CFD Simulation Research of Small Space with Large Temperature Difference

Yao Zhang[1, a], Xiaoya Liu[2,b]

[1]Scool of Computer and Communication Engineering

Northeastern University at Qinhuangdao, Qinhuangdao 066004, Hebei, China

[2]University of Iowa, Iowa City, IA, U.S.A

[a] zhangyao@mail.neuq.edu.cn;[b]xiaoya-liu@uiowa.edu

Keywords: FLUENT; turbulent flow in high-temperature environment; image deterioration; optimal design.

Abstract: When the beam is transmitting, the random fluctuation motion of temperature and pressure of the medium inside the path of transmission will cause the random fluctuation of the index of refraction of the transmission medium. It will form wave front distortion when the beam is transmitting, which is known as the laser transmission turbulence effect. This effect mainly behaves as light intensity flashing, beam drift, phase fluctuation and beam expanding. Using FLUENT software simulate the status of turbulent gas in the environment with small space and large temperature difference (650℃). Verifying the laser transmission turbulence effect can be inhibited by artificial control the distribution of the gas flow inside the flow field, which can optimal the design of the instrument.

Introduction

The way laser transmitted inside the turbulent gas flow environment is shown as figure1. Different size of irregular ball represent turbulent eddy (i.e. eddy). When the diameter of the beam is larger than the turbulent flow size, beam within the interface will contain multiple eddies. Each eddy will refract and diffract incident beam independently, which will cause the light intensity fluctuated at the receiving end. Large-scale of eddy mainly form refraction effect while small-scale eddy mostly cause beam diffraction [1]. Especially the transmission path is under the environment with large temperature difference (650℃), although the distance of laser transmission will become shorter, the index of refraction inside the transmission path will change rapidly. Light intensity flashing, beam drift, phase fluctuation and beam expanding will impact the laser receiving end [2] [3]. Using Fluent software to simulate and analysis the flow field of the laser transmission, by artificially adding low-temperature flow gas as a control method setting up simulating experiment, which is use for optimal the design of instrument.

Figure 1 Beam transmitting inside turbulent gas

Setting up geometric model:

This article uses online measurement System for Glass Thickness as experiment instrument [4]. Helium is the medium. Assume the edge of the temperature field is adiabatic with room temperature.

25℃tank, 700℃ glass plate and 650℃ space environment form model of steady convection. Setting up model for analysis objects, which is the $350\times250\times40mm$ three-dimensional temperature field (HTI3D) between the water-cool probe and glass plate. When finish setting up geometric model in GAMBIT, using TGrid technology forming grid as figure 2.

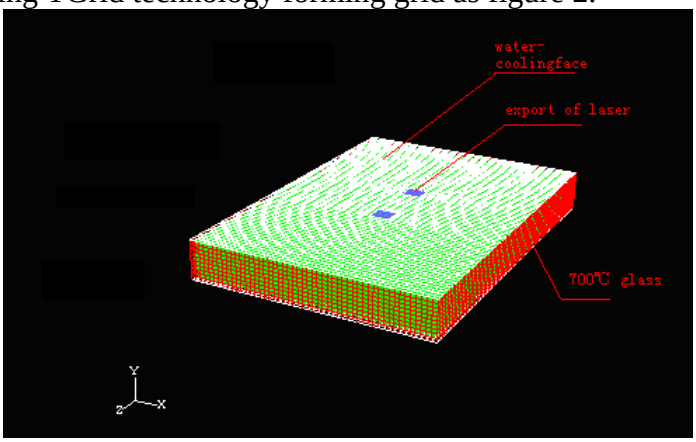

Figure2 Result of (HTI3D) meshing

Turbulent model:

Using standard $k-\varepsilon$ two-equation model as the turbulent model [5][6][7]. Formulas are shown as (2), (3). The relationship among eddy viscosity coefficient, turbulent kinetic energy k and turbulent dissipation rate ε is shown as formula (1).

$$\mu_t = C_{\mu_t} o k^2 / \varepsilon \tag{1}$$

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho u_j k) = \frac{\partial}{\partial x_j}[(\frac{\mu_t}{\sigma_{k0}})\frac{\partial \varepsilon}{\partial x_j}] + G_k - \rho\varepsilon \tag{2}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_j}(\rho u_j \varepsilon) = \frac{\partial}{\partial x_j}[(\frac{\mu_t}{\sigma_{\varepsilon 0}})\frac{\partial \varepsilon}{\partial x_j}] + \frac{\varepsilon}{k}(C_{\varepsilon 1}G_k - C_{\varepsilon 2}\rho\varepsilon) \tag{3}$$

Note, $G_k = \mu_t \frac{\partial u_j}{\partial x_j}(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j})$, C_μ, $C_{\varepsilon 1}$, $C_{\varepsilon 2}$, $\sigma_{\varepsilon 0}$,and σ_{k0} are all coefficient introduced by model. The value of these empirical constants are all fixed [8]: $C_\mu = 0.09$, $C_{\varepsilon 1} = 1.44$, $C_{\varepsilon 2} = 1.92$, $\sigma_{\varepsilon 0} = 1.3$, $\sigma_{k0} = 1.0$.

