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Modeling, Simulation And Implementation Of Adaptive Optical System For Laser Jitter Correction

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ABSTRACT: *Adaptive Optical System (AOS) for correction of beam jitter in a high power laser source is described. The jitter in a high power laser may results from platform vibrations and dynamically varying in-homogeneities in the lasing medium. The effect of beam jitter on the performance of high power laser in directed energy weapon (DEW) system is discussed. Simulation studies have been carried out to optimize parameters of jitter correction system. An experimental arrangement to stabilize a high power laser beam is described and results are presented.*

Keywords: *Adaptive optics, Laser beam jitter, Tip-tilt mirror, Directed energy weapon.*

I. Introduction

Adaptive Optical System (AOS) has emerged as an integral part of optical systems that find applications in various fields such as astronomy, industry, laser communication, medical diagnostics and defence. In astronomy, adaptive optics is an indispensible part of optical systems meant for imaging of variety of stars and other science object of interest. In industry, AO system helps in generation of stable and diffraction limited laser spot for precise cutting, marking or drilling of objects. In free space communication, adaptive optics is used mainly for correction of beam wander to stabilize the laser spot in the receiver plane. Recently, satellite to submarine communication has emerged as another potential application that needs adaptive optics for establishment of effective communication link. Adaptive optics has also been used in ophthalmology for taking clear images of retina for medical analysis related to the eye related problems. In defence, Directed Energy Weapons (DEW) systems find direct use of adaptive optical system to concentrate brute laser power on the target to cause structural or sensor damage. Stabilization of laser beam is also important for beam pointing and tracking the target.

High power lasers system has inherent jitter and aberrations which severely degrade the performance of these systems. The effect of jitter becomes more pronounced as the target range increases. The lethality of a laser based system can be improved considerably by correction of beam jitter inherently present in HPL sources and beam wander resulting from atmospheric turbulence. The source jitter occurs because of mechanical vibrations of laser cavity and the platform supporting various optical components of beam delivery system. Low frequency jitter (beam drift) results from in-homogeneities in the lasing medium. In solid state lasers, in-homogeneities results from the thermal gradients in the lasing rods. In a chemical or a gas dynamic laser, the in-homogeneities results from non uniform mixing of the reacting species. The source jitter can be treated at the point of its origin, itself. Source jitter resulting from platform instabilities can be corrected to some extent by passive means such as using a vibration free table. However, laser source jitter resulting from laser cavity vibrations and in-homogeneities of lasing medium cannot be corrected by these methods. In such situations, adaptive optical jitter correction system is the only solution to correct the laser beam jitter and stabilize the laser beam, in real time.

II. Effect Of Beam Jitter

Small beam jitters result in large beam displacements as the distance from laser source increases. These beam displacements have very detrimental effect on the performance of a DEW system. On the source end the beam displacements severely affect the tracking range and accuracy of gimble stabilized beam delivery system. On the target end beam displacements adversely affect the lethality of the DEW system. The beam displacements in the target plane results in decreasing its power density. Large beam displacements also raise the probability of missing the target. The effect of jitter can be visualized with the help of Fig.1. A Laser beam is focused to a spot of area $\boldsymbol{A}$ on the target at a distance $\boldsymbol{R}$. Due to jitter in the beam, the position of the spot is not stable at the target but keeps varying with time. If $\boldsymbol{\alpha}$ is the maximum angular jitter then the maximum linear movement of the spot on the target is Rα. If this displacement is larger than the the size of the target or the desired region of the target then there are chances of the laser beam mis-hitting the target or the desired location of the target. Even if, the beam displacements are not so large as to cause mis-hit, it definitely reduces the power density of the laser beam, thereby reducing the lethality of the DEW system.

