Investigation of dynamic effects in thermal plasma

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Evropský sociální fond
Praha & EU: Investujeme do
vaší budoucnosti

INTRODUCTION

The instabilities in thermal plasma jets are mostly caused by turbulence, arc root attachment movement or wear of the torch parts. Using tomographic methods of the plasma jet diagnostics[1] it's possible to develop methods which are able to detect new spatial aspects of the instabilities and thus opening possibility for additional improvements to the torches themselves, which will likely result in higher accuracy, longer lifespan and because of that - cheaper operation.

EXPERIMENTAL ARRANGEMENT

The experiments with water-cooled lab DC plasma torch, mounted vertically facing ceiling (Fig. 1) had arc length of 5 mm, nozzle diameter 6 mm and jet height ranging between 10 - 15 mm. The arc currents varied between 100 and 200 A. The used working fluid was argon gas with flow rates 0.5 - 1 g/s. Radiation of the arc and plasma jet was either captured by the CCD camera or projected through 8 objective lens on face areas of linear arrays of optical fibers (formed by 15 elements) arranged at single level capturing the radiation of the plasma jet about 3 mm above the plasma torch nozzle, at 8 directions (arranged into semicircle by 22.5°). The sampling rate of the recording electronic equipment was 468 kHz/channel for the optical fibers and 121.1 kHz for the CCD camera.

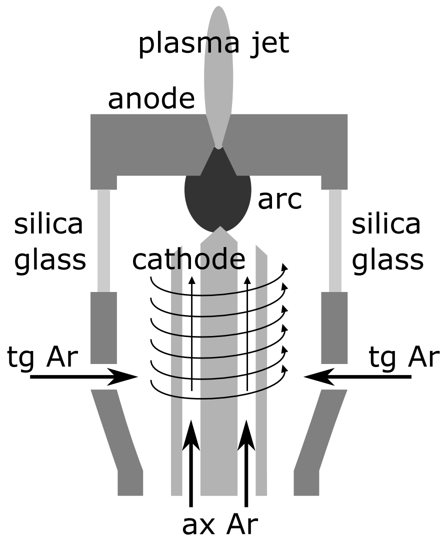

Fig. 1. Scheme of the lab DC plasma torch. The arc chamber is observe-able through silica glass windows.

Experiment with industrial torch had arc length 10 mm and nozzle diameter 2 mm. Torch was aligned vertically facing ground and a copper water-cooled rotating disk served as working arc anode, arc current was 60 - 80 A. Working fluid was air pressurized at about 3 - 5 bar. Capturing device was CCD camera with sampling rate of 121.1 kHz.

NOZZLE WEAR

We investigated influence of damage to plasma torch nozzle affecting the arc stability. The highest probability of damage occurring to nozzle is during the start-up period and is caused by the pilot arc being exhausted out of the torch until finally attaching to the working anode. The arc typically moves through the same inner part of nozzle each time - causing damage which in the end results to nozzle losing its geometry and thus jet getting wider and less stable which greatly influences effectivity of the torch.

To determine jet stability, we measured its axis dispersion and position, jet width and deviation. An algorithm using image filtering and edge detection determinates the area, with highest intensity and analyzes its shape.

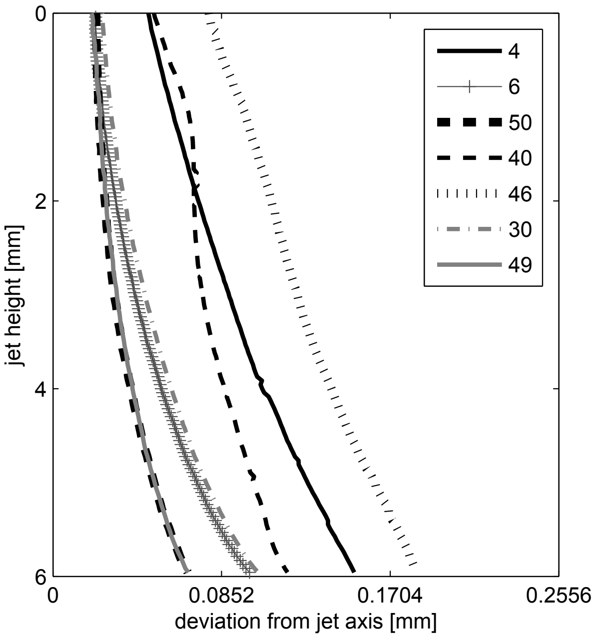

Fig. 2. Deviation of maximum intensity from the jet axis. 49,50 - new nozzle, 4,6,30 - lightly damaged nozzle, 40,46 - heavily damaged nozzle.

It is apparent that the intensity distribution on damaged nozzle is far wider and thus less stable than on new one, Fig. 2,3. The jet shape is mostly influenced by the condition of the nozzle inner gas expansion area.

Measuring the weight of new nozzles and of those after experiments showed no perceptible difference (the weight differences were in most cases were under 0.01 g) and only heavily damaged nozzles show apparent visual changes, because of these results, it's clear that even minor - by naked eye not observable changes in nozzle surface can affect the jet stability. Jet width with nozzle num. 40 reaches twice the width of jet with nozzle num. 6 mounted.