Boundary condition:

a) Helium (low temperature 25℃) inject through 45°symmetry nozzle under the water cooling jacket with the same direction as the laser transmission.
b) Pressure of Helium is $0.03Mpa$. Flow velocity are $v_y = 0.044m/s$, $v_z = 0.037m/s$
c) Field temperature inside tin bath is 680℃. Temperature of glass plate is 650℃.

Analysis of FLUENT low-temperature gas jet flow field.

1. According to the simulation result of low-temperature protective gas flow rate (figure 3), on the stage of protective gas jet through nozzle onto glass plate surface, the section of flow is small,

the flow rate is high, and the direction of the flow basically remains the same. Relatively steady high-speed flow field are formed along the laser transmission direction. After protective gas are jet onto the surface of glass plate, due to the interaction of glass plate and the symmetric-jet protective gas, the fluid flow rate and flow direction inside (HTI3D) are changed, which form complex changing status under the interaction of thermal convection, laminar flow, and turbulent flow.

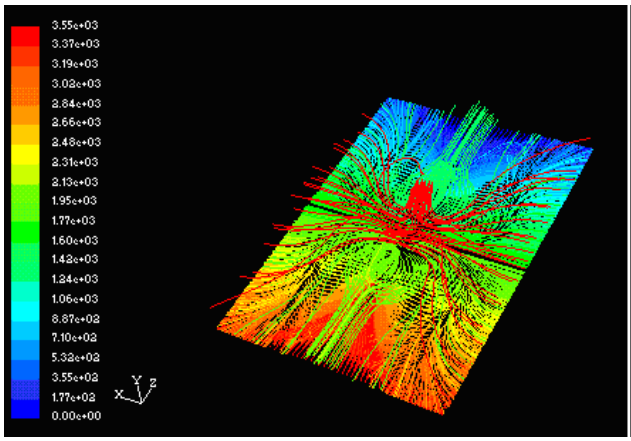

Figure 3 Gas flow rate distribution inside (HTI3D)

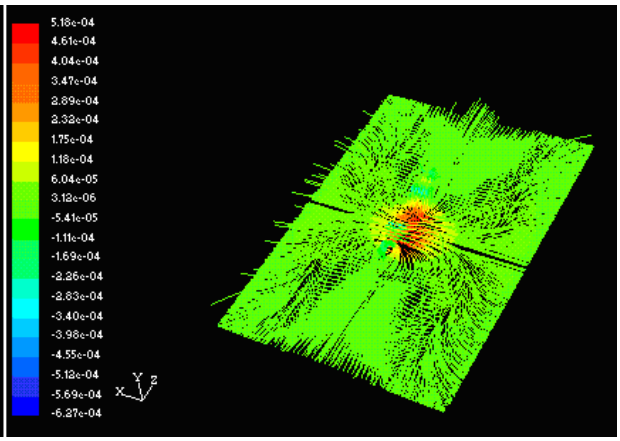

Figure 4 Pressure distributions without air

According to figure 4, which is the pressure distribution simulation result under the situation without outside interference flow, the pressure distributes uniformly. High pressure is found around the symmetric nozzle while the rest of the space has a low pressure. It shows that t Introduction

2. he low-temperature protective gas controls the gas flow field around the local space around the nozzle.

3. Also, according from the corresponding temperature distribution of flow field between the nozzle and glass plate, after low-temperature protective gas are jet though nozzle, temperature of the gas has low temperature and uniformly distribute before reach the glass plate, while the temperature are increase with the decrease of the gas flow rate after the gas reach the glass plate. The direction of the temperature distribution is basically the same as the gas flow rate.

