Laser Alignment Monitor Capabilities

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Abstract:

There may be a need within the muon alignment system for multipoint measurements. A study has been performed at LLNL which characterized the precision measurement capabilities of a laser over the distances required for GEM. Results, which are summarized, can be used to determine the viability of a laser alignment monitor if, indeed, the multipoint requirement materializes.
Memorandum

To: Distribution

From: R. Sawicki [AS]

Subject: Laser alignment monitor capabilities

Date: September 23, 1992

There may be a need within the muon alignment system for multipoint measurements. If that requirement materializes in the final design a multipoint monitoring system with high range and sub-25 micron resolution will have to be deployed. Although the very latest view of muon alignment which utilizes the Mitselmahker interpolation technique in its simplest form does not require such a system, there are reasons why it may be needed including 1) redundancy 2) straightness monitoring of a single chamber. During discussions between Mitselmahker, Paradiso and Sawicki earlier in the year, the concept of using a laser system was proposed. A study has been performed at LLNL which characterized the precision measurement capabilities of a laser over the distances required for GEM. Results, which are summarized below, can be used to determine the viability of a laser alignment monitor if, indeed, the multipoint requirement materializes. This effort was performed by M. Graser (EGG), C. Cochran (LLNL) and R. Combs (LLNL). A detailed report of their work is available upon request.

In Building 121 at LLNL there is a 30 m line-of-sight (LOS) that has been used by various programs to test alignment monitoring systems. The facility provides an enclosed alignment path on optical tables which are rigidly supported on a concrete foundation. The enclosure is a aluminum box structure with sliding doors to permit access to the instrumentation and provide protection from ambient air turbulence when required. Along this path instruments may be placed at almost any location. Figure 2 depicts the test setup that was used for this experiment. A 4 mw Melles Griot HeNe laser head is mounted at one end of the LOS. This laser operates in a single transverse (TEM₀₀) mode, is polarized at 50°:1, has an output beam diameter of 0.80 mm and a divergence of 1.0 mrad, full angle. A beam expander, a pinhole and a collimator are located in front of the laser to provide for the capability of relaying the beam waist to any reasonable location down the optical path. The diameter of the beam is also adjustable with these optics.

Along the laser path UDT SPOT-9D quadrant cell detectors can be located at almost any position. For this experiment they were typically placed at distances of 3, 6, 9, 12 and 15 meters. In some cases simultaneous measurements at two locations were desirable. In order to permit the laser beam to travel beyond the first detector a beam splitter is placed at the location of the first detector to scrape a small fraction of the beam onto the nearby quad cell. The remainder of the beam passes unperturbed to the remaining detector. This beam splitting technique or a semi-transparent photo-detector would have to be utilized if a laser monitor were deployed in GEM. Each of the detectors were mounted on precision translation stages which enabled detector movements to be precisely controlled.

To maximize detector resolution it is desirable to propagate as small a laser beam as possible. Unfortunately, the smaller the beam is the greater will be its tendency to diverge. A computer analysis was performed to determine the optimum beam size for a 15 meter propagation distance.
The analysis took advantage of relaying the beam waist to the midpoint of the path length. This doubles the pathlength over which a particular beam size can be maintained. The optimized result of this analysis is shown in Figure 2. A laser beam, with perfect beam quality and a diameter of 4 mm will converge to a diameter of about 2.5 mm at the focal point 9 m away and then expand to about 3.2 meters at the 15 m position. Imperfections of the initial wavefront (we require a high quality laser source) and deteriorating effects of air turbulence will cause variations in this result.

Figure 3 plots the x and y axis output of the quad cell at the 15 meter position. The horizontal and vertical divisions represent 20 second time and 45.5 micron displacement intervals. During this measurement the enclosure doors were closed and the air conditioning was turned off to establish quiescent conditions. Maximum deviations are much greater than the 25 micron resolution we require. The source of this noise has been identified and is believed to be the tilting of the laser beam. Figure 4 shows the output of the quad cells at the 9 and 15 meter positions measured at the same time. The results are highly correlated which corroborates the hypothesis and provides a means to correct for this error source. The signal at 15 meters can be used to measure the tilt of the laser which in tum can be used to compensate the tilt induced displacement at any other point. Other signals at any position in the LOS can be compensated for this effect.

Signal outputs for measurements made at 3, 6, 9 and 12 meters are shown in the upper traces of the plots in Figure 4. During each measurement the quad cell was moved 25 microns every 10 seconds. The test was conducted to see if the quad cell could resolve these motions. In each case it is clear that the motion is readily resolved although in the 9 meter case noise in the raw signal degrades the resolution. The lower line in each of the plots is the reading at the 15 m position measured at the same time as the quad cell of interest. As shown by the magnitude of this signal, laser tilt is contributing to the system noise. The middle line of each plot shows the raw signal which has been compensated for laser tilt as measured by the 15 m signal. This result shows that resolution is improved by the compensation and that the overall capability to resolve the induced motion is much better than 25 microns. It should be noted that these tests were performed with the laser beam enclosed in a cabinet with the air conditioning off.

To determine the sensitivity of the monitoring system in the presence of air turbulence, the cabinet doors were opened and the air conditioning was turned on. Figure 5 shows that at the 9 m position, the aforementioned compensation technique still provides an improvement although not as great as in the quiescent condition. 25 micron resolution capability is still maintained but just barely. The second two plots in Figure 5 show the improvement that is obtained by conditioning the output signal of the quad cell with R-C low pass filters with a time constants of 1.1 seconds and 11 seconds respectively.

The results of this preliminary survey indicates that a HeNe laser optical system is a viable candidate for measuring the alignment of muon chambers over the distances required. In order for this technique to be successful there are several important conditions that must be satisfied.

1) The laser source must be of high quality. Beam intensity uniformity and wavefront flatness must be satisfy stringent requirements. If not, the beam intensity distribution in the far field will become distorted which will induce false displacement readings.

2) The tilt of the laser beam as it exits the laser must be either maintained less than 1 microradian (if propagation distance = 15 m) or compensated by the technique suggested by the report.

3) Air turbulence must either be controlled to minimal levels or its effect reduced by electrical or digital filtering. Beam pipes surrounding each beam could provide the turbulence.
control required, but this would have to be studied to assure that air currents in the tube would be acceptable.

Given the above caveats, 25 micron resolution using a laser beam appears to be achievable over the distances required. The proposed technique can be used for many points in a common line-of-sight. Range capability is also important to the muon alignment system. The quad cells that were used had an aperture which permits motions up to 3 mm with a 4 mm diameter beam. This approaches the 5 mm range goal that has been established and could be improved with a development effort.

cc: L. Griffith  
    M. Harris  
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Figure 2. Test setup
20-Aug-92
14:36:00

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Figure 3. Quocell Noise @ 15M

All doors closed  A/c off  72°F
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16:21:12

Main Menu

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X at 9 M
9.3 µm/div

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-2
10 s 50 mV

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Chan 1
10 s 50 mV

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- X at 15 M
22.8 µm/div

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CH1 50 mV =
CH2 50 mV =

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T/div 10 s

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All doors closed

---

A/C off

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Noise
Figure 5. Diode responses at different distances

12 M

9 M

6 M

3 M
Figure 6. Detector response at g/m with fully turbulent air conditions.