sufficient for the application of the FFT yielding a detailed view of the oscillation phenomena in the plasma flow. The tomographical reconstruction of planar distributions of the jet radiation intensity from interpolated data was carried out via the inverse Radon transform. Significant oscillations were identified and their planar distributions examined by means of the Fourier transform. In this work we show differences between oscillations of electric and hydrodynamic origins. Different spatial distribution, stability and energy dynamics is shown. Possible case of close and mutually influencing frequencies is also described.

1. Introduction

Thermal plasma is due to its specific characteristics used in an increasing number of technological applications. The most common devices for the generation of thermal plasma jets (plasma torches or plasmatrons) use dc-fed electric arcs for heating the flowing gas media. Resulting strong temperature, velocity and density gradients in the generated plasma flow lead to turbulent phenomena influencing the involved technological processes. A better knowledge of these effects, which can cause instability of conditions and a bad reproducibility of the processes, is desirable for their future development [1,2]. Along with fluctuations introduced by the modulation of the electric arc current these effects result in oscillations which may be indicated in the plasma optical radiation [3] or electric potential [4] and analyzed by various methods. In the case of sufficiently long records, the fast Fourier transform (FFT) is an efficient tool for these analyses [5]. It allows us to distinguish various harmonic oscillations by their frequency and to identify important inherent frequency intervals for the process. Moreover, if we apply spatially resolved measurements, we can then analyse spatial distribution of different oscillations [6].

The results acquired by the FFT analysis of photodiode [7] or CCD camera [8] records of the plasma the jet optical emission have shown a high variety of possible oscillation modes, but all findings concerning the characteristics of various oscillation types lead in principal to the basic assortment into two basic groups – oscillations of either electric or hydrodynamic origins which show different spatial distributions of the oscillation amplitudes. However, the investigations of these phenomena hitherto have not reveal the complete spatial distributions of the studied fluctuations in the plasma jets because they have been based on single-direction observations. In this work we describe new results obtained from multi-directional observations of the plasma jet in the planes perpendicular to the jet axis at various distances from the plasma torch nozzle. These results principally confirm the previous results but they also show some new phenomena which could not be revealed by single-direction observations.

2. Experimental arrangement

In our experiments (Fig.1) the plasma jet was generated by a vertically oriented cascaded plasma torch with the maximal arc length 44 mm, arc current 150 A and nozzle diameter 8 mm.

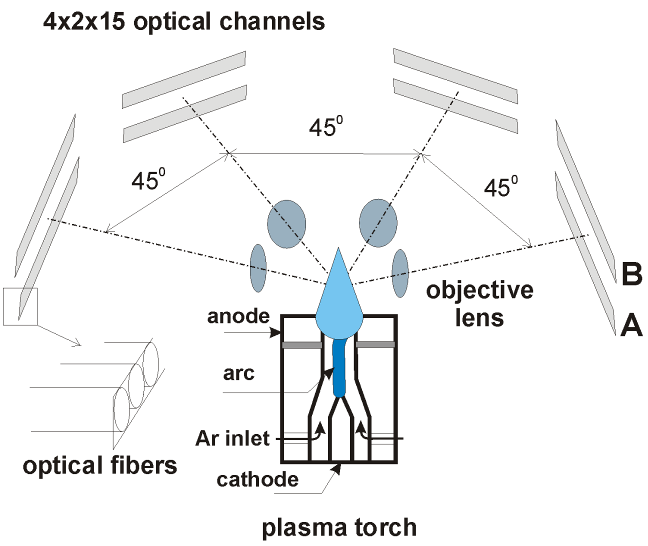

Fig. 1 – Experimental arrangement

The plasma torch was working with argon and the results presented here were acquired at the flow rate 30 slm. The plasma jet radiation was projected through 4 objective lens on face areas of linear arrays of optical fibers with diameters 1 mm. The arrays consisted of 15 elements each and they were arranged at 2 levels above the nozzle. The arrays at one level captured the radiation 2 mm above the nozzle orifice (denoted as **B** in Fig.1) and the arrays at the second level detected radiation 6 mm above it (denoted as **A** in Fig.1). The arrays detected the plasma jet radiation from 4 directions separated by angle intervals 45°.

The electronic part of the measuring equipment consisting of photodiodes, amplifiers, multiplexers, A/D converter and computer provided the records with the sample rate 468 kHz/channel and record lengths 1 Msample/channel. For the data evaluation we have used the method of trigonometric and polynomial interpolations extending the number of the input profiles for the inverse Radon transform which was computed in MATLAB [9]. With these methods we could reconstruct either the distribution of plasma jet radiation intensity or distribution of specific oscillations in each of the planes depending on the kind of profiles taken as an input for the inverse Radon transform. Four time-dependent or mean radiation side-on intensity profiles are used in the former case and four power spectral density (PSD) profiles for the specific frequency (acquired by the FFT of each measured channel) in the latter one. When we use mean radiation profiles, we calculate the mean from the whole record. FFT is also applied to the whole 1 Msample record.

