Calibration System Description: Model TRD-1
Outside Diameter Measurement System

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Revision History:

1 Scope

This document provides details of the calibration method and requirements of the Model TRD-1, Outside Diameter Measurement System manufactured by Laser Metric Systems, Inc. 37 Kinnaird Street, Cambridge, MA 02139 (hereafter, "**LMS**").

We follow ANSI/NCSL Z540-1-1994 Parts I & II: Quality Assurance Requirements for Measuring and Testing Equipment (M&TE) ("**The Standard**").

2 References

1. ANSI/NCSL Z540-1-1994 "American National Standards for Calibration - Calibration Laboratories and Measuring and Test Equipment - General Requirements"
2. Handbook for the Interpretation of ANSI/NCSL Z540-1-1994, October 1995
3. ANSI/NCSL Z540-2-1997, "U. S. Guide to the Expression of Uncertainty in Measurement.

3 Definitions

We refer to the list of definitions in ANSI/NCSL Z540-1-1994, section 3, pages 1 through 3. The definitions are numbered 3.1 through 3.27 and are in alphabetical order.

We also refer to the terminology of reference 3.

4 Calibration System Description

We follow the outline of sections 18.1 through 18.12 of reference 1.

4.1 General Background

The Model TRD-1 (MT&E) is a laser-based, non-contact outside diameter (OD) measurement system. This system is also called "the gage" and the process of measurement is also called "gaging". The Model TRD-1 is designed to measure cylinders and cylindrically symmetric rings such as ball bearing inner races.

The Model TRD-1 is intended for use primarily as a production part gage although in controlled environments it can be used as fast calibration equipment for reference parts.

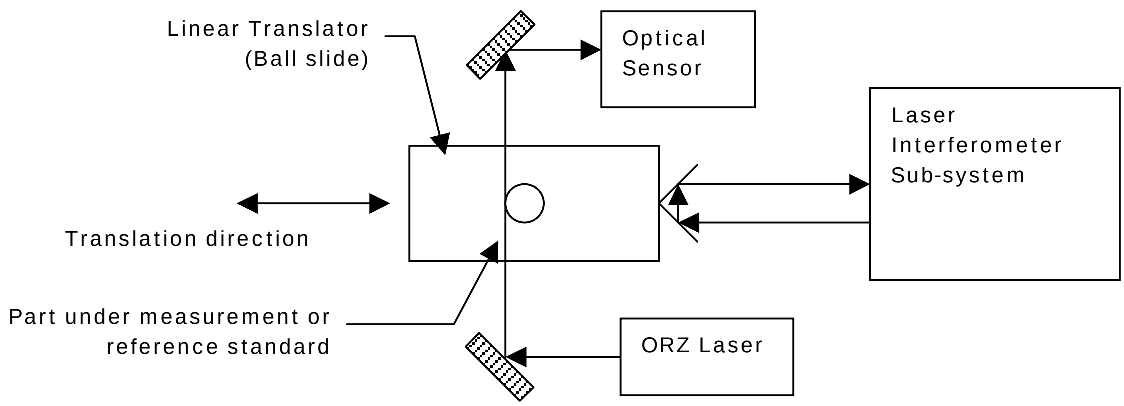
A schematic drawing of the Model TRD-1 is shown in figure 1 below.

The part or reference standard is translated past the Optical Reference Zone (ORZ) laser beam at a steady speed. As the part enters the ORZ, the shadow of the part is imaged onto the optical sensor. At this point, a translation displacement reading is taken by the laser interferometer. While the part eclipses the ORZ beam the laser interferometer continues reading the displacement until the other side of the part begins to exit the ORZ and the edge (shadow) of the part is sensed. A second translation displacement reading occurs as the shadow is sensed. The two displacement readings of the edges of the part are used to provide an accurate measurement of the OD.

The laser interferometer uses a second laser which is frequency stabilized ("the interferometer laser"). The properties of this laser will be discussed in following sections. The laser interferometer measures displacement by counting fractional wavelengths of laser light.

The part under measurement is located to the linear translation stage (linear ball-bearing stage) using a fixture. Typically the fixturing tolerances are very generous (+/- 0.005") which allows inner races to sit loosely on the fixture using the inner diameter. Most users of the Model TRD-1 provide their own production fixturing.

Figure 1: Schematic of Model TRD-1 OD Measurement System



4.2 Relevent Operating Specifications

These specifications are cited for use in a production environment, not as calibration laboratory equipment. Vibration isolation system is in operation.

