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Principles of Operation

Introduction

The measurements that an Agilent laser measurement system can make depend on the measurement optics (interferometers and retroreflectors) that are used.

The basic measurement made by all Agilent laser measurement systems is a linear measurement of the relative movement between an interferometer and its associated retroreflector, along the path of the laser beam. In most cases, the interferometer is the fixed optic and the retroreflector is the one that moves.

Agilent offers interferometers and retroreflectors that allow measurements of angles, flatness, and straightness to be made. However, all of these measurements represent special applications of the basic linear measurement. An angular measurement, for example, represents the difference in two linear measurements whose separation is precisely known.

The length standard for all of these measurements is the wavelength of laser light from the laser head. Relative motion between the interferometer and its retroreflector generates a series of interference fringes in the laser beam. The interference fringes are converted to electrical pulses in a receiver, and sent to the measurement electronics, which processes them as required to provide the desired measurement data.

The interferometric measurement system is sensitive enough that its measurements can be affected by changes in the measurement environment. These changes can affect both measurement accuracy and repeatability.

The wavelength of laser light, which is the length standard for measurements, can be affected by the characteristics of the environment between the interferometer and its associated measurement reflector. The process of determining the correct wavelength-of-light value for the measurement conditions is called compensation. Agilent offers devices (air sensor, wavelength tracker) which can be used to provide automatic compensation for the wavelength of light. Alternatively, wavelength-of-light compensation can be performed manually, by measuring the atmospheric temperature, pressure, and humidity, and calculating the compensation value or looking it up in a table. Additional information about wavelength-of-light compensation is provided in Chapter 16, “Wavelength-of-light Compensation,” of this manual.

Another environmental factor that can affect the measurement is the temperature of the material being measured. Agilent offers material temperature sensors that can enable automatic compensation for the effects of temperature changes. Material temperature compensation can also be performed manually, by measuring the material temperature and calculating the effect of the difference between the standard temperature and the temperature at the time of the measurement. Chapter 17, "Material Expansion Coefficients," in this manual provides expansion coefficient values for many commonly-used materials.

Measurement Technique

Introduction

Agilent laser measurement systems measure displacement by:

1. generating a two-frequency laser beam.
2. sampling part of the beam, to determine the frequency difference between the two frequencies in the beam. This difference frequency is sent to the measurement system electronics as the Reference Frequency.
3. sending the two-frequency laser beam to an interferometer that separates the beam into two single-frequency beams. Each beam has one of the two frequencies of the original beam.
4. sending one interferometer output beam to a non-moving reference retroreflector, or a plane mirror, that returns it to the interferometer.
5. sending the second interferometer output beam to a measurement retroreflector, or a plane mirror, that returns it to the interferometer.
6. within the interferometer, combining the beams returned from the two retroreflectors to produce a difference frequency beam that is used as the interferometer's output.
7. sending the interferometer output to a receiver that converts the optical difference frequency from the interferometer to a series of electrical pulses at that frequency that is sent to the measurement system electronics for processing and any further use specified by the user and allowed by the electronics.

The main benefit of the two-frequency technique is that the distance information is carried on ac waveforms, or carriers, rather than in dc form. Since ac circuits are insensitive to changes in dc levels, a change in beam intensity cannot be interpreted as motion.

Creating the two-frequency laser beam

The ac signals representing distance change are analogous to the intermediate frequency carriers in FM heterodyne receivers. In the Agilent laser measurement system, the ac signal or “intermediate frequency” is produced by mixing two slightly different frequencies, near 5 × 1014 Hz (500,000 GHz), differing by only a few megahertz.

Using different sources to generate the two frequencies would require ultra-stable sources and periodic calibration. However, a laser can be forced to output a laser beam composed of two frequencies simultaneously, by applying an axial magnetic field. The two resultant frequencies are very close together, but have opposite circular polarizations. Both frequencies are extremely stable and do not require recalibration. Waveplates within the laser head convert the circularly polarized beam components to orthogonally polarized components before the beam leaves the laser head. A polarizing beam splitter in the interferometer is used to separate the two beams.

Using the two-frequency laser beam at the interferometer

One of the laser frequency components (f_1) is used as the measuring beam and reflects from the external cube corner back to the beam splitter. Here the measuring beam mixes with the second or reference frequency (f_2) to produce fringe patterns. These patterns are composed of alternate light and dark bands caused by successive reinforcement and cancellation (interference) of the beams. If the movable cube corner reflector remains stationary, the interference rate (beat frequency) will be the exact difference between the laser’s two frequencies, about 1.5 to 3 million fringes per second, depending on the laser head used.

