MAPPING OF THERMAL PLASMA JET NON-LINEAR DYNAMICS IN RECONSTRUCTED PHASE SPACE

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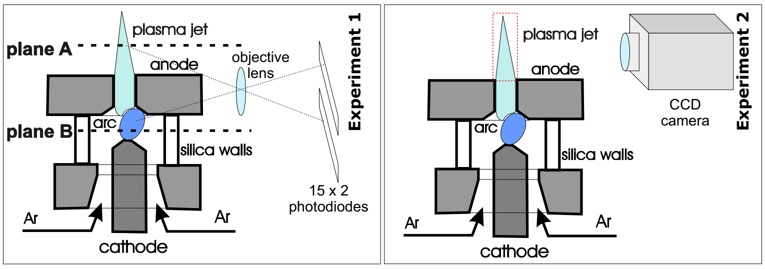
ABSTRACT

Thermal plasma jet optical radiation was observed by the arrays of optical fibers and by high-speed CCD camera. We then used method of time-embeddings for reconstruction of dc plasma torch dynamics in the reconstructed phase space. Different properties of the plasma flow dynamics and dependence of this dynamics on input conditions (gas flow rate) is then described. We focused on non-linear and chaotic phenomena and tried to estimate the correlation dimension related to (supposed) strange attractor of the dynamics. Sufficient spatial resolution allowed us to map distribution of this estimated correlation dimension in different areas of the plasma jet and to compare it with distribution of significant oscillations. This offers alternative method to describe the dynamics and provides strong tool for the analysis of the stability of plasma torch working conditions.

EXPERIMENTAL ARRANGEMENT



D.C. fed Ar plasma torch (plasmatron), mean arc current 90 - 210 A, flow rate of argon 0.5 - 3 g/s, maximal arc length 5 mm, nozzle diameter 6 mm. Sampling rate 468 kHz (photodiodes) and 100 kHz (CCD camera)

ESTIMATION OF CORRELATION DIMENSION

Correlation dimension measures chaoticness of the process by estimating "dimensionality" of underlying attractor. Data is embedded into n-dimensional phase space and we estimate correlation sum (normalized number of points within all hyperspheres of radius *r*) by randomly choosing many pairs of points. For each *r* we get different correlation sum. Data were divided into subsequent chunks, normalized and correlation dimension estimated as mean along higher embedding dimensions in the same scaling region for all the chunks.

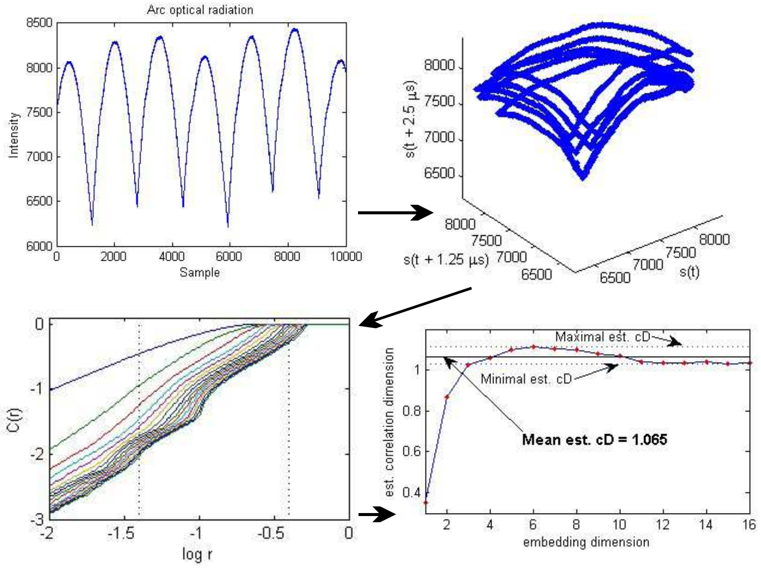
$$C(r)=\frac{2}{N(N-1)}\sum_{j=1}^{N}\sum_{i=j+1}^{N}\Theta(r-r(i,j)) \qquad cD=\lim\frac{d\log(C(r))}{d\log(r)}\ ,\quad (r\to 0)$$

METHOD OF MEASUREMENT

The plasma jet radiation was projected on face areas of linear arrays of optical fibers. The arrays at **plane B** captured the radiation of the arc inside the chamber and the arrays at **plane A** captured the radiation of the plasma jet 2 mm above the nozzle orifice. In the second experiment, optical radiation was recorded by high-speed CCD camera.