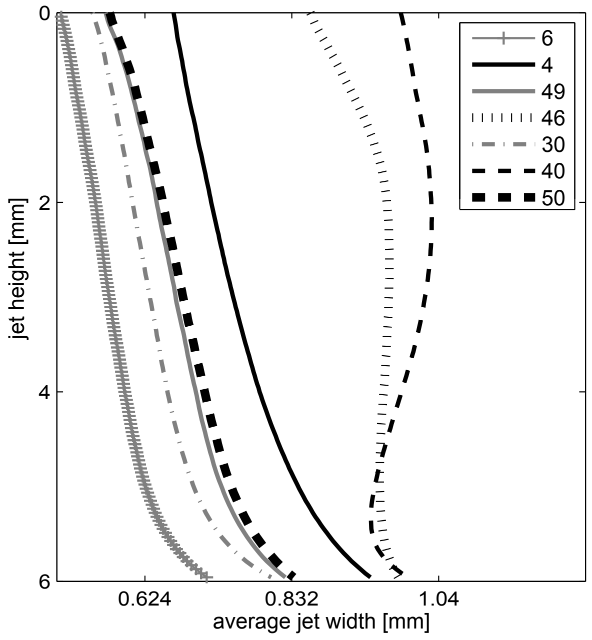

Fig. 3. Average jet width. 4,6 - new nozzle, 30,49,50 - lightly damaged nozzle, 40,46 - heavily damaged nozzle.

JET RECONSTRUCTION

To better observe and understand the jet behaviour it was necessary to create a reconstruction of its inner structure. With the tomographic method, we were able to recreate 3D pattern from the multidirectional CCD camera data - 3 profiles (in 120°) and cut through the jet structure with data collected from the optical fibers - 8 profiles (in 22.5°).

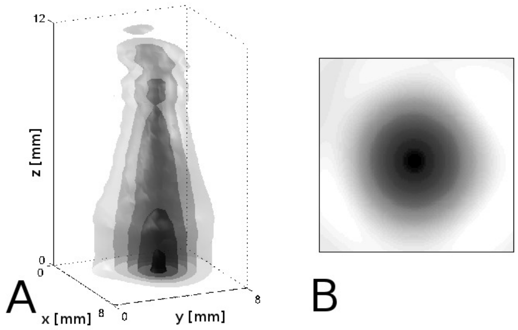

Fig. 4. Reconstruction using inverse radon transform. A - 3D with CCD camera images, B - 2D with optical fibers. Darker color represents higher intensity.

The inverse radon transform is a method to reconstruct data from their projections along multiple directions. The transformation used by us is modified [2] version of MATLAB [3] iradon function. The measured side-on profiles are approximated by polynomial function to increase number of profile points. Input data for the IRT consist of 3 or 8 original profiles plus their mirror profiles and additional interpolated profiles, results shown in Fig. 4.

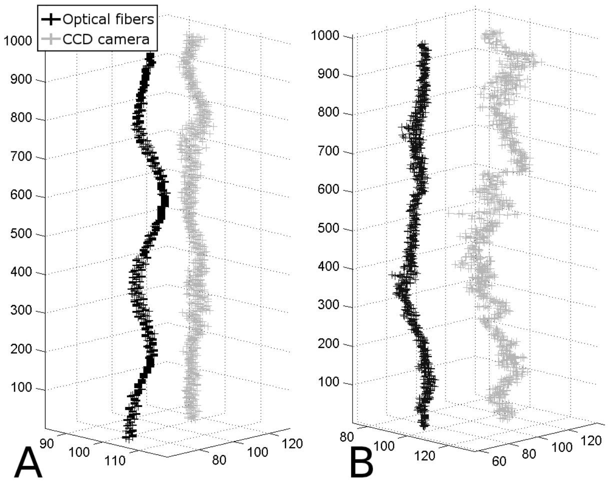

Fig. 5. Movement of the jet axis in single height level through time. A - current 150 A, gas flow 1 g/s axial, B - current 150 A, gas flow 0.4 g/s axial and 0.6 g/s tangential

RESULTS

When observing its behavior at single height level (Fig. 5), the jet axis displays rotational movement even when the working fluid is forced in only axially. The helix shows light pulsation, which follows the oscillation of electric current. 3D reconstructed image from CCD camera image is compared to the reconstruction image from optical fiber experiment which is performed with identical parameters. It's apparent, that optical fibers show results with lower uncertainty. The axis oscillates in area with approximately 0.5 mm in diameter.

CONCLUSIONS

The plasma jet behavior shows proximity towards current flowing through arc. Decreasing its oscillation on the side of the power source by using stabilised power supply would likely improve stability.

It is neccessary to balance axial and tangential filling into plasma torch, as it increases frequency of changes in the jet flow. To better observe behavior of tangential flows, usage of device with higher sampling frequency might be necessary - however the instabilities and high friction while the jet density is rather low are the still the main reasons of unpredictable movements and are hard to influence.

ACKNOWLEDGMENT: This article was created with support of the Institute of Thermomechanics AS CR as a part of project Cesta k Vědě.

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