When the cube corner moves, the frequency of the returning beam shifts up or down by ($f_1 \pm \Delta f$), depending on the direction (and velocity) of the motion. A cube corner velocity of 300 millimeters per second (one-foot per-second) causes a frequency shift of approximately 1 MHz.

When a plane mirror interferometer is used, the measurement beam makes two passes to the measurement mirror. As a result, when the measurement mirror moves at 300 mm/second, the frequency shift seen in the measurement path is approximately 2 MHz.

The frequency shift is monitored by a photodetector and converted to an electrical signal (f_2 - ($f_1 \pm \Delta f$)). A second photodetector inside the laser head monitors the fringe frequency before the paths are separated, and provides a reference signal that corresponds to zero motion (f_2 - f_1).

Doppler frequency shifting

Frequency shifting that results from (or indicates) relative motion between the source and receiver (observer) is known as Doppler shift. One example often used is the apparent change in pitch of a whistle or horn as the distance between the it and the listener changes. Another example is the red shift in the spectrums of stars, indicating that the universe is expanding.

The two frequencies from the photodetectors are sent to a special counter. The counter counts up on the Doppler-shifted signal from the retroreflector and down from the reference signal. With no retroreflector motion, the frequencies are equal, and no net count is accumulated. When the retroreflector moves, the Doppler frequency increases or decreases to produce net positive or negative cumulative counts corresponding to the distance and direction traversed, in wavelengths of light.

Basic Measurement System

A basic Agilent laser measurement system consists of: 1) a laser head, 2) an interferometer and its associated retroreflector, 3) a measurement receiver, and 4) measurement and control electronics. See Figure 14-1.

Because it is often not possible to line up the laser head output with the interferometer input aperture, the system will also include beam-directing optics.

Additionally, the system may also include environment sensing or wavelength tracking devices or both.

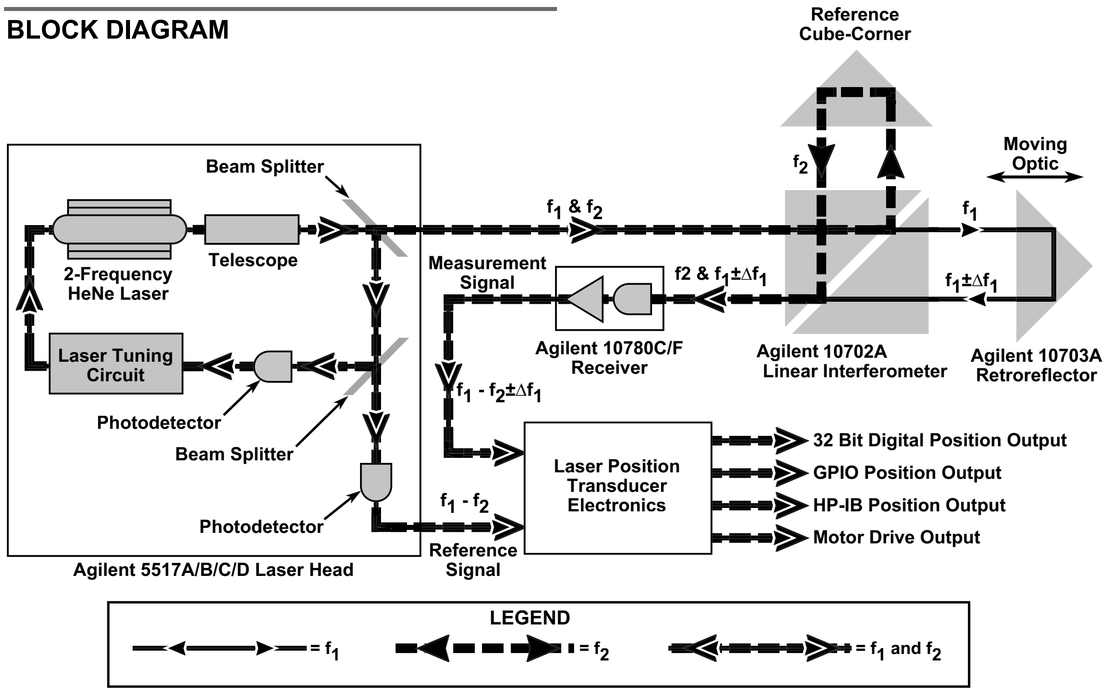

Figure 14-1. Typical (older) Agilent Laser Position Transducer block diagram

Basic Agilent Laser Measurement System Components

The laser head serves as the light beam and reference frequency source.

