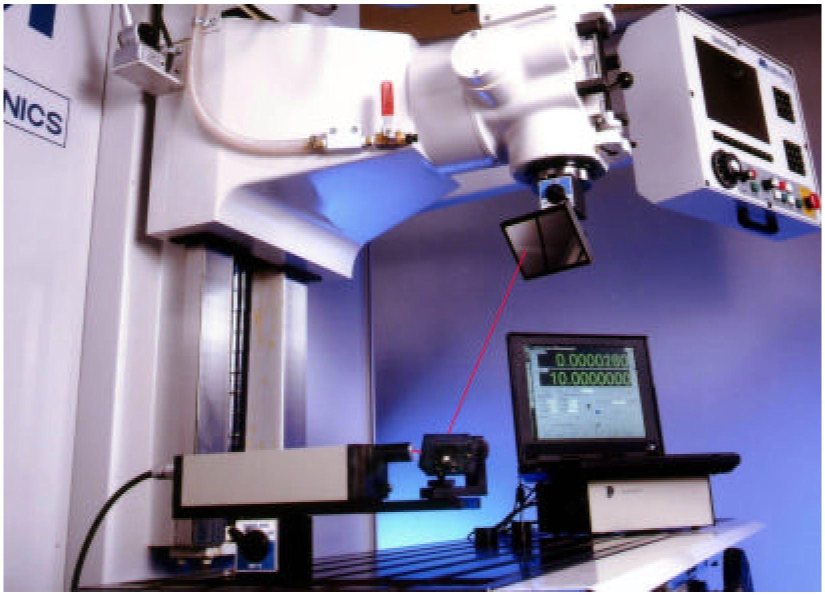
A Laser System for Volumetric Positioning and Dynamic Contouring Measurement

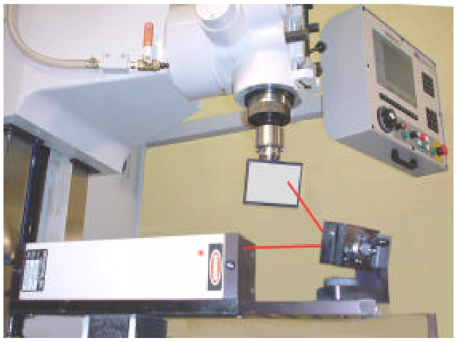


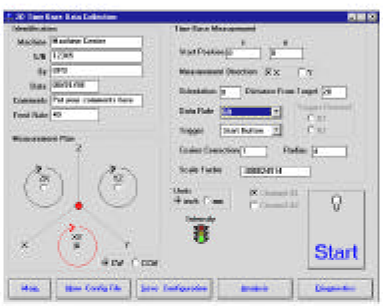
MCV-500, LB-500, SD-500 and SQ-500
A world class laser system for the volumetric calibration and compensation, squareness and straightness error measurement, and for non-contact circular contouring measurement

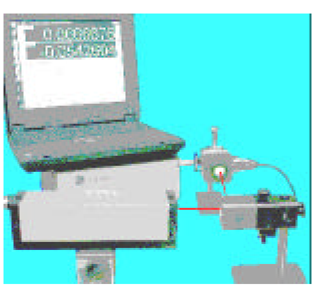
OPTODYNE

Optodyne, Inc.
1180 Mahalo Place
Compton, CA 90220
310-635-7481
www.optodyne.com

Improving Your Machine Tool Performance







What is the performance of your machine tools?

It is better to catch errors before they appear in parts by measuring both the volumetric positioning accuracy and the dynamic contouring accuracy.

Volumetric positioning accuracy

Using the laser vector technique (patent pending), 3 displacement errors, 6 straightness errors and 3 squareness errors can be determined in a few hours while conventional laser interferometers may takes a few days.

Dynamic contouring accuracy

Using the laser/ballbar (patent pending),contouring accuracy of various radii at high feed rates can be determined. Furthermore, the true radius, actual feed rate and acceleration can all be determined.

Break through in laser technology

Unique single-aperture laser head using flat-mirror target simplifies the setup and operation. The software allows for automatic data collection and analysis. Laser/ballbar measurement is non-contact, no need for centering, and no cable's in the way.

Other benefits

The laser system can be used for acceptance testing, scheduled calibration, ISO 9000 documentation, quick checks and diagnosis of problems.

