OPERATIONAL ISSUES IN THE USE OF OPTICAL LASER LINKS FOR HIGH FREQUENCY BROADBAND STOCHASTIC COOLING SYSTEMS

D. Vander Meulen, FNAL*, Batavia, IL 60510, USA

Abstract

1300nm IR (Infrared) laser links have replaced the more conventional coaxial cable trunks in the FNAL Antiproton Source Accumulator 4-8 GHz stochastic cooling systems. Operational problems unique to this method of transporting microwave signals from pickup to kicker include laser misalignment due to thermal variations, system gain modulation by vibration sources, and control of optical input power to maximize the link's dynamic range. This paper will discuss solutions to these problems.

1 INTRODUCTION

RF signal attenuation, dispersion, and phase wrap are all consequences of coaxial cable trunks; in cases where cable lengths are long, system dynamic range can also suffer. The FNAL Accumulator ring has both horizontal and vertical 4-8 GHz stochastic cooling systems that now utilize IR laser links[1].

The goal was to produce links that did not need active feedback systems to maintain alignment. Such systems are simpler and more dependable.

The primary problem was link misalignment due to thermal variations in the enclosure. Different machine running modes create temperature changes in the enclosures and cause distortion to link components; the results are angles and displacements being introduced in the alignment. Careful design of support stands and thermal control of particular components controls this problem.

Vibration sources in the enclosure produce periodic misalignment, which modulate the received signal. The modulation of the signal itself is not of much concern, but the amplitude of the vibration can cause alignment mechanisms to 'walk' over a period of time and produce misalignments.

To maintain the maximum possible dynamic range of the link, the laser input power must be controlled as a function of the beam signal. This is done with a feedback system in the microwave hardware.

2 SYSTEM LAYOUT

The two laser links are orientated vertically with respect to one another, the horizontal link being on top (see Figure 1). Both transmitter and receiver support stands are aluminum and mount rigidly to the enclosure ceiling. It was necessary to mount things in this way due to floor space restrictions. The receiver support stand is common to both links, whereas the transmitters are separate (this was necessary due to system timing issues and obstructions in the enclosure). The lengths of the links are roughly 284-ft horizontally and 278-ft vertically.

Figure 1: Insulated vertical laser transmitter

The transmission launch uses single mode fiber and a GRIN (Graded Index) lens. The receiver uses a Hamamatsu fast photo diode since it has a much larger target cross-section and does not have the angle sensitivity of single mode fiber[2]. Both ends of the links use 20X expander telescopes (see Figure 2).

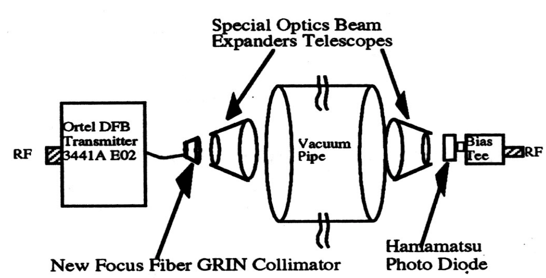

Figure 2: Optical link hardware configuration

Both transmitter and receiver ends of the links are contained in stubrooms, small enclosures off the main tunnel. A 253-ft long, 20-in diameter evacuated pipe connects the stubrooms, and is the conduit through which the laser light travels. The stubrooms are common to the tunnel and thermally coupled to it.

3 SYSTEM DESIGN

3.1 Stubroom Temperature Control

Since both of the stubrooms are connected directly to the enclosure, a temperature change in one stubroom would be mirrored by a similar change in the other. Thus, it was assumed vertical displacements caused by expansions or contractions of the support stands would at some level cancel each other out as both ends of the link move together. The symmetry of the support stands would prevent any horizontal movement as the optics are mounted in their centers. It was therefore desirable to keep temperature changes in the stubrooms to a minimum and to insure the temperature rate of change was similar at both ends of the links.

Cable trays mounted along the ceiling between the main tunnel and the stubrooms restrict airflow. Two 6” LCW (Low Conductivity Water) headers run parallel to these cable trays on the stubroom side and can vary by as much as 16° F. Together they produce a pool of warm stagnant air on the ceilings of both stubrooms (see Figure 3). This situation was particularly bad on the transmitter end of the links due to the close proximity of the optics to the headers. Temperature differences of up to 7° F were regularly seen between the top and bottom of the vertical transmitter support stand.

Figure 3: LCW headers and cable trays

Small, high volume fans force cooler air into the stubrooms and displace this warm pool back out into the main tunnel. This, along with one inch of fiberglass insulation around the LCW headers, reduced the temperature difference across the vertical support stand to less than 1° F.

