EFFECTS OF ARC CURRENT MODULATION ON DOMINANT OSCILLATIONS IN PLASMA JET

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ABSTRACT

Stability phenomena and time constants of instabilities in thermal plasma jets are essential in thermal plasma applications. We present observation of a thermal plasma jet generated by DC (direct-current) argon plasma torch by 8x15 matrix of fast photodiodes. The arc current was intentionally modulated in intervals 0.25 s long interposed by unmodulated gaps of the same length. Record of plasma radiation was analyzed by Fourier transform yielding spatial distribution of oscillations at selected frequency intervals. Results show that the oscillations present during unmodulated part in some frequency intervals are suppressed in the modulated part of the record. Suppression of oscillations depends on the location in the jet. It is strongest near nozzle orifice and weakest in the shear layer for frequencies lower than the modulation frequency. Suppressed higher frequencies show opposite spatial characteristics.

1. INTRODUCTION

Stability phenomena and time constants of instabilities in thermal plasma jets are essential in most technological applications using plasma torches (e.g. for cutting, welding, spraying, etching, waste treatment, chemical synthesis etc.) [1]. In the cases when time constants of the participating processes are high (such as heating of particles in plasma spraying), faster plasma fluctuations with shorter time scales will not be significant. Ability to suppress or induce specific oscillations in plasma flow can be advantageous for improving technological applications. Instabilities and oscillations can be influenced either by torch design modifications [2] or flexibly by ad hoc modifications of operating parameters.

In this paper, we present observation of a thermal plasma jet generated by DC argon plasma torch by a matrix of fast photodiodes. The oscillations of plasma density and temperature and consequently plasma radiation intensity are caused and influenced by several factors (e.g. irregularities in input current, hydrodynamic phenomena and acoustic effects imposed by plasma torch geometry). A relatively easy way to influence flexibly the oscillations is additional modulation of arc current [3]. In our experiment, the arc current 145 A was supplied by DC power supply. Due to the properties of power supply, arc current shows about 10 % ripple modulation at 300 Hz. The arc current was additionally modulated in intervals 0.25 s long interposed by unmodulated gaps of the same length. Sinusoidal waveform with amplitude 30 A and frequency 15 kHz was used as a modulation. Modulated and unmodulated parts of the record were then compared.

2. EXPERIMENTAL ARRANGEMENT

We have used a vertically oriented water-cooled DC plasma torch characterized by a short arc (its length is about 6 mm) and nozzle diameter 6 mm. Plasma torch operated in ambient atmosphere at atmospheric pressure. We used argon as working gas with total flow rate 0.65 g/s. Argon was fed in both tangentially (0.4 g/s) and axially (0.25 g/s). The plasma torch was working with arc current 145 A (ripple modulation approx. 10 %).

The plasma jet radiation was detected by optical system composed of optical fibres connected to photodiode array. Fibres were arranged in 8x15 matrix and plasma jet was projected on it (Fig. 1). Sampling frequency was 468 kHz/channel. The whole record covered the time interval 1.8 s.

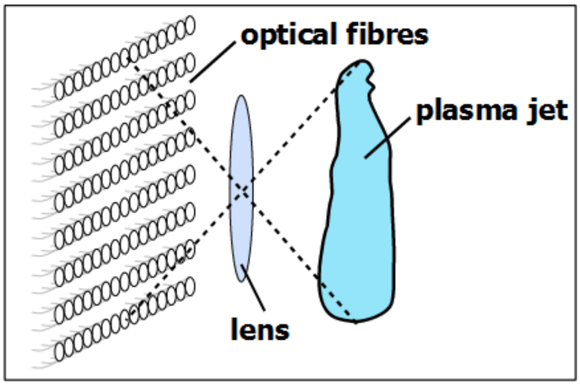

Fig. 1 Experimental arrangement.

3. RESULTS

Separate analysis of unmodulated and modulated parts yields slightly different frequency spectra. We have calculated PSD (power spectral density) of optical signal averaged over all 120 channels in order to cover phenomena both in the jet core and on the boundaries. Modulation frequency 15 kHz is clearly visible. There are also peaks at frequencies 15 kHz ± 300 Hz, which indicate interaction of modulation frequency with current ripple (Fig. 2). Frequency spectrum of arc current records in the modulated part shows the peak corresponding to modulation frequency, but it shows no peaks at 15 kHz ± 300 Hz. Any distinctive peaks at subharmonics (7.5 kHz, 3.75 kHz, etc.) are not present neither in arc current records nor in optical signal.

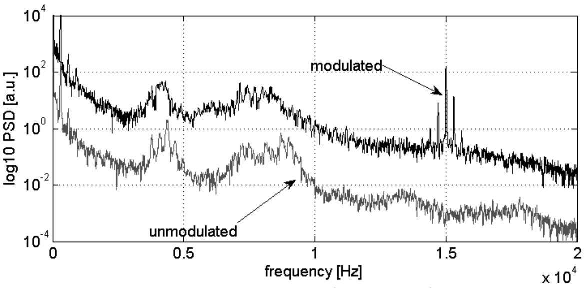

Fig. 2 Power spectral density of radiation fluctuations (all channels -summarized signal) in the unmodulated and modulated intervals. Modulated plot is shifted for better clarity.