Save time and money! Volumetric calibration and compensation in 4 easy setups by your regular machine operator in as little as 2 to 4 hours for a working volume smaller than 1 cubic meter. The conventional approach takes about 5 times longer and requires a highly trained specialist.

The measured volumetric positioning errors can be used to generate the 3 dimensional error lookup table for the on-machine probing.

At high feed rates, to ensure high part accuracy die or mold manufacturing, the measured radius shrinkage and feed rate change can be used to check the dynamic compensation algorithms of the control and replace the expensive and time consuming cutting tests.

Laser Measurement is Our Only Business

Optodyne, Inc., designs, manufactures, and markets laser-based precision measurement equipment for machine tool calibration and compensation, metrology, OEM, and a wide variety of other industrial applications. Optodyne believes that quality improvements will be the key to improving productivity in manufacturing. The company is dedicated to making quality affordable for its customers by incorporating laser technology in precision measurement equipment. The company's goal is to continue to provide innovative, superior quality products while maintaining the industry's best price/performance ratio.

Static and Dynamic Machine Performance Made Easy With Optodyne's Laser Measurement System

Measures volumetric positioning errors, not just linear displacement errors.
Compensates positioning errors volumetrically, not just pitch errors.
Non-contact measurement of circular contouring at various radius down to 0.1" and at high feed rate.
Measures the absolute radius, feed rate and acceleration.
Complete volumetric measurement in hours not days.

$$E_x(x) = d_x(x) - y * a_z(x) + z * a_y(x)$$
$$E_x(y) = d_x(y) - z * a_y(y) + y * q_{xy}$$
$$E_x(z) = d_x(z) - z * q_{xy}$$
$$E_y(x) = d_y(x) - z * a_x(x)$$
$$E_y(y) = d_y(y) - z * a_x(x)$$
$$E_y(z) = d_y(z) - z * q_{yz}$$
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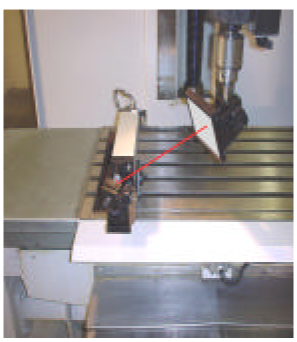
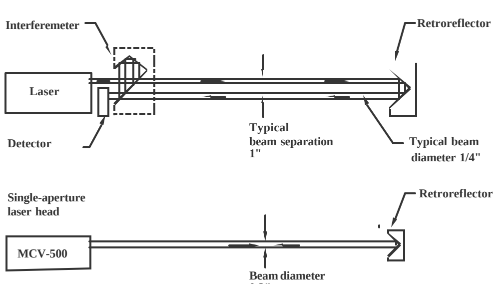


Helping you to meet world competition & industry standards

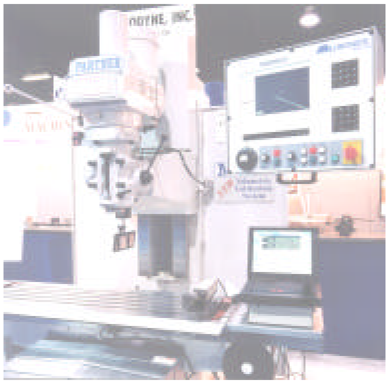
Higher productivity
Tighter tolerance
Better process control
Superior quality standard

Patented technology using modern electro-optics and digital Electronics



Optodyne's products are based on the Laser Doppler Displacement Meter (LDDM), proprietary, patented technology. US Patent numbers 4,715,706; 5,116,126; 5,394,233; 5,471,304;5,724,130; and many pending.
Optodyne has effectively combined the most recent developments in laser technology with microelectronics, computer, electro-optic, and heterodyning technologies to offer sophisticated instruments with practical industrial applications.
Traceable to NIST.