Description	Value or range	Notes
Measurand	Outside Diameter	Usually expressed as *nominal* (target) value plus/minus a size *difference* of the part from the nominal.
Operating Temperature Range:	20 °C +/- 5 °C	Gage readings are compensated for atmospheric pressure, but *not* for actual gage/part temperature. A compensation factor must be applied to correct for temperature effects.
Operating Humidity Range (non-condensing on part or gage)	20% - 80% RH	Non-condensing relative humidity does not affect steel parts but does change the laser wavelength slightly.
Part diameter range	0.1" to 4.5"	Appropriate fixturing required

Track radius range	0.02 to cylinder	This applies to ball-bearing races. The part must fixtured to find the minimum reading at the bottom of the groove. Track-to-face tolerances apply.
Single reading Uncertainty (part-gage at 20 °C) (one sigma)	+/- 8 ppm (+/- 8 µin/in)	This is the standard deviation of a single reading including all influence quantities except part temperature.
Multiple reading uncertainty (part gage at 20°C – one minute period (one sigma)	+/- 3 ppm (+/- 3 µin/in)	This is the standard deviation of the average of several (usually ten) readings, lasting less than one minute, including all influence quantities except part temperature.
Long-term uncertainty of average (part-gage at 20°C, multiple reading) (one sigma)	+/- 4 ppm (+/- 4 µin/in) (at six months interval)	This is the standard deviation of average readings taken months or years apart. When this deviation exceeds the tolerable level, this sets the calibration interval. Gages may be checked more frequently.

5 Adequacy of Measurement Standards

The Model TRD-1 depends on two kinds of reference standards or reference material for the integrity of it's measurements:

- Laser frequency standards - for the interferometer laser sub-system
- Steel Plug gages (cylinders) – for the ORZ sub-system

The collective uncertainty of these standards is +/- 2 ppm (1-sigma) which is 25% of the specification stated in Section 4.

5.1 Laser Frequency Standards

The speed of light in a vacuum is now defined as an actual constant that does not need to be measured. The NIST and international value is: 299,792,458 meters/second exactly. This allows the definition of the meter to depend on the time standard alone. The wavelength of light is defined as follows:

$$\lambda = c/\nu$$

Where λ is the wavelength, c is the speed of light and ν is the frequency in cycles per second.

5.1.1 Traceability and Calibration Uncertainty

The interferometer laser in the Model TRD-1 is a "frequency stabilized" Helium-Neon laser (HeNe). This laser has a frequency of 473,612,236 MHz +/- 500 MHz when calibrated against an Iodine-stabilized HeNe laser traceable to NIST.

The vacuum wavelength is now known from the previous formula: 632.991376 +/- 0.0006 nanometers.

5.1.2 Refractive Index of Air Effects

The wavelength in operation must be corrected for the refractive index of air according to the formula

$$\lambda_{air} = \lambda_{vac} / n_{air}$$

The Model TRD-1 references the refractive index to air at 20°C, 40% relative humidity and a pressure of 760 mmHg. The gage includes a strain gage based absolute pressure sensor to correct for pressure related changes in refractive index. Air temperature and humidity effects are not compensated for automatically.

The collective uncertainty (1-sigma) of the Model TRD-1 displacement readings due to all influence quantities on the wavelength is +/- 1 ppm of reading. (ppm is parts-per-million) over the entire range of conditions.

5.2 Steel Reference Cylinders (Plug Gages)

Plug gages are used to calibrate the Optical Reference Zone (ORZ) sub-system. We use a set of 22 plugs ranging from 0.1” to 4.5” in diameter. These plugs are measured by sub-contractors to LMS. The suppliers are accredited calibration laboratories using NIST traceable methods.

5.2.1 Plug Gage Calibration

The relevant measurand is for plugs is Outside Diameter (OD). Plug gages are highly cylindrical with little variation is OD over the central portion of the cylinder. Plugs are measured usually using a comparison method. A precision mechanical comparator is set up with calibrated gage blocks (a.k.a. Johansson blocks). Gage blocks are solid rectangular blocks with two, optically smooth, flat, parallel steel surfaces. The distance between these surfaces is measured using a laser interferometer method.

Due to the temperature expansion factor of steel, plugs diameters are referenced to 20 °C and measured as close to 20 °C as possible.

The following specs apply to plug gages used for calibrating the Model TRD-1:

Description	Value or range	Notes
Measurand (at 20C)	Outside Diameter	Usually expressed as *nominal* (target) value plus/minus a size *difference* of the part from the nominal.
Total Uncertainty (+/- 1 sigma)	+/-0.3 ppm (µin/in)	This requires control and measurement of the part temperature.
Calibration Interval	Two years (nonwearing)	Depends on use. In non-contact applications, plugs will not wear. The calibration interval is set by confidence that plugs have not been lost, misidentified or damaged.

