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Application Note No. 21: Complete Fringe Stabilization Techniques

Active Fringe Control Systems, Environmental Isolation Enclosures & Research-Grade Mounting Systems for Advanced Modern Interferometer Systems

Main Features of the Data Optics FC-300 Fringe Control System*

- Large Dynamic Range
- High Locking Stability
- Excellent Frequency Response
- Control Feedback Monitoring

Main Features of the Data Optics Environmental Isolation Enclosures*

- Air and Light Tight
- Temperature and Humidity Stabilization
- Air Turbulence and Acoustic Noise Protection
- Modular Construction for Easy Access
- State-of-the-Art Lightweight Materials

Main Features of the Data Optics Research-Grade Mounting Systems*

- Extremely Rigid and Stable
- Precision Dovetail Alignment Along the Optical Axis
- Remote Focusing via Rack & Pinion
- Unique “V” Shaped Holes to Eliminate Wobble
- Optional “V” Shaped Rods Retain Angular Alignment

* Patents Pending

Introduction

Interferometric techniques have become extremely useful tools in many fields of modern science and technology, and have been applied to various applications such as recording image holograms, making holographic optical elements (often called diffractive optical elements), precision metrology, and nondestructive testing. Most of these applications require stable interference fringe patterns. Consequently, scientists and engineers have developed both passive and active techniques to stabilize fringes. This application note shows how to obtain stable fringes and why both passive and active fringe control methods are necessary to utilize the maximum capability of most interferometric systems.

Since the fabrication of high quality holographic optical elements is one of the most difficult applications of interferometers, we will focus on how to achieve stable fringes in systems for recording them. The recording of holographic optical elements is even more difficult than recording diffused object holograms because they do not have redundancy and must meet stringent performance requirements. Although this application note will focus on how the Data Optics fringe control system, environmental isolation enclosures and mounting systems have been effectively used in holographic systems, most of our discussions can be applied to other interferometric systems as well.

Main Causes of Fringe Instability

A typical hologram recording interferometer system used in the fabrication of reflective holographic optical elements is shown in Figure 1. Most of the components necessary in setting up a system have been well developed and are readily available. Since a hologram is a record of complex fringe patterns formed between several (typically two) mutually coherent beams, it is

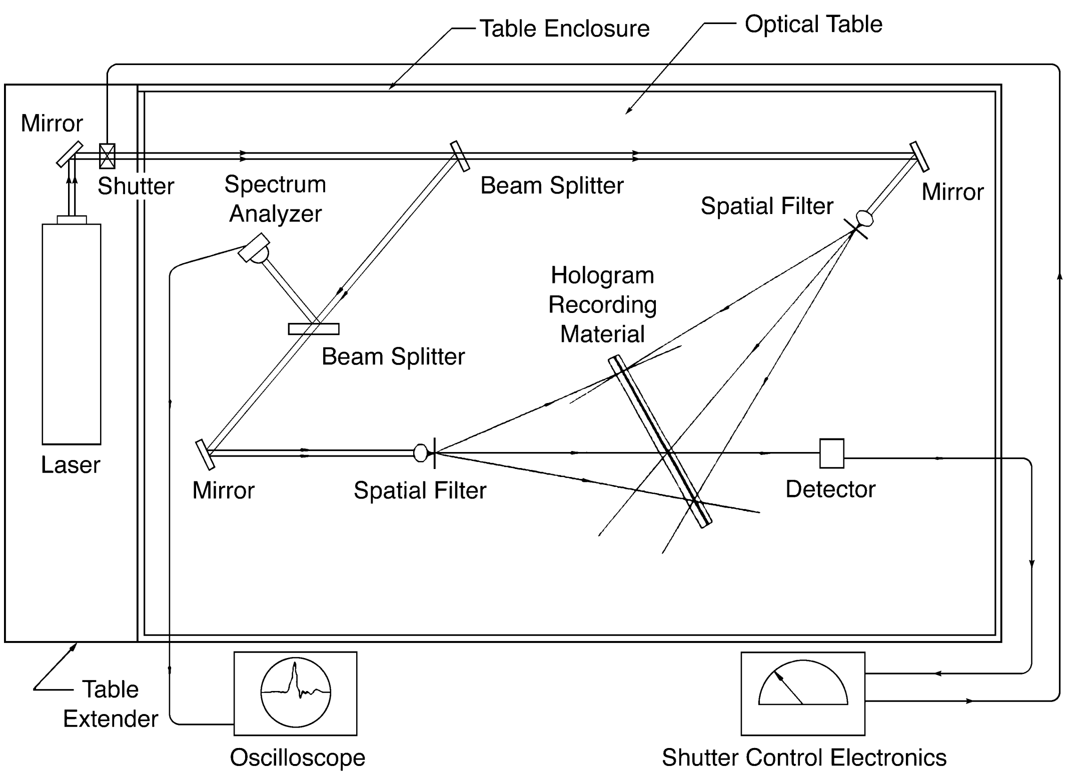

Figure 1. Layout of a typical hologram recording system.

in theory relatively easy to record a holographic optical element. In practice, however, it is difficult to repeatedly record good holographic optical elements having desired characteristics such as diffraction efficiency, angular and spectral bandwidths, and efficiency uniformity.