Designed for machine tool builders to

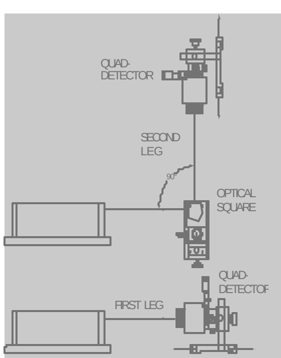


- Improve performance of the machine
- Improve alignment and building procedure
- Cut down build cycle time
- Verify machine performance
- Document the manufacturing process
- Improve the volumetric accuracy of the machine

Used by machine tool distributor/service for

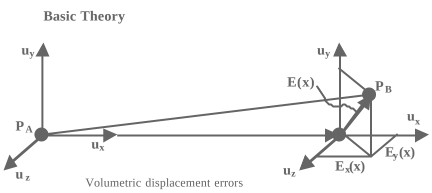
- High quality after-sales service
- On-site calibration,compensation and certification
- Periodic and predictive maintenance
- Quick check and diagnosis of problems

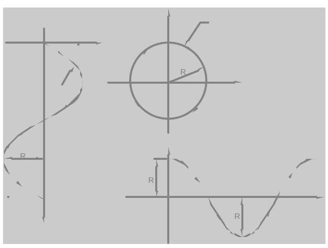
Benefited to machine tool user or shop owner by

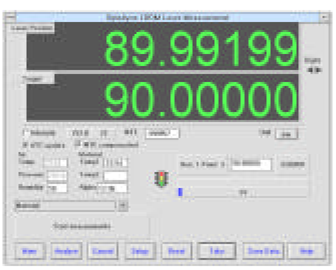


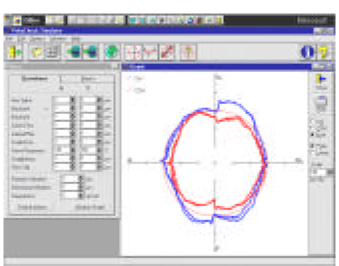
- Validating the quality of new machine upon delivery
- Grading the performance of all machines in shop
- Winning contracts from competitors
- Minimizing scrap and improve parts accuracy
- Minimizing machine down time
- Optimizing machine performance
- Inspecting the finished part on-machine
- Extending the life of the machine
- Complying with ISO 9000

A laser system for volumetric and dynamic machine performance measurement & enhancement









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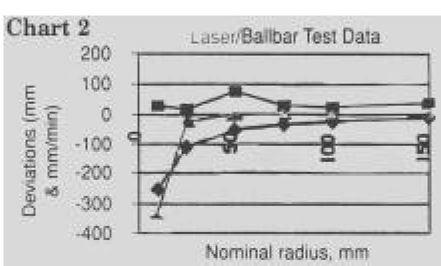
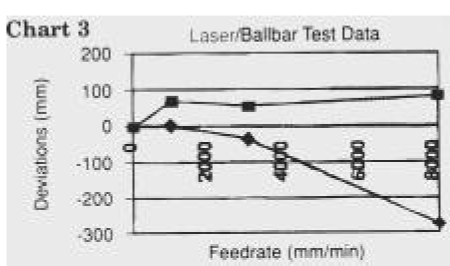
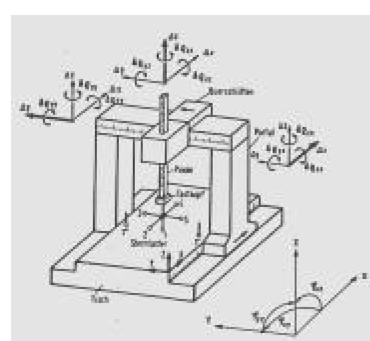
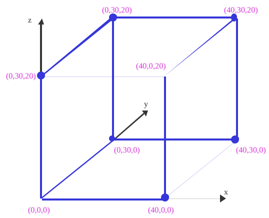




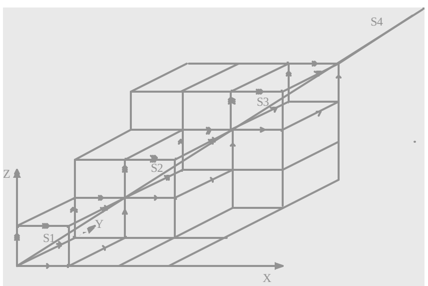


Volumetric Calibration and Compensation

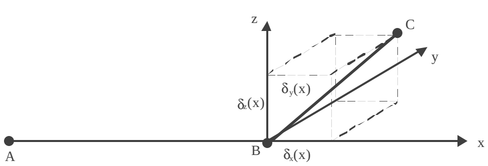


What are the volumetric positioning errors?

