Investigation of power dissipation in a collimated energy beam

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Cranfield University campus
From: www.cranfieldmaintenance.com/about-us

Royal Air Force, Cranfield, 1937
From: www.cranfield.ac.uk/about/cranfield/heritage

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From: www.cranfieldprecision.com/cupe.php
Structure

1. Introduction
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3. Numerical analysis
4. Power dissipation calculation
5. Conclusion and future work
1. Introduction

Research motivation

There is a large marketing demand for metre scale ultra-precise optical surfaces

Ground telescope  EUV lithography  Laser fusion energy
1. Introduction

Rapid process chain

A fast process chain of three sequential machining steps proposed by Prof Shore
1. Introduction

Plasma figuring process

This figuring process uses an **Inductively Coupled Plasma** (ICP) torch that provides a controllable **chemical reaction** for etching local regions of a surface.

State-of-the-art plasma figuring process

(Courtesy Carr et al)
1. Introduction

Previous achievement

Initial figure error

Residual figure error after second figuring

(RMS: 373nm
PVr: 2.3 μm)

(RMS: 31nm
PVr: 249nm)

(Carried out by Castelli [10, 12])
1. Introduction
Mid Spatial Frequency (MSF)

Surface topography and Power Spatial Density (PSD) showing the MSF features

(From Castelli and Jourdain)
2. Methodology

To create highly collimated energy beams to reduce MSF errors.

Footprint profile

ICP torch with De-Laval nozzle
2. Methodology

To guarantee sufficient energy for processing

$\Delta E_{\text{input}} = \text{Forward power} = \Delta E_{\text{coolant}} + \Delta E_{\text{gas}} + \Delta E_{\text{radiation}}$

Energy dissipation rate (power dissipation)
3. Numerical analysis

Benchmark models vs author’s model

Comparison of profiles along the symmetric axis

Ref: Morsli, 2007
3. Numerical analysis

CFD model of plasma figuring

**Governing equations**
Navier – Stokes equations: momentum, mass, and energy conservations

**Turbulence characteristics**
Reynolds number (Re = 3800 ~ 10350)
Literature information [Morsli, 2007]

**Boundary condition**
Computational domain
Input parameters

Standoff distance:
13 times smaller than Morsli’s model
3. Numerical analysis

CFD results

Data along POI
3. Numerical analysis

Correlation between axial velocity and footprint
4. Power dissipation calculation

Flow rate and temperature measurement

(Flow rates were measured using Platon NGX flowmeter)
4. Power dissipation calculation

Correlation between TD and FP

TD = T_{Return\ total} - T_{Supply\ total}
4. Power dissipation calculation

Energy absorbed rate by coolants

\[ \Delta E_{\text{coolant}} = C_c \, v_c \Delta T = 664 \text{ watts} \]

Energy dissipated rate by argon gas

\[ E_{\text{argon}} = \int_{T_{\text{room}}}^{T} (C_a v_a) dT \]
\[ \Delta E_{\text{argon}} = v_a (6090.5 + 20.79T - 1.6 \times 10^{-5} T^2 + 1.72 \times 10^{-8} T^3) = 394 \text{ watts} \]

Energy dissipated rate by radiation

70 to 200 watts

41 watts

(Ref: Wilbers, 1991 & Benoy, 1993)
5. Conclusion and future work

Pros and cons of the model

- HTG - plasma;
- No EM effects;

  - Meet the demand: aerodynamic property investigation
  - Reduced computational time

Discussion of the power dissipation calculation

\[ E_{\text{input}} = \text{Forward power} = \Delta E_{\text{coolant}} + \Delta E_{\text{argon}} + \Delta E_{\text{radiation}} \]

Energy dissipated by radiation was double counted
5. Conclusion and future work

Sketch of the energy dissipation rate

- Radiation (air & aluminium trumpet) ~12%
- Coolant 55%
- Gas heating 33%

% to coil
% to nozzle

Future work

(Courtesy Serantoni)
Thank you!

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