Although post-exposure processing steps may be potential causes of poor hologram quality, the main cause of failure in making good holographic optical elements is fringe instability, i.e., the movement of fringes during the exposure. The movement of fringes is due to the change in the optical path difference between the two recording beam paths. The change in the optical path difference can be caused by several factors as follows:

1. Laser wavelength shift or mode hopping due to instability in the laser cavity.
2. Optical table warping due to improper balancing or slow air leakage in the pneumatic suspension legs.
3. Movement of mechanical components holding beam-forming optical elements due to mechanical vibrations transmitted through the floor, acoustic noise transmitted through the air and from thermal expansion and contraction.
4. Local air density variations due to turbulence, temperature and humidity drift.
5. Thermal expansion or contraction of optical elements due to changes in room temperature.
6. Thermal expansion of optical components such as lenses and mirrors due to the heat generated by recording laser beams.

Before we discuss fringe stabilization techniques, let us review the several causes of fringe instability. Figure 2 shows typical fringe movements as a function of time which can often be observed in an interferometer similar to that shown in Figure 1. The fringe movement can be observed using a fringe monitoring (sampling) interferometer.

Figure 2A shows that as soon as the laser beam starts to illuminate the cold optical components, it starts to heat and expand them, changing the relative optical path lengths. As a result, the fringes start to move. As the exposure time increases, the thermal expansion of the optical components slows down and finally reaches a new thermal equilibrium point. The fast fringe movement in the earlier part of the exposure is primarily due to the rapid thermal expansion of

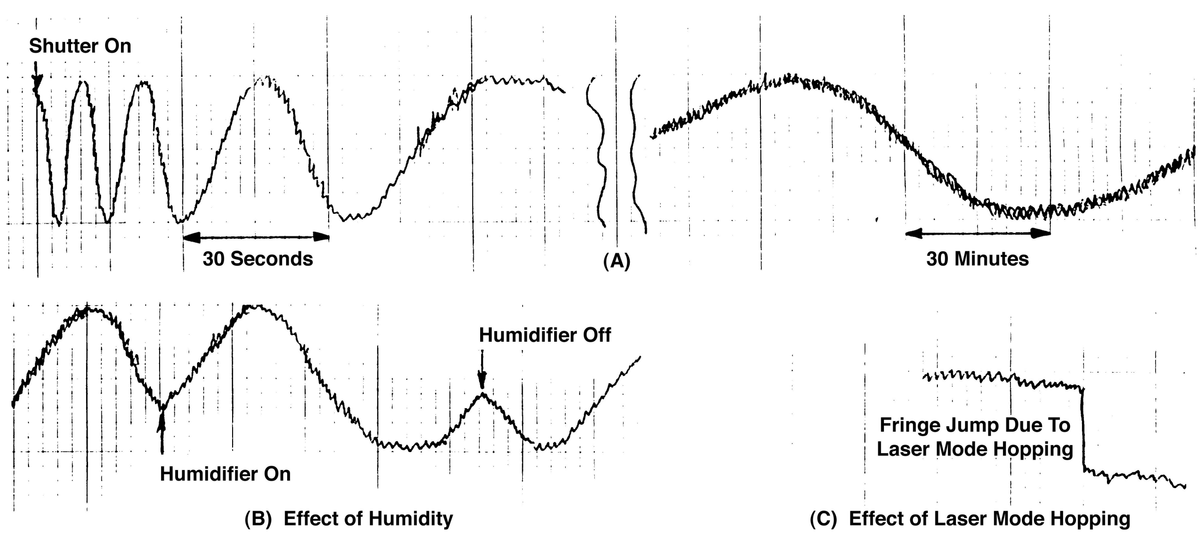

Figure 2. Typical fringe movements observed in an interferometer similar to that shown in Figure 1.

beam-forming optical components, and the slow drift of fringes in the latter part of the exposure (i.e., after the optical components are thermally stabilized), is primarily due to the slow change of either the room temperature, humidity, or both. Also, other factors, such as slow table warpage due to the leakage in table's pneumatic suspension legs, can be causes of slow fringe drift. The high frequency noise on the fringe movement curves are due to mechanical vibrations transmitted through the floor, acoustic noise transmitted through the air, or both.