A linear displacement error is the positioning error in the same direction as the axis direction. The volumetric positioning error is the positioning error in a spatial direction not necessarily in the direction of the axis motion. Hence this error is a vector and its three components are the linear displacement error, the vertical straightness and horizontal straightness. Using conventional laser interferometer to measure these errors is very complex, time consuming, and costly. The key is how to measure all these errors accurately and quickly.



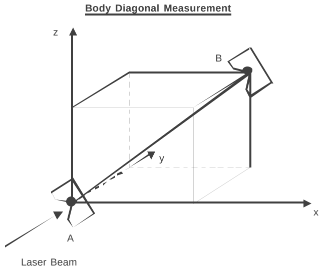
Volumetric Errors



Why you need to calibrate and compensate your machine volumetrically?

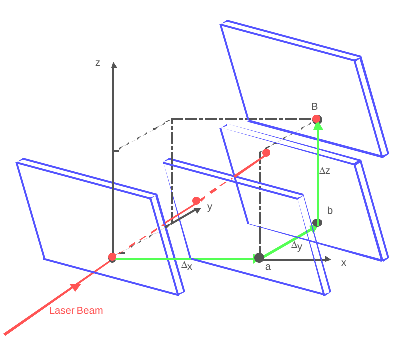
Competition in the global manufacturing market today requires improving the CNC machine tool performance to achieve higher productivity, better quality and less downtime. With the latest generation of CNC controls it is now possible to achieve higher accuracy even on a lower cost machine. To do this it is important to measure the volumetric errors of the machine and to compensate these errors. The key is how to measure all these errors accurately and quickly. Using conventional laser interferometer to measure these errors, it is very complex, time consuming and costly. This is one of the major reasons these errors are not compensated. The other reason is time, with the cost of machine time most companies are not willing to invest the 16 to 20 hours required to measure all these errors.

Body Diagonal Measurement



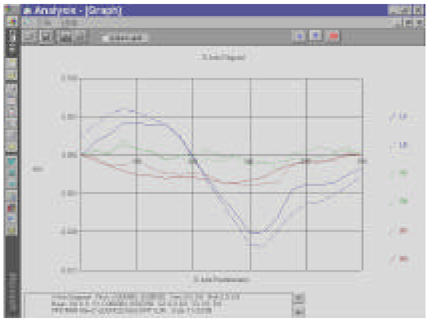
Why calibrating and compensating the displacement error is not enough?

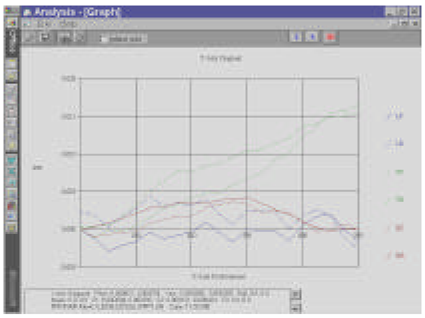
In general, calibrating the machine displacement accuracy over the 3 axes, or compensating the machine pitch error over 3 axes is not enough. There are many other errors, such as the straightness of the guide way, the squareness of the axes, the effect of weight shifting, counter balancing etc, which cause far larger errors than the 3 pitch errors.

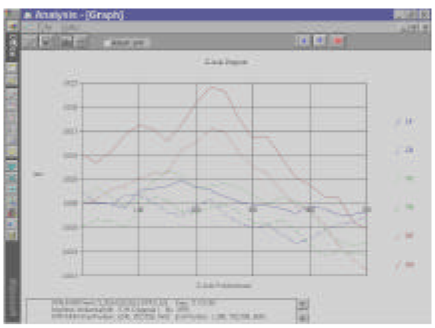


How to compensate the volumetric positioning errors?

Most modern controller have the capability of volumetric compensation (or sometimes called sag compensation, or cross compensation), the measured volumetric positioning errors can be used to generate the volumetric compensation files for the controller to compensate the machine errors and achieve higher volumetric accuracy.







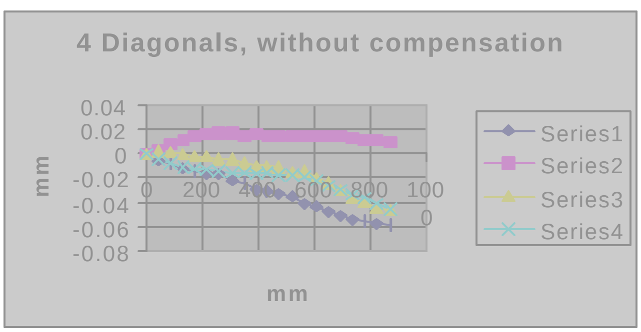
What is the laser vector measurement technique (patent pending)?

