Schlieren Technique Applied to Magnetohydrodynamic Generator Plasma Torch

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Introduction

- Magnetohydrodynamic (MHD) generators augment traditional combustion schemes for creating electrical power.
- Recent revitalized interest due to advances in
  - superconducting magnets
  - solid-state power electronics
  - materials science governing electrodes
  - carbon capture and sequestration

- A schlieren imaging system is used to evaluate electron and various ionized species densities in a plasma torch
  - An automated analysis and calibration program in Python is developed
  - We observe spatial resolutions less than 1mm with electron density of $\mathbf{n_e = 1 \times 10^{16}}$ cm^{-3}

MHD Generator Concept

- Energy is extracted in the form of a Hall current generated via the motion of the plasma torch through an externally applied **B**-field.
  - No moving parts
  - Can augment existing fossil fuel plants to increase fuel efficiency
- End goal of this project: utilize schlieren imaging diagnostic to obtain radial density profile of an MHD generator's plasma jet

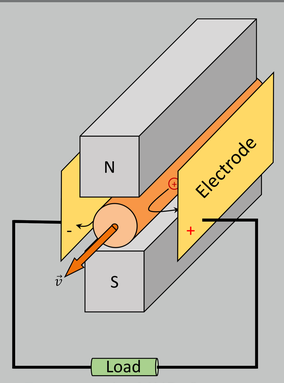


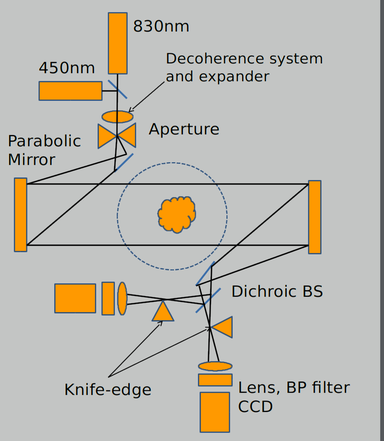
Figure 1 : An MHD Generator

The Schlieren System

- Two-color schlieren allows evaluation of electron (e), ion (+), and neutral (n) refractivities ($\mathbf{N \equiv n - 1}$) separately

$$\mathbf{N}_{\text{tot.}} = \mathbf{N}_e + \mathbf{N}_+ + \mathbf{N}_n$$
$$\mathbf{N}_e \propto \lambda^2 \mathbf{n}_e$$
$$\mathbf{N}_{+,\,n.} \propto \alpha_{+,n}(\lambda)\mathbf{n}_{+,n}$$

- Blue $\lambda = 450$ nm at the resonant frequency for ions and/or neutrals
- Near-infrared $\lambda = 830$ nm to image the electrons
- Z-type 2-mirror system
  - No coma or chromatic aberrations
  - Cost effective



Calibration: Matching greyscale value and angular deflection

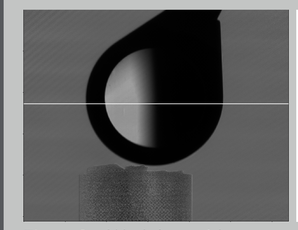


Figure 2 : Weak lens with selected region

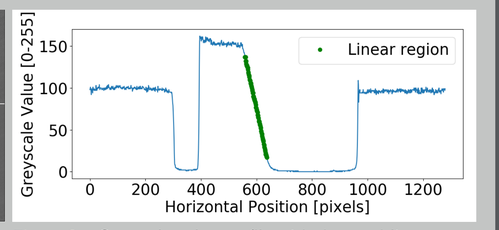
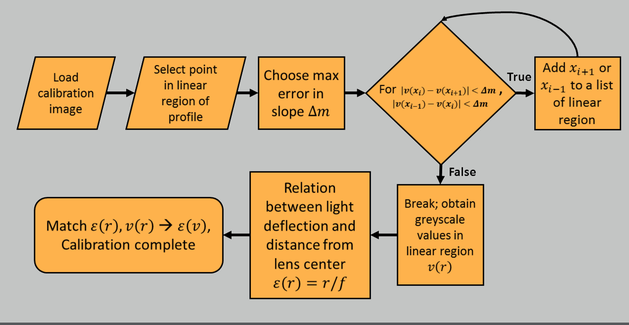