3. Results

The reconstruction of the average total jet radiation intensity in both planes yields expectable results. This radiation intensity shows cylindrical geometry and distributions similar to gaussian ones (Fig.2). In this and all the following figures red colours correspond to high intensity values, while blue colours show regions with small values of the intensities or oscillation amplitudes. The distribution is more uniform in the plane B, which is closer to the nozzle. In the plane A we can see some displacement of the intensity maximum and a more irregular shape.

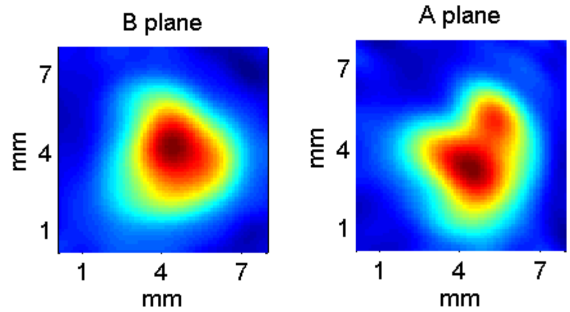

Fig.2 – Total jet radiation intensity in both recording planes

In coherence with our previous results the oscillations at electric frequency (300Hz) are present mainly at the jet axis and their distribution is similar to that of the total jet radiation intensity (Fig.3). These oscillations originate from the small ripple in supply current and the energy concentrated in these oscillations decreases with the distance from the plasma torch nozzle (Fig 4). Comparison of spatial distribution of these oscillations between plane A and plane B shows that radial and angular positions of these oscillations in the plasma flow are relatively stable. However we can still see some displacement which can probably be ascribed to the vortex structures or to the collective (maybe rotational) movement of the jet.

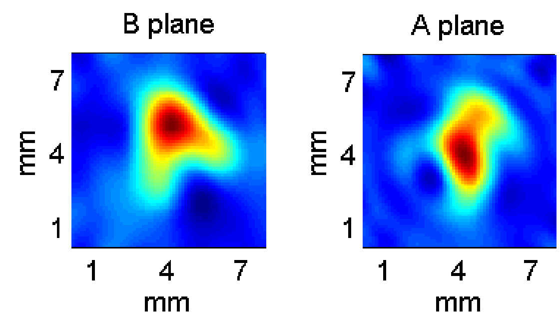

Fig.3 – Distribution of oscillations at 250-350Hz in both recording planes

The structures characteristic for higher frequencies, which are hydrodynamic in origin, manifest themselves in the boundary layer. This is the area of mixing with external air and more turbulent flow (Fig.5). These oscillations gain more energy in the downstream parts of the flow and some of them are actually generated “on the way” (Fig.6).