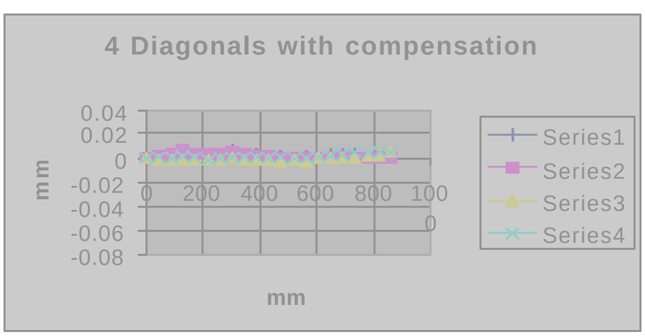
The key to the laser vector measurement technique is that the measurement direction or the laser beam direction is not parallel to the displacement direction. Hence, the measured displacement errors are sensitive to the errors both parallel and perpendicular to the direction of the linear axis. One way to implement this technique is to perform the sequential step diagonal measurement discussed below.

What is the body diagonal measurement?

The ASME B5.54 standard section 5.9.2 Volumetric Performance Using Diagonal Displacement Measurements section states that "The volumetric accuracy may be rapidly estimated by measuring the displacement accuracy of the machine along body diagonals". This is because the diagonal displacement error is sensitive to all the error components. However, if the measured errors are large, there is not enough information to identify the error sources.

What is sequential step diagonal measurement?



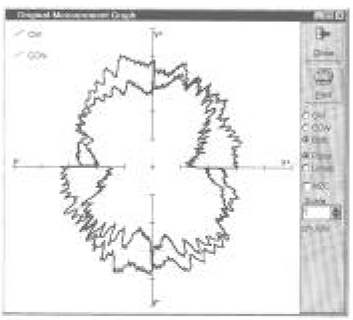


Similar to the diagonal measurement, the laser beam is pointing in the diagonal direction, instead of moving x-, y- and z-axis continuously in the diagonal direction, the machine is now programmed to move x-axis, stop, collect data, then move y-axis, stop, collect data, then move z-axis, stop, collect data. The process is continued till the opposite corner is reached. Hence it is called sequential step diagonal measurement. The major advantages are 1) 3 times more data are collected, 2) x, y, and z motions are separated, and 3) all error components can be measured. With 4 setups (4 body diagonals), all 3 displacement, 6 straightness and 3 squareness errors can be determined. On a machine with a work volume of 1 cubic meter, all four diagonals can be measured in 2 to 4 hours.

Dynamic Circular Contouring Measurement

Why check the contouring accuracy?

For high quality and productivity machining, high speed machining operations or die and mold manufacturing, to achieve the high precision and super-finishes, static positioning accuracy is not enough. The acceptable contour will depend on the volumetric positioning accuracy and the dynamic contouring accuracy, the machine acceleration and deceleration rate, and the servo algorithem. The standard verification of machine contouring accuracy is the use of circular tests. However, traditional telescoping ballbar is rather limited in its capability to measure small radius contours at high speed.



Why perform a circular contouring measurement?

The circular test provides a rapid and efficient way of measuring a machine tool's contouring accuracy. The circular tests show how the two axes work together to move the machine in a circular path. As the machine is traversing with multiple axes along a circular trajectory, each axis goes through sinusoidal acceleration, velocity and position changes. The measured circular path data will show any deviation the machine makes from a perfect circle. The shapes are diagnosed and correlated to servo mismatch, backlash, reversal spikes, squareness error, cyclic error, stick slip, machine vibrations, etc.

What is the limitations of a telescoping ballbar?

Most telescoping ball bar systems normally work with radii of 50 mm to 600 mm, hence the inability to perform circular tests with smaller radii as required in some applications. Also, the errors the telescoping ball bars detect usually are a combination of problems with the machine's geometry and the controller or servo systems. These errors are then larger than those produced by the control loops only.

Why use non-contact laser circular contouring measurement?