RESULTS

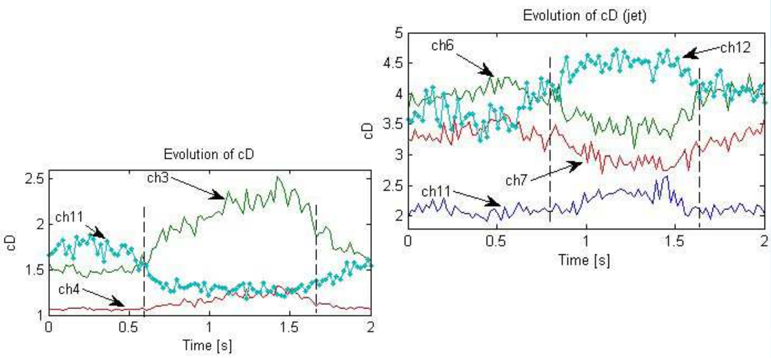
SAMPLE RECORD



For each chunk of data, we calculate correlation sum for each embedding dimension. Slope of the *log C(r) / log r* graph is the estimated correlation dimension. We then use mean of these estimates along embedding dimensions 4 - 16 as final estimate. We also keep in mind maximum of the estimates (along embedding dimensions) in each analyzed case to assess how good this estimation is.

EVOLUTION OF ESTIMATED CORRELATION DIMENSION

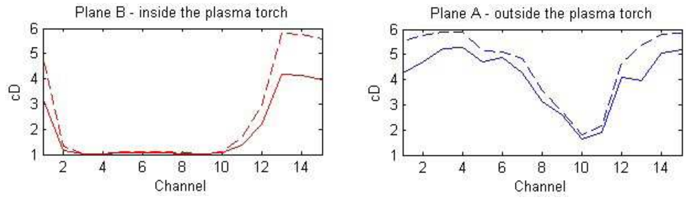
(arc and jet recorded simultaneously, gas flow rate 0.5 g/s)



The record was divided into 100 chunks, each chunk corresponds to 62.5 ms. We can see that complexity evolves and that decrease of cD in boundary channels on one side is *coincident* with increase in boundary channels on the other side. Estimated correlation dimension is *higher in the plasma jet* than in the arc.

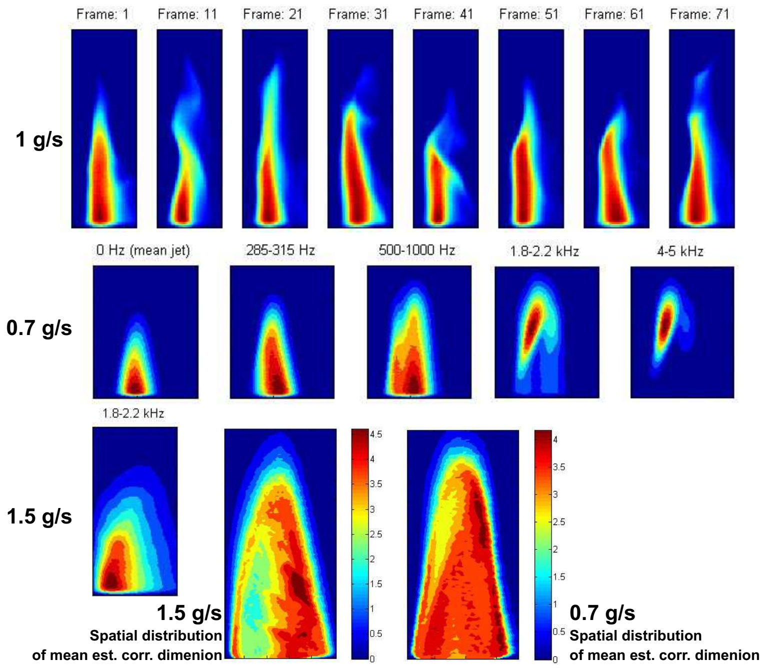
PROFILES OF ESTIMATED CORR. DIMENSION

(for one of the optical records)



These profiles were estimated from record with gas flow rate 0.5 g/s. Other records lead to similar profiles with lower estimated correlation dimension in the plasma jet core and higher at the boundaries. Results indicate, that the axis of the plasma arc is not the most stable region.

SAMPLE FRAMES RECORDED BY CCD CAMERA, DISTRIBUTION OF SOME SIGINFICANT FREQUENCIES AND DISTRIBUTION OF EST. CORRELATION DIMENSION



CONCLUSION

We have estimated correlation dimension for records of plasma optical radiation. Our method is based on Grassberger-Procaria algorithm. We have found uniform scaling region for all the normalized data, leading to nice convergence for low-noise records and to still meaningful and comparable numbers for more noisy and unstable records from the jet shear layer.

Est. corr. dimension evolves, increases with gas flow rate and its spatial distribution is quite complicated, forming layered or helix-like structures. Generally it is higher at the turbulent jet boundary. In the area of significant and stable oscillations is est. corr. dimension decreased. All this reflect dynamics of the process and offers, besides other methods, alternative view to this dynamics and its analysis.

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