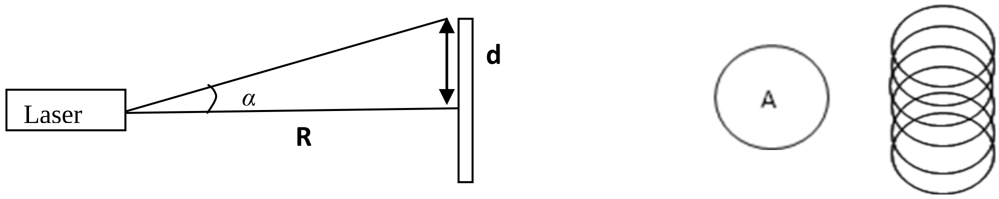
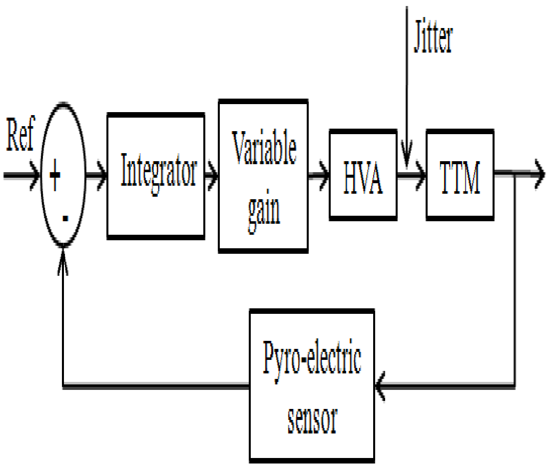


Fig. 1 Effect of beam jitter

If Pr is the power received in the target plane, the power density at the target in the absence of beam jitter would be Pr / A. In the presence of beam jitter at the source end, the displacement of the beam in the target plane increases the effective area. If A' is the effective area of the laser spot due to tilt errors, the effective power density reduces to Pr / A' . As a rule of thumb, the beam jitter correction should be such that there is at least 50% overlap of the laser spots resulting from residual tilt errors. This will reduce the power density to half of its value obtained in the absence of any tilt errors. This power density should be more than the threshold power required to incorporate structural damage to the target or incapacitate its sensor unit. A higher degree of jitter correction at the source end would increase the region of overlap of the laser spots on the target plane and thus improve the lethal power of the DEW system. Alternately, it would require lesser laser power at the source end to inflict the same damage to the target. In this entire discussion, the effect of beam wander resulting from atmospheric turbulence has not been taken into account. Effect of beam wander is indeed small for shorter target ranges or when atmospheric turbulence is low particularly for large laser wavelengths. However, for higher degree of atmospheric turbulence and for longer ranges, a separate adaptive optical jitter correction system is invariably required for correcting beam wander, in real time.

III. Simulation of Jitter Correction System

A jitter correction system has been designed using Tip-tilt mirrors (TTMs) and pyro-electric quadrant detectors for real time correction of a CO_2 laser beam. Correction algorithm sums up the current error sample with the previous one to obtain overall jitter error. Fig. 2 depicts block diagram of complete error correction system. The control loop is simulated using LABVIEW control module as shown in Fig. 3.



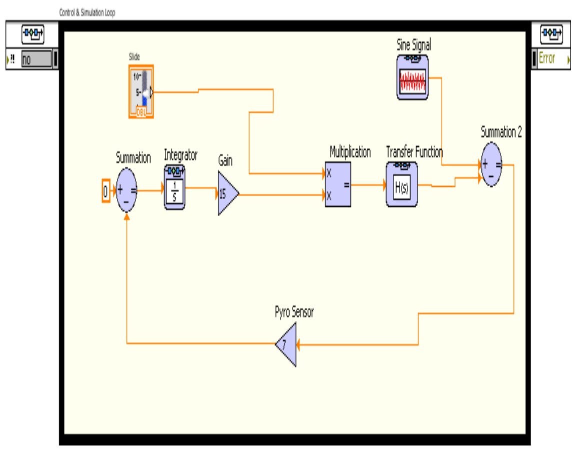


Fig. 3 Control loop simulation

TTM is modeled as a second order system with the transfer function as 4769856/ (S^2+1747S+4769856) and resonant frequency 1800 rad/sec (~287 Hz). Bode plot of the TTM is depicted in Fig. 4. The plot shows an infinite Gain Margin (GM) at infinite phase crossover frequency and ~ 69 as Phase Margin (PM) at 2547.1 rad/s Gain crossover frequency Bode Plot of overall closed loop system is depicted in Fig.5. The closed loop system has a Gain Margin of 22 at 2184 rad/s phase crossover frequency and Phase Margin of 87.1 at 135.5 rad/s gain crossover frequency. Simulation results clearly indicate that the close loop system is stable.