However, oscillations in the frequency intervals 3-5 kHz and 8-10 kHz are influenced and slightly suppressed by the modulation. This effect is more significant if we focus on individual channels and therefore distinctive areas of the jet. We can get a relatively good picture (considering resolution of only 120 pixels) of mean jet intensity after smoothing and interpolating the images of the plasma jet.

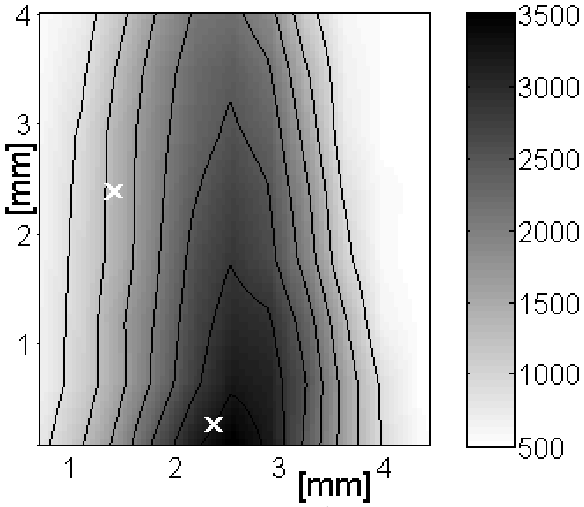

*Fig. 3 The average intensity [a.u.] of the plasma jet (isolines: step = 500). Channels (4,4) and (7,8) are marked by white marker **x**.*

The average image is in Fig. 3. Positions of channels used as representations of jet core and jet boundary are also marked in Fig. 3.

Comparison of power spectral density of fluctuations in the jet core and at the boundary show that 15 kHz modulation leads to suppression of some distinctive peaks in 3-5 kHz interval and slight suppression of frequencies in the 8-10 kHz range (Fig. 4). Although subharmonics of modulation frequency themselves are not pronounced they can significantly influence close frequencies. Modulation increased some oscillations in the range 6-6.5 kHz at the jet boundary.

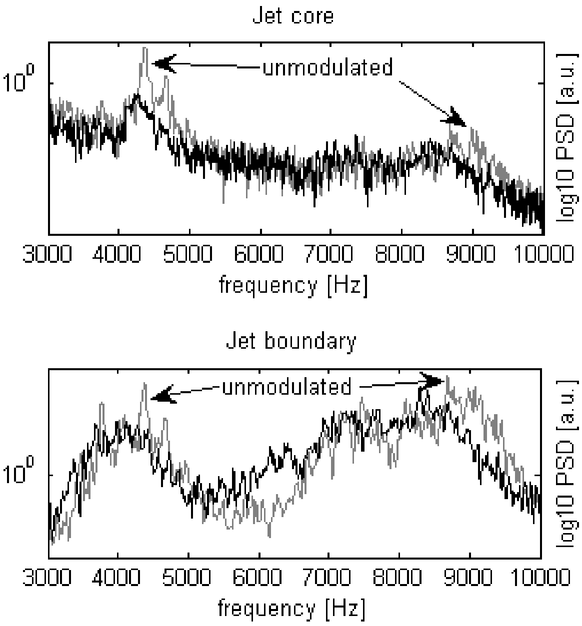

Fig. 4 Power spectral density of signals from chan. (4,4) and (7,8) in modulated (black) and unmodulated (gray) part.

Our record contains 3 modulated and 3 unmodulated intervals. Energy content in selected frequency ranges is quite consistent with presence/absence of modulation, although there are also some minor differences between individual modulated intervals (and between individual unmodulated intervals). The results further confirm suppression of lower frequency oscillations in 2 of 3 analyzed frequency ranges (Fig. 5).

Overview of spatial distributions of the modulation influence on PSD in selected frequency intervals show areas near jet core as the most affected (Fig. 7).

Values outside jet shear layer are not reliable, because the difference can be caused by slight change in jet shape and position of its boundaries. For reference about jet shape see Fig. 3.

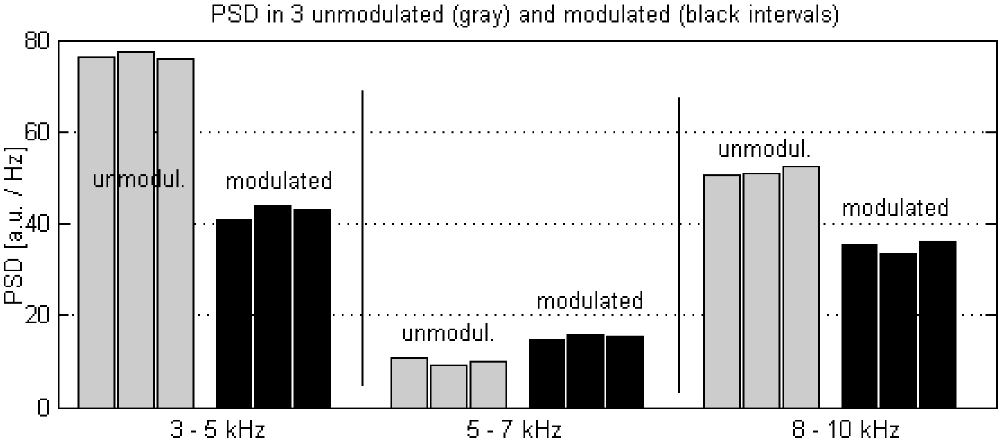

Fig. 5 Power spectral density summed in selected frequency intervals. Averaged data from all 120 channels.