Figures 2B and 2C show the effects of room humidity change and laser mode hopping, respectively. Although the effects of both laser mode hopping and temperature change are well known, the effect of humidity change is not well characterized. In order to maintain fringe stability, it is imperative to maintain a relatively constant humidity in the surrounding environment. Data Optics environmental isolation enclosures are designed to maintain a constant temperature and humidity inside the enclosure for long periods of time, regardless of environmental parameter changes outside the enclosure.

Passive Fringe Stabilization Methods Using Environmental Isolation Enclosures

In order to record good holographic optical elements having desired characteristics, we have to either completely eliminate all potential causes of fringe instability, or dynamically compensate for the change in the path length difference. The potential causes mentioned above can be eliminated or significantly reduced by using several passive techniques:

1. The proper selection, tuning and warm-up of the laser before the adjustment of beam-forming optical elements can eliminate wavelength shift due to mode hopping. The typical warm-up period for an individual laser can be determined by monitoring the laser spectrum with a spectrum analyzer. Since each laser can require a significantly different warm-up period and have significantly different steady state stability, it is very important to carefully select a laser for your unique application.
2. Use of an optical table having a proper pneumatic suspension system can eliminate optical table warping and the movement of mechanical components due to mechanical vibrations transmitted through the floor Proper design and adjustment of the pneumatic legs is extremely important when long exposures are required.
3. Selection of stable and robustly designed mechanical components to hold and position the optical components, spatial filters and hologram recording media can reduce many of the effects of vibration and movement due to temperature variations.
3. Employment of a properly designed environmental isolation enclosure can effectively minimize or eliminate the movement of mechanical components due to acoustic noise transmitted through the air, the expansion or shrinkage of optical components and their mounts due to room temperature changes, and air density changes due to air turbulence, temperature drift and humidity fluctuation. Note that improperly designed enclosures will amplify acoustic noises, rather than reduce them. Data Optics environmental isolation enclosures, which are specially designed for stringent interferometer systems, have been successfully used for the fabrication of quality holographic optical elements and effectively isolate the hologram recording system from the room environment.
4. Placing the shutters just before the hologram recording fixture, and warming up the beam-forming optical components with the laser beam before the exposure can almost entirely eliminate thermal expansion of optical components due to the heat generated by the laser beam.

5. Lastly, selecting the right time for the exposure to start by monitoring fringe stability can also significantly improve the performance of a interferometric system. Figure 3 shows an improved hologram recording system having shutters near the hologram recording fixture and a fringe stability monitoring interferometer.