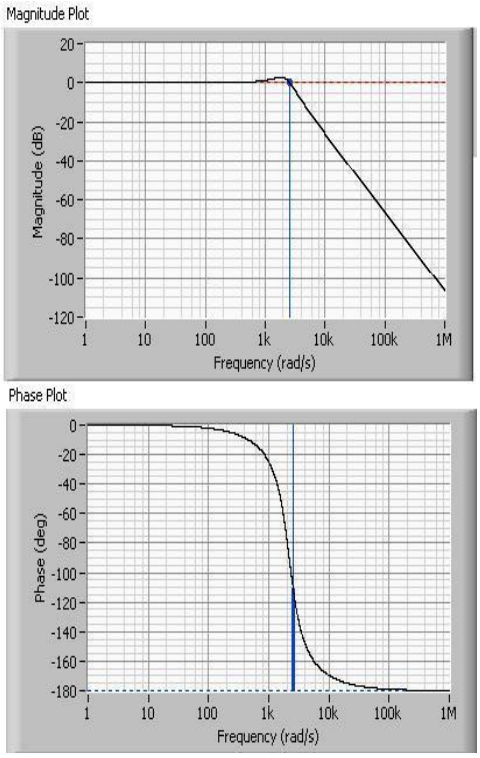


Fig. 4 Bode plot of the TTM

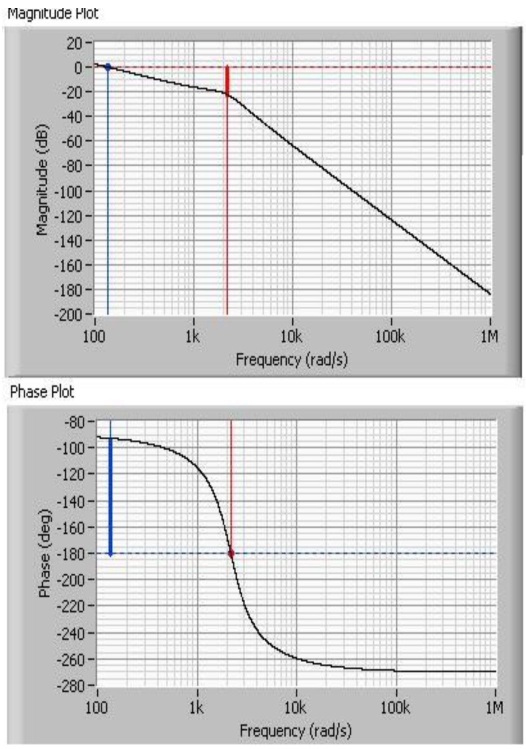


Fig. 5 Bode plot of closed loop system

IV. Experimental Arrangement

Schematic of closed loop jitter correction system is shown in Fig. 6. The system uses a pair of tip-tilt mirrors, pyro-electric quadrant detectors and the control electronics for online correction of laser beam jitter. A tip tilt mirror TTM1 is used to incorporate tilt errors of desired amplitude and frequency. The other two TTMs, TTM2 and TTM3 dynamically adjust themselves to ensure that the beam jitter is corrected without altering initial optical axis of the laser beam. A He-Ne laser (632.8 nm)) is co-aligned with the CO2 laser beam (10.6 µm) for ease of optical alignment. A part of CO2 laser beam is sampled using a beam splitter and is made to incident on pyro quad detectors. Output of pyro-quad detectors is processed in a quadrant detector electronics unit to generate electrical signals corresponding to source beam jitter. The electrical signals are then digitized and processed in the controller to generate desired correction signals. Equivalent analogue voltages are generated through D/A converters interfaced with the controller. The analog voltages are then suitably amplified using high voltage amplifiers and fed to TTMs to nullify the effect of source jitter. In close loop modeling, only one TTM is used to correct the jitter but practically two TTMs are, in general, employed to correct the jitter all along length of laser beam. Alignment of pyro-quad detectors is bit tricky as these detectors respond only to temperature variations.