Decrease is most significant in the range 3-5 kHz (44% decrease in modulated parts). Higher frequencies near 18 kHz and 27 kHz are also influenced same way in some areas of the jet, meaning decrease in modulated intervals (Fig. 6). Increase due to modulation (besides around modulation frequency itself) is present in the range 5-7 kHz and it is most pronounced at the jet boundary near jet tip.

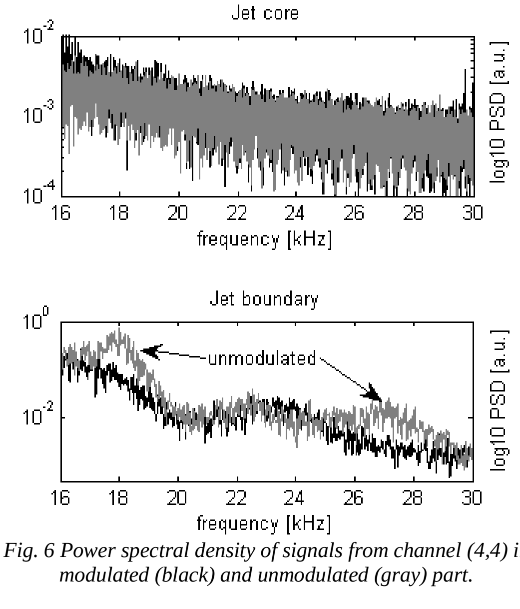

Fig. 6 Power spectral density of signals from channel (4,4) in modulated (black) and unmodulated (gray) part.

4. CONCLUSION

We have analyzed thermal plasma jet generated by DC argon plasma torch in the situation with and without additional modulation of arc current. Results show that modulation by frequency 15 kHz has impact on both lower and higher frequencies. Power spectral density is suppressed by tens of percent in some frequency intervals. This suppression of lower frequencies is strongest near nozzle orifice and weakest in the shear layer and near jet tip where, on the other hand, higher frequencies are suppressed better. Asymmetries in spatial distributions of oscillations and in the effect of modulation can be ascribed to even small asymmetry of arc root attachment and imperfections in cathode geometry.

The phenomenon of influencing instabilities with frequencies far from the modulation frequency may be explained by redistribution of some energy from frequencies introduced by hydrodynamic or acoustic oscillations to the higher frequency ranges that may be insignificant for some thermal plasma applications.

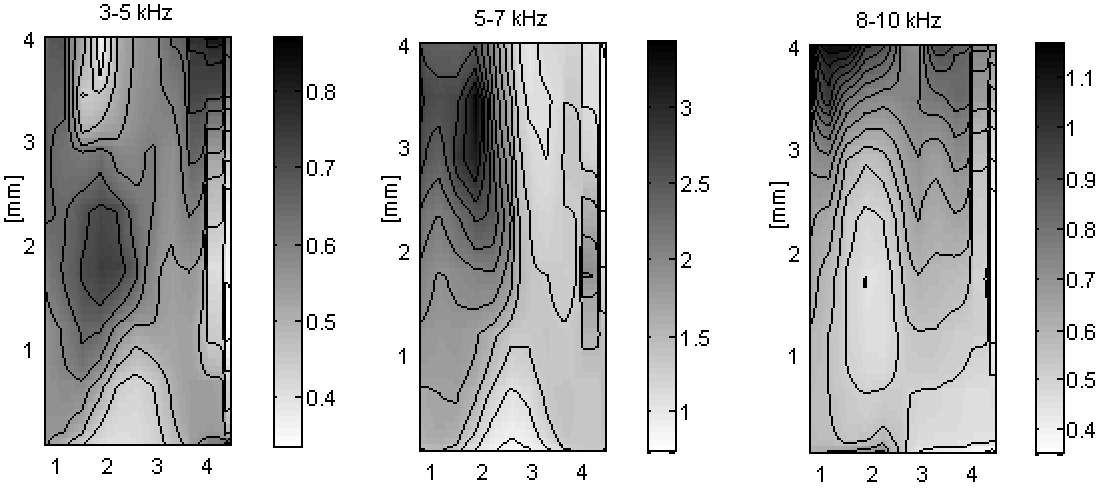

Fig. 7 Spatial distribution of ratio
(PSD in modulated interval)/(PSD in unmodulated interval)

ACKNOWLEDGEMENT

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