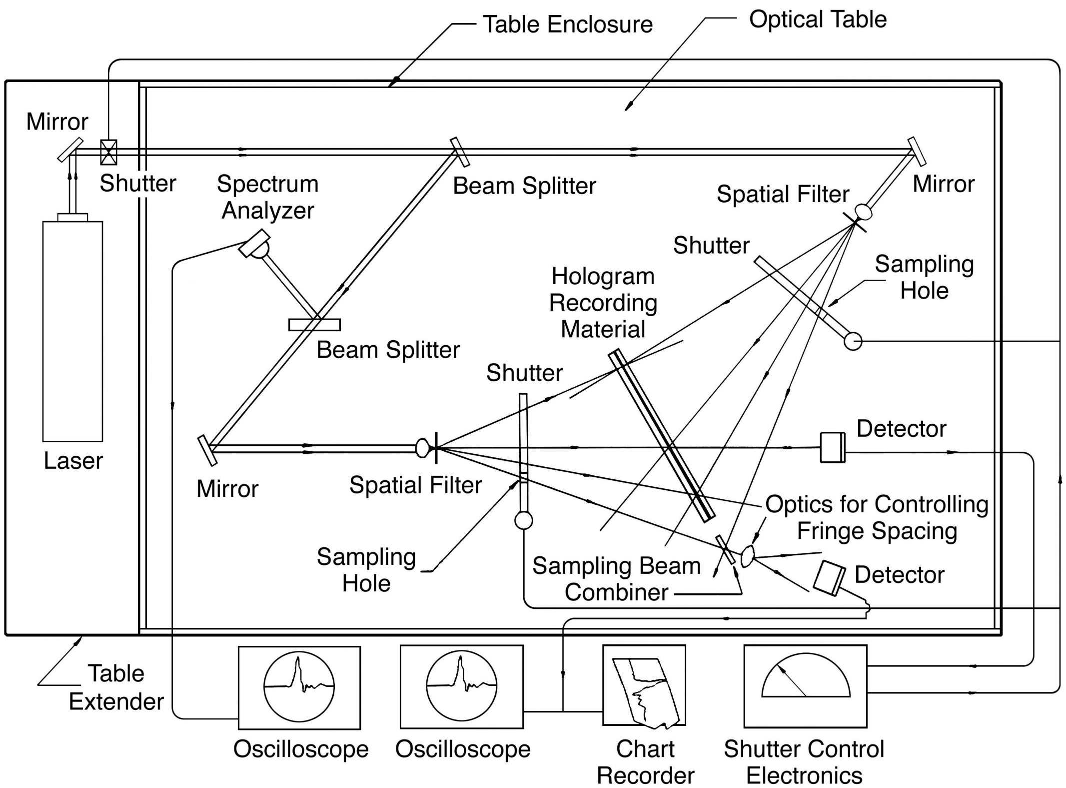

Figure 3. Layout of an improved hologram recording system employing a fringe-monitoring interferometer

Most holographers recognize that the use of good vibration-isolated optical table is essential for recording good holograms. However, many of them may not realize that the use of a properly designed environmental isolation enclosure is also extremely important. While vibration-isolated optical tables reduce only one factor, i.e., mechanical vibrations transmitted through the floor, properly designed environmental isolation enclosures can eliminate or significantly reduce all other factors such as air turbulence, acoustic noise, humidity fluctuation, temperature drift and airborne pollutants. <u>In fact, the use of properly designed environmental isolation enclosures may be more critical for recording good holograms than that of an expensive vibration-isolated optical table</u> (particularly when an active fringe control system is employed). Drawing upon the experience of researchers who have been involved in the development of holographic optical element fabrication technologies during the last twenty years, Data Optics is able to produce light weight, modular environmental isolation enclosures using advanced materials and unique fabrication techniques that satisfy the stringent requirements of this application.

Although all these passive methods can improve the fringe stability, and fringe monitoring can tell us when we may start to expose a hologram, there is no guarantee that fringes will be stable during the exposure period. In order to completely achieve fringe stability during the exposure, it is essential to properly implement the active fringe stabilization technique. In the next section, we will briefly discuss how the Data Optics FC-300 Fringe Control System is used in an advanced hologram recording system.

The Role of Active Fringe Control in Hologram Recording System

An advanced hologram recording system employing both an active fringe control system and all other passive fringe stabilization techniques discussed previously is shown in Figure 4. This configuration is similar to that shown in Figure 3, but there are three important differences. First, this system has an electronic fringe controller, the heart of the fringe control system. Second, the single fringe stability monitoring detector has been replaced by a pair of detectors able to sense absolute fringe movement. Third, one of the fixed position path-folding mirrors has been replaced by a movable mirror mounted on a bimorphic or piezoelectric element. This element moves the mirror according to the feedback signal generated by the controller electronics to compensate for the movement of fringes sensed by the detector pair. All three components are included in Data Optics FC-300 system.