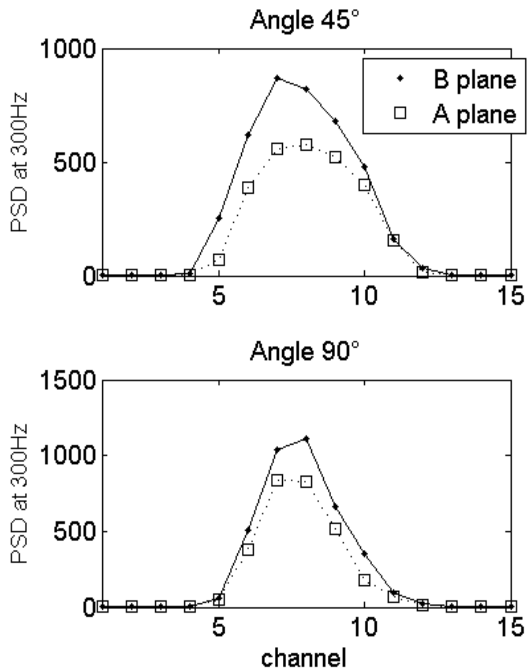

Fig.4 – Profiles of PSD around 300Hz in two planes and for two angles of view

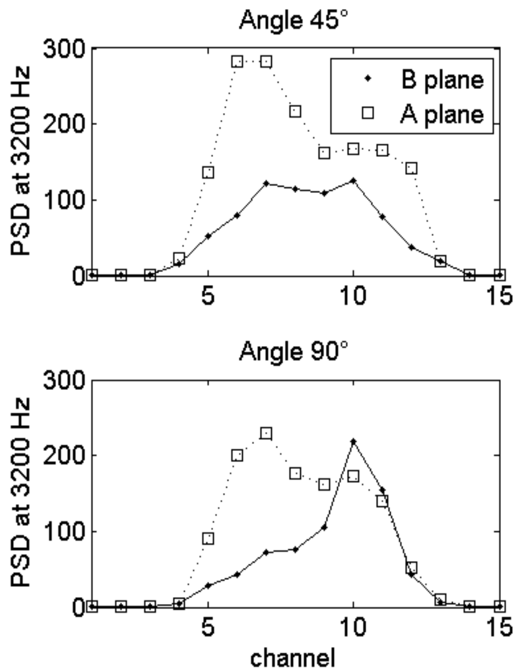

Fig.6 – Profiles of PSD around 3200Hz in two planes and for two angles of view

Comparison of spatial distribution of these oscillations between plane A and plane B shows that these oscillations change their position in much more vivid way. This can probably be ascribed to the vortex structures.

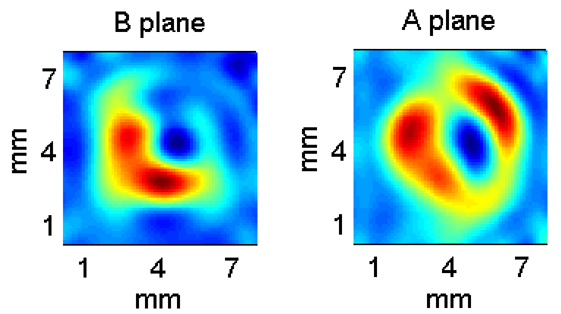

Fig.5 – Distribution of oscillations at 3150-3250Hz in both recording levels

Interesting phenomena occur in the frequency interval, where the harmonic of the main electric frequency and subharmonic of the hydrodynamic frequency are very close to each other. We can speculate, that the strong electric frequency (600 Hz, Fig.7) supported from inside parts of the plasma torch "energizes" one of the subharmonics (582 Hz, Fig.7) of the hydrodynamic frequency (1164 Hz, Fig.7).

Resulting oscillations form very stable and well localized regions (Fig. 8). In the downstream parts of the flow (in the plane A) those regions join into a ring-like structure.

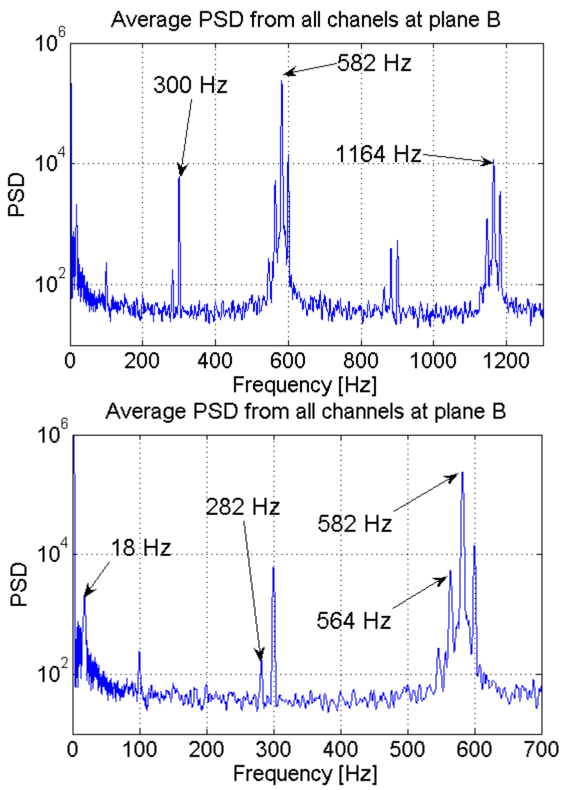

Fig.7 – High resolution PSD for plane B (with detail 0-700 Hz at the bottom).

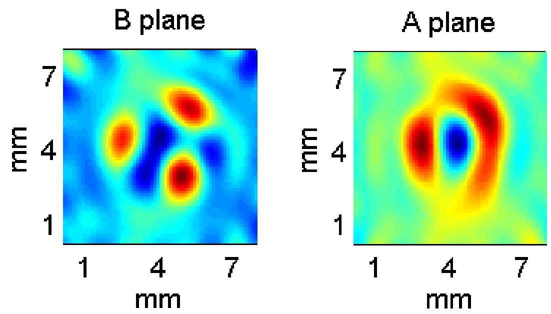

Fig.8 – Distribution of oscillations at 500-700Hz in both recording planes

4. Conclusion

A new way of plasma jet optical radiation measurements performed simultaneously from different angles allowed us tomographical reconstruction of spatial distributions of different oscillation structures. Low-frequency oscillations, which are electric in origin, manifest themselves in the jet core and show a relatively stable behaviour. High-frequency oscillations are created and manifest themselves in the boundary areas and possess vivid dynamics. The results have also shown an interesting example of possible interaction and energy transfer between different oscillation types.

Acknowledgement

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6. References

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