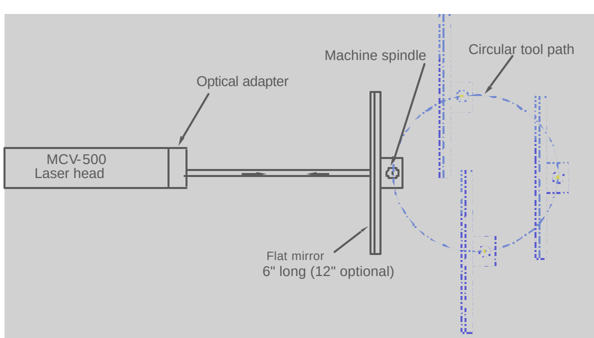
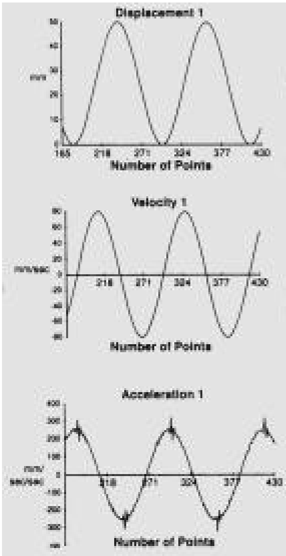


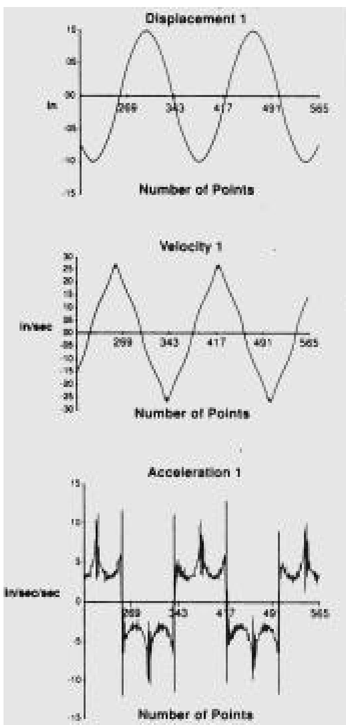
FIG. 8-4 SCHEMATIC OF LASER CIRCULAR TEST

In today's manufacturing world, high-speed machine tools are frequently required to deliver accuracy in the order of a few micrometers, while moving at relatively high feed rates. It is important to know what is the maximum feed rate while meeting the required accuracy. For example, for most dies and molds the radius of curvatures are less than 50 mm and the feed rates are a few meters per minute, and it is more desirable to perform the contour tests at smaller radius and at high feed rate.



What is a laser/ballbar?

A laser/ballbar is designed for the non-contact circular contouring measurement (Patent pending). The hardware used for the test are an MCV-500 laser calibration system, an optical adapter, and a flat-mirror target with an adjustable mount, a PC interface card, and a notebook PC with Windows™ software. For a small radius or high feed rate circular test, high data rate is required. With a special PCMCIA interface card, a data rate up to 1000 data/sec can be achieved. The software for the data collection and data processing is a Windows based software. With a few clicks, the data can be collected automatically and processed to generate a polar plot of the circular path.

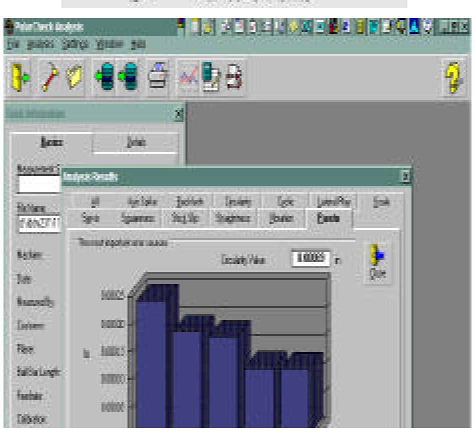


How the laser/ballbar work?

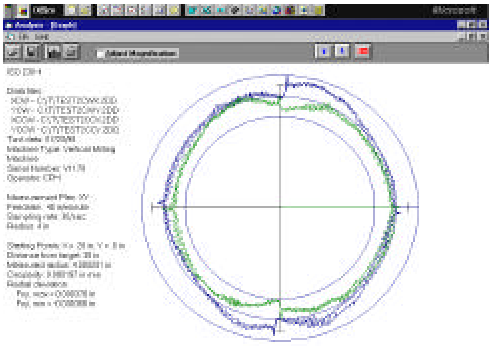
First, the laser is pointing perpendicular to the flat-mirror, which is mounted on the spindle. As the machine spindle moves along a circular path, the flat-mirror remains perpendicular to the laser beam and the displacement along the laser beam direction is measured even with a large lateral movement. Second, repeating the same measurement in the direction 90 degrees from the previous measurement with the same spindle motion, the displacement along the laser beam direction is again measured. Assuming the spindle motion is repeatable, the data on these two measurements can be combined to generate the actual circular path.