The uncertainty (1-sigma) of the Model TRD-1 displacement readings due to all influence quantities on plug gages (ORZ calibration) is +/- 1 ppm of reading. (ppm is parts-per-million) over the entire range of conditions. (Note: ORZ calibration is performed with known reference temperature.)

6 Environmental Conditions

The Model TRD-1 is a relatively large and heavy equipment. It is undesirable to move them from a production area to a calibration laboratory and back again. Therefore these gages are calibrated "in situ". The environment for gaging precision ball-bearing races is quite good overall but some correcting compensations are necessary.

The following table outlines the gaging environment compatible with precision measurement in a production facility.

Description	Value or range	Notes
Dust and particulate	Clean room or equiv. (Class 10K)	Class 10000 clean room. Operators wear appropriate coveralls.
Vibration	Variable	The Model TRD-1 uses a vibration isolation system to avoid the vibration caused by machine tools.
Electromagnetic Interference	FCC specified	The Model TRD-1 uses shielded cables, metal case to avoid interference.
Ambient Temperature	20 °C to 25 °C typical	The range is larger than a calibration laboratory . Plug and gage temperature is recorded during calibration.

6.1 Temperature Compensation Method

A platinum RTD-based digital thermometer is used to monitor the temperature of plugs and gage during calibration. Platinum RTDs are exceptionally stable devices that use the known temperature coefficient of resistance of pure platinum. Uncertainty of temperature measurement is +/- 0.05C (1-sigma).

The known expansion coefficient of steel plugs and the temperature effect on laser wavelength are used to compensate readings during calibration. This results is a residual uncertainty of +/-0.3 ppm.

The temperature and the compensating values are recorded during calibration.

7 Intervals of Calibration

The time interval of calibration is set by system understanding and operating experience based on periodic checks of the equipment. Operating experience with the Model TRD-1 shows that it is stable over years. However, when components fail or are replaced at end of life, a check with three plug gages verifies stability.

LMS recommends and performs at least an annual check of Model TRD-1 systems using reference plug gages (three plugs are adequate to verify calibration).

7.1 Interferometer Laser Replacement

These lasers have a limited life of about 2 years and require replacement. A tolerance check should be performed after replacement. If an out-of-tolerance condition is detected, a calibration should be performed (see Section 8).

8 Calibration Procedures

The Model TRD-1 uses an IBM compatible PC for system control and calibration. Calibration software prompts the operator through the process of measuring 22 plug gages and entering environmental data. Calibration data is stored on a hard drive and can be saved on removable media.

For details, we refer the reader to the Model TRD-1 Calibration Software Manual.

Calibration technicians are trained at LMS facility and are aware of all aspects that affect calibration quality. Deviations from accepted practice or results are subject to documentation and review by LMS and customer.

9 Out-of-Tolerance Conditions

LMS shall record and report significant out-of-tolerance conditions identified during calibration or system check to it’s customers.

A significant out-of-tolerance condition is defined as operation exceeding the specifications described in Section 4.2. In addition to measurand results, out-of-tolerance conditions can include: environment problems, operator knowledge and behavior, customer awareness of system requirements.

The customer and supplier may agree to redefine “significantly” based on the actual effect of measurement results on the customers end product. Some customers use Model TRD-1 systems as “relative” gages where only short-term stability is needed and “absolute” calibration is not necessary.

10 Adequacy of Calibration System

LMS maintains a field-service and calibration database which tracks the history of each system. The responsibility is on the supplier (LMS) to maintain documented procedures and initiate appropriate safeguards and corrective actions.

11 Calibration Sources

The Model TRD-1 is calibrated by trained personnel and accredited sub-contractors as per The Standard. Details have been provided in the previous sections.

12 Records

LMS maintains records from the inception of operation of each gage. Each gage is tracked by serial number. A field service record is kept for each visit to a customer. This record documents changes including: date of visit, part replacement, power levels of lasers, reading deviations from nominal, procedures used, calibration sources.

13 Calibration Status

LMS shall label the calibration or verification status on the gage per the Standard.

14 Control of Subcontractor Calibration

LMS is responsible for assuring it's subcontractors' calibration/verification system conformance to the Standard.

15 Storage and Handling of M&TE

The Model TRD-1 is rarely moved from the factory gaging area as noted previously. Special crates are available for shipping these systems. All systems are checked after shipping to a new location. Sub-systems are shipped in custom, shock absorbing, high impact resistance plastic crates and cases. Lasers are generally hand-carried by service personnel. Gage blocks and plug gages are hand-carried or shipped in shock absorbing cases.

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