Figure 3 : Greyscale value profile with detected linear region



Schlieren Image

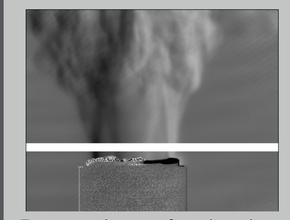


Figure 4 : Image of torch with selected region highlighted

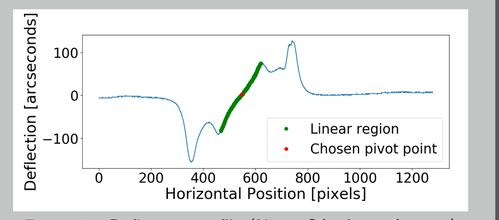
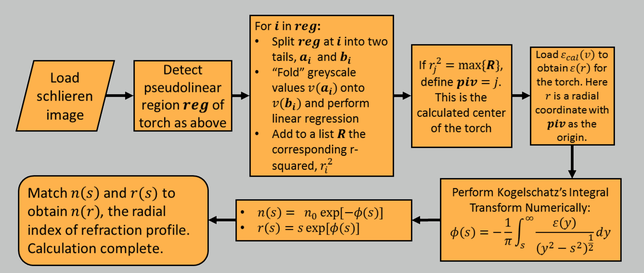


Figure 5 : Deflection profile (Note: **21 pix = 1 mm**)



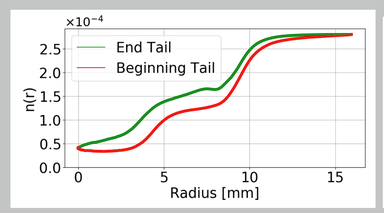


Figure 6 : Radial index of refraction profile, calculated for the two different halves of the

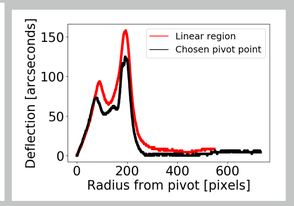


Figure 7 : An example iterate of the folding algorithm

System Diagnostics and Sensitivity Analysis

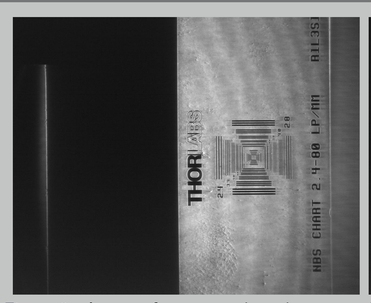


Figure 8 : Image of target card used to evaluate spatial resolution. Setup can distinguish at least **6.8 lp/mm**, or lines that are $\mathbf{147}\mu\mathbf{m}$ apart.

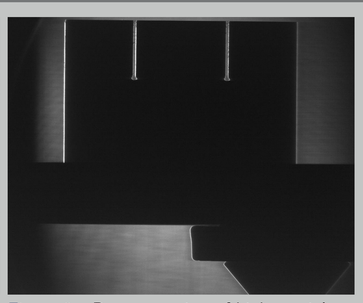


Figure 9 : Demonstration of high spatial resolution: imaging of thermal expansion relief-cuts in high-Z PFC material.

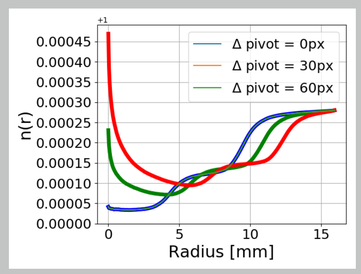


Figure 10 : Index of refraction profile for various errors in choice of center. Demonstrates that diagnostic is extremely sensitive to choice of center.

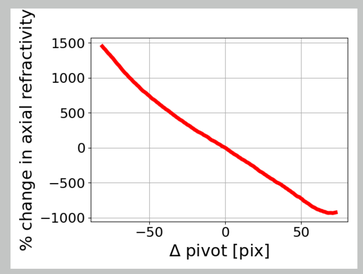


Figure 11 : Sensitivity of axial index of refraction to error in choice of center of jet

Conclusions and Further Research

- Python image analysis software developed to evaluate index of refraction, and hence densities of different species, in axisymmetric plasma jets
- Next step: apply image analysis to MHD generator relevant plasma jet burning with hydrocarbon combustion products and seed metals
- Will aid in investigations of arcing behavior near MHD generator electrodes

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