3.2 Temperature Control of Optical Hardware

Various pieces of optical hardware at both ends of the link were heated with a hot air blower while the receiver diode current was monitored. This gave a very quick and accurate accounting of those components that distorted and caused misalignment. Only one item was found to require strict temperature control. The adjustment stages that the telescopes mount to are constructed of aluminum and stainless steel (see Figure 4). When the stage temperature changes, these materials expand or contract by different amounts and introduce angle changes into the alignment.

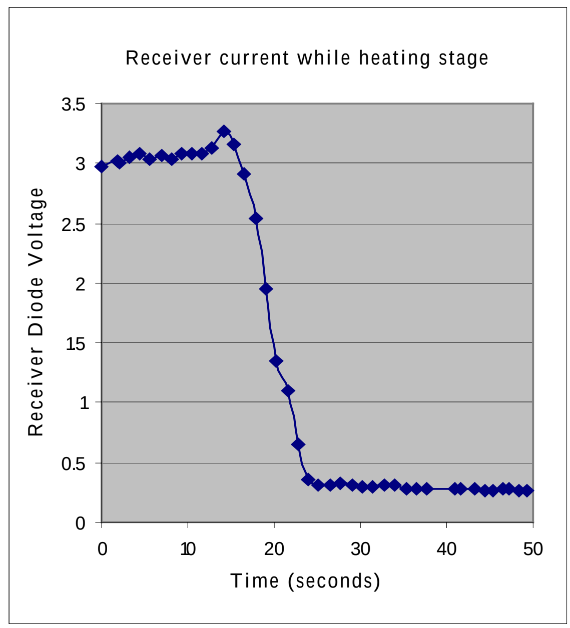

Figure 4: Effect of temperature changes on stage

Each stage was mounted to an aluminum base plate and the assembly encased with ½” of foam insulation. Temperature control was done using a feedback system constructed using platinum RTDs (Resistance Temperature Detectors) mounted on the stage, resistive heating elements on the base plate, and temperature control units located upstairs in the service buildings. This system will hold the stage temperature to within 1/2° F even during rapid changes in tunnel temperature and to 1/10° F during steady state conditions. Each of the four telescope/stage assemblies have independent temperature control, are set to operate at 105° F (which is warmer than the tunnel is likely to get), and are thermally isolated from their respective support stands.

3.3 Support Stand Insulation

When the links were installed and aligned, the completed assemblies were surrounded with ½" of foam insulation, completely isolating the optics and support stands from tunnel drafts and further isolating the optics from tunnel temperature variations. This additional insulation also provides a slower rate of temperature change in the support stands and minimizes temperature gradients.

3.4 Vibration Damping

A 30 Hz vibration present in the tunnel structure modulated the vertical receiver output by 8%. It was determined that most of this particular problem was due to the LCW system, and the vibration it caused was particularly notable at the transmitter end of the link since the LCW headers were rigidly mounted to the ceiling of the enclosure within inches of the support stands. Simply by replacing the existing pipe mounts with rubberized spring mounts, the amplitude of the vibration in the vertical laser link was reduced by almost 50%. It is planned to remove the ceiling mounts altogether and replace them with rubberized floor mounts. This will greatly increase the path length from pipe to optics and will further damp the vibration.

There are also acoustic sources of vibration in the links that have their origin in the LCW system. One benefit of the fiberglass insulation that was installed to reduce thermal problems in the stubrooms is that it deadens some of the water system noise. Additional acoustic insulation will soon be added to further reduce this problem.

3.5 Laser Input Power

Because the lasers have a lower dynamic range than the coaxial trunks, it was necessary to have an automated system to monitor the laser's front-end power and adjust it to maintain optimum dynamic range. Because the Accumulator is a storage machine and the beam current increases over time, constant adjustments must be made as the output power of the pickup arrays increases. This feedback system also protects the laser transmitter from excessive input power, which can cause beam heating and in extreme cases, damage to the laser.

In both systems, a hybrid was installed in the microwave trunk downstream of an attenuator. One of the outputs of the hybrid supplies the microwave input for the laser; the other is fed into a diode detector and produces a voltage proportional to the microwave signal on it. The maximum operating input power to the laser is 10 dBm. A careful set of measurements were made to determine what voltage was produced by the diode at 10 dBm, and a software feedback loop was designed to control the upstream attenuator in order to maintain the correct microwave power into the laser.

4 CONCLUSIONS

The laser links have been used operationally for approximately seven months. Although thermal and vibration problems made it necessary to realign both systems periodically during commissioning, both links are now stable enough that after four months of running, the horizontal link has only drifted down by 3%. The vertical link is less stable with a downward drift of 13% in the same time period. Further improvements to the vertical link will include acoustic insulation and additional aluminum stiffening members on the transmitter support stand, and improved insulation of the receiver support stand.

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