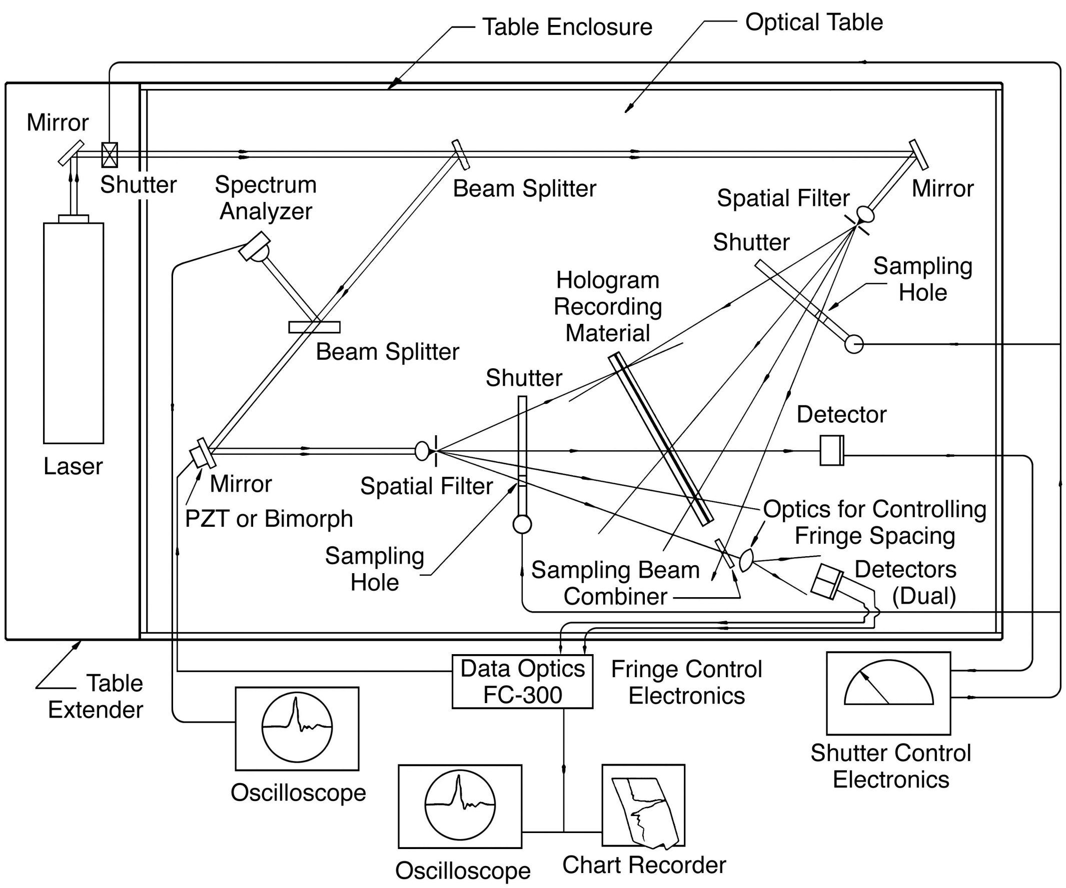

Figure 4. Layout of an advanced hologram recording system employing an active control system

The fringe control system can stabilize the fringe pattern for an indefinite period of time by completely compensating for the optical path length change, without using any passive techniques. However, since the fringe control system corrects the optical path length at a single point, it is still necessary to employ all passive techniques, especially for recording large holographic optical elements. The use of both properly designed table enclosures and active fringe control systems is necessary for repeatedly recording good holographic optical elements.

In summary, two basic roles of Data Optics active fringe control system, the FC-300, in the hologram recording system are as follows:

1. <u>Monitoring the system stability</u>: Set-up procedures such as adjustment of beam-forming optical components, installing film into the exposure fixture, and installing environmental isolation enclosure panels will disturb the stability of the interferometer system and also its surrounding environmental parameters (i.e., temperature and humidity). Before the exposure starts, all interferometer components, as well as surrounding air , should be significantly stabilized in order to assure recording a desirable hologram over the entire hologram plate. The output signal from the FC-300 has been designed to monitor the movement of the control mirror, and thus the stability of the recording interferometer system. The chart recorder trace can be used to determine when the hologram can be exposed.
2. <u>Active fringe stabilization</u>: During the exposure, the fringe control system continuously compensates for the optical path length change that is due to the slow change of environmental parameters such as room pressure, temperature and humidity. Thus, active fringe stabilization will assure the recording of good quality holograms.

Data Optics can assist you in effectively setting up a hologram recording interferometer or other interferometric systems using our FC-300 fringe control system and our environmental isolation enclosures.

Figure 5. The Data Optics FC-300 Fringe Control System

Other Applications for Data Optics Environmental Isolation Enclosures

Many modern, sophisticated instruments and machines, such as low-level electronic signal measuring instruments and diamond turning machines require the precision control of environmental parameters, such as temperature, humidity, acoustic noise, mechanical vibration and stray light.

Often the source of error in electronic measurements is fluctuating humidity. The more sensitive the measurement is, the more critical the control over the surrounding environment becomes. The best approach is to conduct all experiments by placing instruments in a room or enclosure with tight control over temperature and humidity.

Figure 6. Data Optics Environmental Isolation Enclosures.

Many expensive environmental rooms having dedicated air conditioning and humidification systems have been built to precisely control environmental parameters. Although most of these rooms can maintain uniform, time-average temperature and humidity, they are not able to maintain constant temperature and humidity as a short-term function of time. Also, the presence of operators in the controlled room breaks the environmental stability of the room because operators can significantly increase both temperature and humidity. Therefore, precisely controlled rooms are not ideal solutions unless instruments are isolated from the operators. The isolation of instruments has been more effectively carried out by placing instruments into properly designed enclosures.

Data Optics offers unique environmental isolation enclosures, which have been effectively used for stringent interferometer systems, and can be effectively used for low level light measurements, low level electronic signal measurements and spectroscopy.