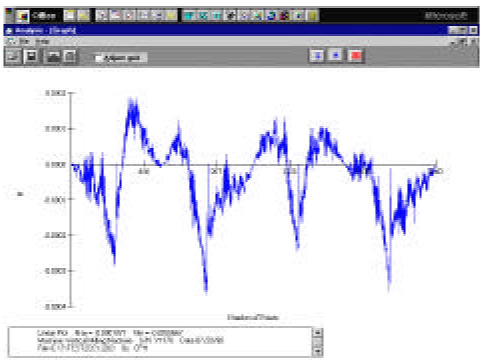
Compare with a telescoping ballbar

The laser/ballbar is a 2-dimensional measurement, both the x-coordinate, and y-coordinate are measured to generate the circular path. The telescoping ball-bar is a 1-dimensional measurement, only the radius changes along angular positions are measured. Of course, the 2-dimensional laser/ballbar measurement will provide more information, such as feed rate or tangential velocity and acceleration.



The laser/ballbar measurement is non-contact. Hence centering is not required and the radius of the circular path can be continuously varied. For a telescoping ballbar, there is a cable between the transducer (inside the telescoping bar) and the electronic processor. This cable is always in the way and makes the circular path with multiple revolutions very difficult if not impossible. Also, because the length of the telescoping bar is fixed, the radius of the circular path are fixed and very difficult to do small radius circles.





The laser/ballbar uses a laser Doppler displacement meter for the measurement. Hence the accuracy is very high, typically 1 ppm and traceable to NIST. The telescoping ballbar uses a transducer for the measurement. Hence the accuracy is low, need periodical calibration and it is sensitive to temperature changes.

Of course, two sets of measurements with two setups are needed for the laser/ballbar to generate the circular path as compare to telescoping ballbar, only one setup and one set of measurement is needed. A performance comparison is shown below.

What are the major features and benefits?

The major features are: the measurement is non-contact; the circular path radius can be varied continuously from less than 1 mm to 150 mm; all linear accuracy are traceable to NIST; the feed rate is up to 4 m/sec; the data rate is up to 1000 Hz; and the actual feed rate, velocity, and acceleration profiles can also be determined. This information are important to determine the motion dynamics of the machine and the servo performance.

A comparison of laser/ballbar and telescoping ballbar

Performance	**Laser/ballbar**	**Telescoping ballbar**
Measurement sensor	Laser Doppler Displacement sensor	Transducer
Measurement method	Measures x-coordinate and y-coordinate to generate the circular path. Basically a 2-dimensional measurement	Measures the radius changes along angular positions on a circular path. Angular positions are not measured. Basically a 1-dimensional measurement.
Sensor Calibration	Linear accuracy is traceable to NIST	Transducer needs periodical calibration
Sensor range	Up to a few meters	Up to a few mm
Non-contact measurement	Yes	No
Radius of circular path	Continuously variable from 1 mm to 150 mm	Fixed radius with increment of 50 mm
Measures feed rate	Yes	No
Sampling rate	1000 data/sec	250 data/sec
Maximum feed rate	Up to 240m/min	Up to a few m/min

MCV-500 Machine Calibration System

P-108D

A compact laser system for the calibration and compensation of CNC machine tools, coordinate measuring machines (CMMs), and other precision measuring machines and stages.

L-109

This compact laser system is designed for easy setup and operation. The basic system, including Windows software, automatic temperature and pressure compensation, and accessories are packaged at an extremely affordable price. The system is very compact and fits in one small carrying case.

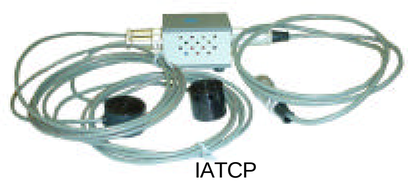
The Windows software, running on any notebook computer, is user friendly and is designed to collect data automatically and to analyze data in accordance with a variety of industry standards, such as NMTBA, VDI, ISO and ASME B5.54. The laser system is calibrated and traceable to NIST.