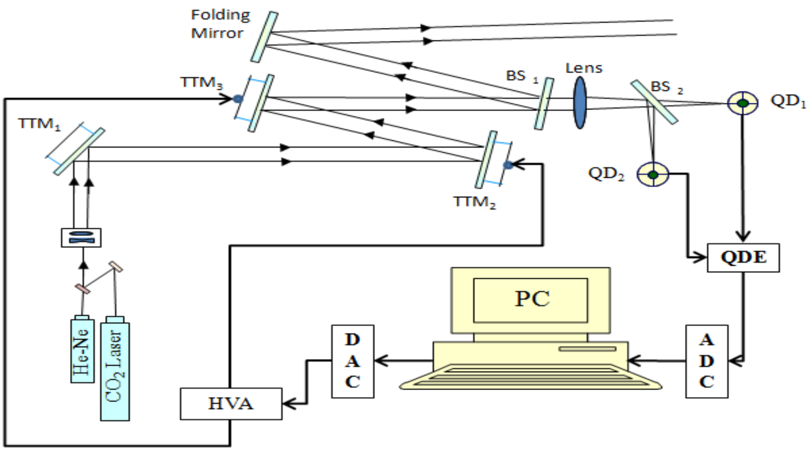
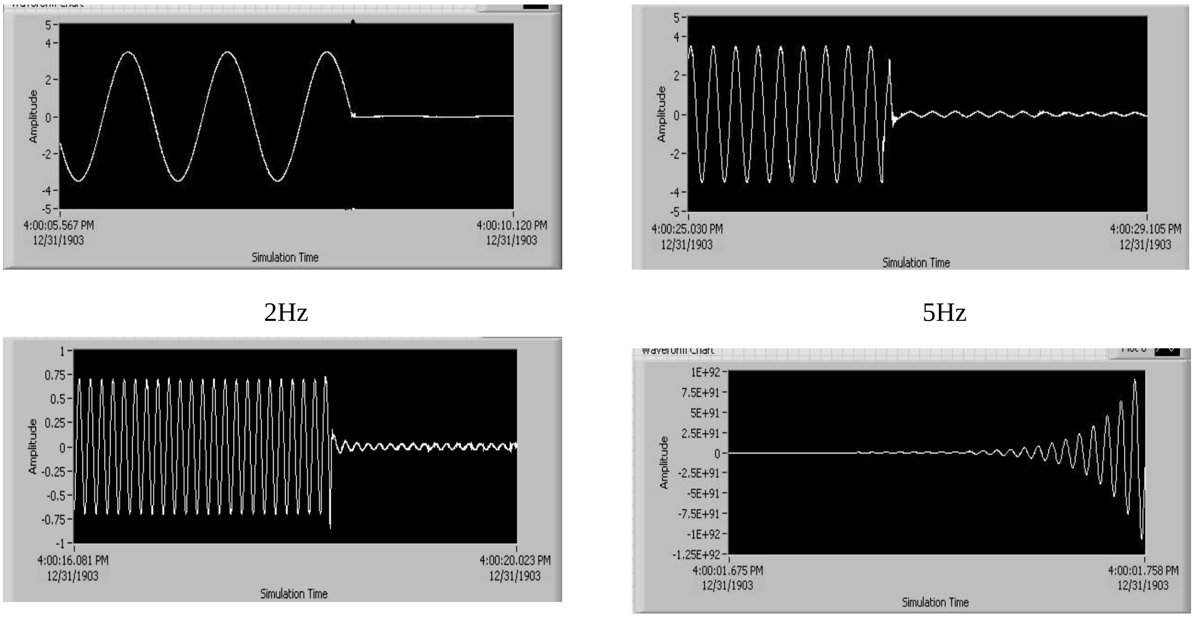