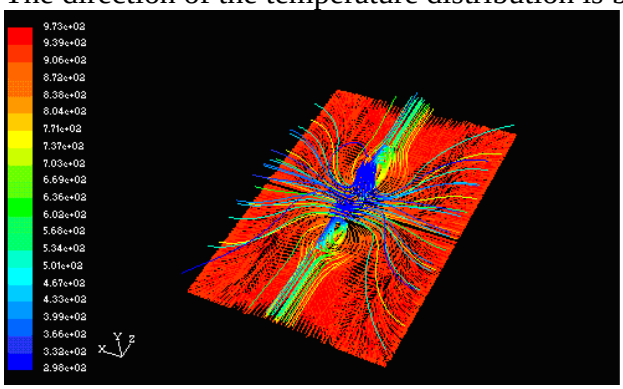

Figure 5 Temperature distributions inside (HTI3D)

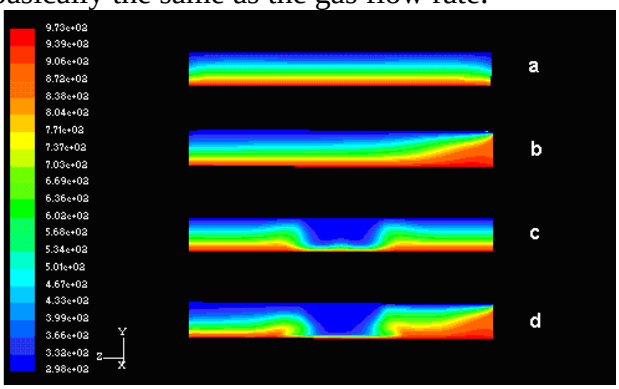

Figure 6 Temperature field change along (HTI3D) optical spindle

Conclusion:

Comparing the two simulating experiment above, specific analysis the temperature field changing status which are closely related to the measuring, which is the temperature field changing status on optical spindle during laser transmission. As shown in figure 6:

Comparing from figure 6, it shows that low-temperature gas can control most of the measurement area inside optical spindle no matter if there are any outside gas turbulence exist. By extruding high-temperature gas around glass plate, the low-temperature protective gas flow basically controls laser transmission area of the measuring instrument.

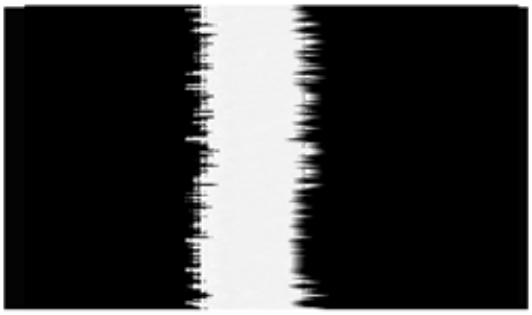

Figure 7 Scanned image without single image spot of gas flow

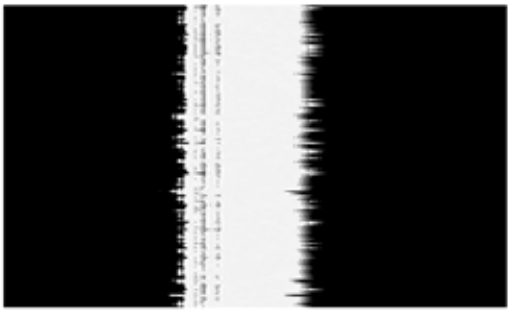

Figure 8 Scanned image with single image spot of gas flow

According to the result of the simulating, approved by the conclusion of comparing without adding single image spot (figure 7) and adding single image spot (figure 8), although high-temperature turbulent image deterioration cannot be removed completely, adding low-temperature protective gas with the same direction as the laser transmission can reduce the image spot flicker and jitter effectively under the situation of high-temperature turbulent flow , which can increase the overall performance of the instrument.

References

[1] CARBILLET M, RICCARDI A. Numerical modeling of atmospherically perturbed phase screens: new solutions for classical fast Fourier transform and Zernike methods [J].App1.Optics, 2010, 49(31):47-52.

[2] TAN H,CHEN J,LIN X. Research on Molten pool temperature in the process of laser rapid forming[J].Journal of Materials Processing Technology，2008,198(1／3):454-462.

[3] CHEN CH Y, YANG H M, JIANG H L. Research progress of mitigation technologies of turbulence effects in atmospheric optical communication [J]. ActaArmamentarii，2009,36(6):779-791.(in Chinese)

[4] LIU Li-shuang, ZHANG Yao, LU Hui-qing, WANG Bao-guang. Online Measurement System for Glass Thickness Based on CCD [J]. Journal of Transduction Technology, 2006, 19(3), 652-654.

[5] NUEMEISLAND M, DIXON A G, CFD study of fluid flow and wall heat transfer in a fixed bed of spheres [J]. AICHE Journal, 2004, 50(5):906-921.

[6] K. Hemtiwakorn, N. Phoocharoen, S. Tungjitkusolmun, and C.Pintavirooj, "Nasal airflow simulation in human using a computational fluid dynamics (cfd)," presented at the 2nd Biomedical Engineering International Conference (BMEiCON2009), 2009.

[7] Han Zhanzhong, Wang Min, Lan Xiaoping, et al. FLUENT- The case and application for Journal of Fluid’s Engineering simulation calculation [M].Beijing: Beijing institute of technology press, 2010.