The optics and the measurement receiver use the laser beam to generate the measurement signal. The reference and measurement signals, along with the environment sensor signals, are used by the measurement electronics to generate linear displacement information.

The system controller can read and display this information. In addition, the controller can send destination input data to the measurement electronics, which outputs a real-time error signal representing the difference between the destination and the actual position. This error signal can be used in servo electronics to drive a stage's positioning motors.

Laser head

A low-power helium-neon laser emits a coherent light beam composed of two slightly different optical frequencies, f_1 and f_2, of orthogonal linear polarizations. (See Figure 14-1.) Before exiting the laser assembly, the beam passes through a beam splitter where a small fraction of the beam is sampled. This portion of the beam is used both to generate a reference frequency and to provide an error signal to the laser cavity tuning system. The difference in the amplitudes of f_1 and f_2 is used for tuning while the difference in frequency between f_1 and f_2 (between 1.5 MHz and 3.0 MHz, depending on the model of the laser head) is used for the reference signal.

The wavelength of light from the laser head is used as the length standard for Agilent laser measurement systems. The laser head generates a coherent (all light waves in phase), collimated (all waves traveling parallel to one another) light beam consisting of two orthogonally polarized frequency components. The laser measurement system uses this beam to generate measurement signals (MEASurement Frequency). In addition to this beam, the laser head generates an electrical reference signal (REFerence FREQuency).

System optics

The major portion of the beam passes out of the laser head to an interferometer. The interferometer is a polarizing beam splitter that reflects one polarization (frequency) and transmits the other. The beam splitter is oriented such that the reflected and transmitted beams are at right angles to each other. The reflected beam (f_2) is reflected off a fixed retroreflector or mirror, usually mounted directly on the interferometer. The transmitted frequency (f_1) passes through the interferometer and is reflected back to the interferometer by a movable retroreflector or plane mirror. If the distance between the interferometer and the movable retroreflector remains fixed, the difference frequency (f_2-f_1) equals the reference signal. Under these conditions, the Agilent laser measurement system electronics detects no change in relative position of the interferometer and the movable retroreflector. When the movable retroreflector changes position relative to the fixed interferometer, a doppler frequency shift occurs. This Doppler-shifted frequency becomes $f_1 \pm \Delta f_1$ depending on the direction of reflector movement. The two frequency components, f_1 and f_2, exit the interferometer as a coincident beam.

One of the two frequency components is directed toward the object whose motion is being measured. There it is reflected by a mirror or retroreflector (cube-corner) and returned to the interferometer.

The other frequency component travels a fixed path through the cube corner mounted directly to the interferometer, where both components recombine into a single beam. Both cube-corner retroreflectors offset their corresponding beams and return them parallel to the incoming beam path. Small rotations or perpendicular movements will not affect the accuracy of the measurement.

Each laser measurement system axis must have an interferometer and retroreflector. Machine design considerations determine which type of interferometer is optimum. The choice of the interferometer for each axis usually specifies the retroreflector or plane mirror for that axis.

The Agilent 10717A Wavelength Tracker is an interferometer and etalon (fixed-length reference cavity) combination that measures changes in laser wavelength, not displacement. It measures apparent change in a fixed distance, which is interpreted as a variation in the laser wavelength.

For more detailed information on the individual optical components available from Agilent, refer to Chapter 7, “Measurement Optics,” Chapter 6, “Beam-Directing Optics,” and Chapter 9, “Accessories” in this manual.

Receiver

The coincident beam is directed to a receiver (e.g., Agilent 10780C or Agilent 10780F) where the two frequency components interfere (mix) at the receiver’s polarizing plate. This produces a difference frequency which is detected by the receiver's photodetector and converted to an electrical signal. The receiver Circuitry then amplifies the signal which becomes the measurement frequency. Displacement information is obtained in the measurement electronics by a comparison of both the measurement and reference signals.

Environment sensors

As described at the beginning of this manual chapter, the laser measuring system is sensitive enough that its measurements can be affected by environmental conditions during the measurement.

The Agilent 10751C or Agilent 10751D Air Sensor can be used with measurement electronics to automatically and continuously provide compensation for changes in the wavelength of laser light resulting from changes in the atmospheric conditions at the time of the measurement.

The Agilent 10757D, Agilent 10757E, or Agilent 10757F Material Temperature Sensor can be used with measurement electronics to automatically and continuously enable changes in measurement information based on changes in the temperature of the item being measured.

The Agilent 10717A Wavelength Tracker, described in subchapter 7I of this manual, is also an environment sensor.

This is a chapter from the manual titled:
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