Fig. 6 Schematic of jitter correction system

V. Results

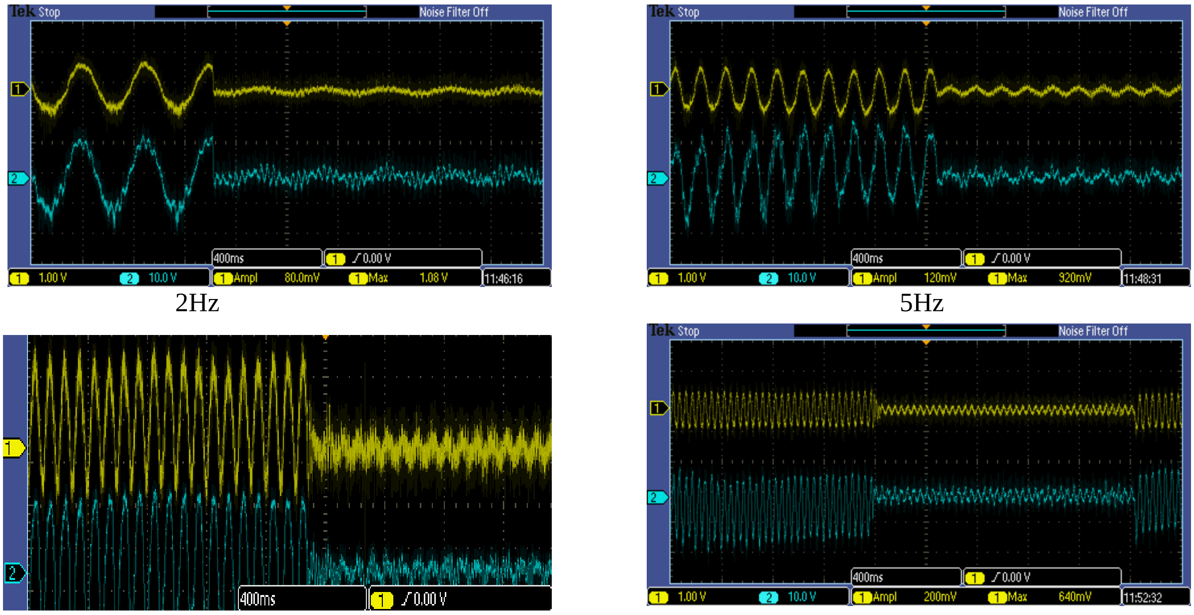
Results of closed loop jitter correction, using adaptive optical system described herein, are shown in Fig. 8. Experimental system has maximum jitter correction of 94% and closed loop bandwidth 25Hz. Regeneration effect at higher system gain as shown in simulation results was verified experimentally.



2Hz 5Hz

10Hz Regeneration

Fig. 7 depicts the results of simulated jitter correction at different frequencies



2Hz 5Hz

10Hz 20Hz

Fig. 8 Experimental jitter correction at different frequencies

VI. Conclusions

A closed loop jitter correction system has been developed using a pair of tip tilt mirrors and pyro-electric quadrant detectors. The system has been successfully used to correct beam jitter in a 100 watt CO_2 laser. The control loop was simulated using LABVIEW control module. Simulated jitter correction results at various frequencies were found to be very close to actual experimental results.

REFERENCES

[1] Gregory C Loney. Design of a small-aperture steering mirror for high bandwidth acquisition and tracking. Opt Eng, 1990, 29(11), 1360-1365.

[2] Robert K. Tyson. Principles of Adaptive Optics, Taylor & Francis Group, CRC Press, 2011.

[3] Devinder Pal Ghai*, Anuya Venkatesh, Het Ram Swami, and Anjesh Kumar, Large Aperture, Tip Tilt Mirror for Beam Jitter Correction in High Power Lasers, Defence Science Journal, Vol. 63, No. 6, November 2013, pp. 606-610.

[4] Corley, C.M.S., Nagashima, M. & Agrawal, B.N, Beam control and a new laboratory testbed for adaptive optics in a maritime environment",IEEE Aerospace Conference. Big Sky, Montana, USA 2010.

[5] Tapos, F.M.; Edinger, D.J.; Hilby, T.R.; Ni, M.S.; Holmes, Buck C. & Stubbs, David M. High bandwidth fast steeringmirror. Optomechanics, Proc. SPIE, 2005, 5877, pp. 60-73.

[6] Patel, B.. Flexure design for a fast steering scanning mirror. U.S. Patent 5550669. 27 August 1996.