R-102

W-500

Major features and benefits

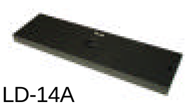
Compact and light-weight
Rugged and long life
Easy to setup and operate
Automatic data collection
Automatic comp file generation
NIST traceable accuracy
No tripod and no interferometer
RS-232 interface
Automatic environmental compensation
Support NMTBA, VDI, ISO and ASME B5.54



IATCP

LD-03

LD-37



LD-14A

Major Applications

Calibrate and compensate CNC machine tools, CMMs, leadscrews, precision measuring machine and DROs
Quality control and maintenance
Ultra precision positioning
One-day quick check of machine tools

LD-21L

LD-20D

Configuration:

Single aperture laser head,	L-109
Processor module	P-108D
Half-inch diameter retro-reflector	R-102
Metrology/analysis program	W-500
Automatic temperature compensation	IATCP
90 degree beam bender	LD-37
Magnetic base	LD-03
Adapter platform	LD-14A
12 ft cable set	LD-21L
Carrying case	LD-20D
Notebook computer (not included)	LTC

LTC

Capability:

Laser stability	0.1 ppm
System accuracy	1 ppm
Resolution	1 microinch (0.01 um)
Range	50 ft (15 m)
Slew Rate	144 ips (3.6 m/s)

Environment and power requirement

Power	90 to 230 VAC, 50 to 60 Hz
Temperature	60 to 90 F (15 to 32 C)
Altitude	0-10,000 ft (0-3000 m)
Humidity	0-95% non-condensing

SD-500 Volumetric Calibration and Compensation

This is an add-on package to the MCV-500 laser calibration system for the measurement of volumetric error components, including 3 displacement errors, 6 straightness errors and 3 squareness errors.

The combined system provides a rapid and efficient way of measuring a machine's volumetric accuracy over the working volume. The software also generates axis specific files, 6 bi-directional displacement errors and 12 bi-directional straightness errors, that can be used to generate volumetric compensation tables. The available compensation file format is usable on controllers such as Giddings and Lewis, Milltronics, Siemens 840, Fanuc 15, 16/18, and many others.

Major features and benefits

Single-aperture laser head and flat-mirror target
Measures the volumetric positioning errors in 4 simple setups
User friendly Windows software for automatic data collection,
analysis, and volumetric error compensation file generation
Quick and efficient measurement

Major applications

Volumetric calibration and compensation of CNC machine
tools, and CMMs.
On-machine inspection
Identify error sources
Quick check of volumetric accuracy

Configuration

Laser calibration system	MCV-500
Flat-mirror target 3" x 4"	LD-71S
Optical adapter	LD-69
Magnetic base and post	LD-03P
Windows software	W-500SD
Steering mirror	LD-37S


LD-71S


LD-37S


LD-69

Capability

Displacement error
Straightness error
Squareness error


LD-03P


W-500SD

LB-500 Laser/ballbar (Non-contact circular contouring tests)

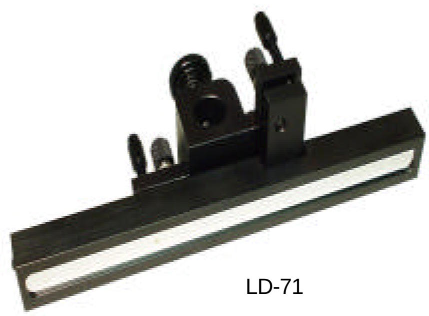
This is an add-on package to the MCV-500 laser calibration system. The combined system is designed to perform circular contouring measurement of CNN machine tools, CMMs, and other precision measuring machine, for servo tuning and dynamic testing.

The laser/ballbar provides a rapid and efficient way of measuring a machine's contouring accuracy along a circular path. The circular test shows how the axes work together to move the machine in a circular path The deviation from a perfect circle are caused by errors such as backlash, servo mismatch, scale mismatch, machine geometry, periodic errors, stick-slip, etc. A polar plot is then generated to show the machines true contouring capabilities, and a Polarcheck program is provided for the diagnosis of problems.

Because of the unique capabilities, high data rates, high resolution and small radius, dynamic errors at high machine feed rates can be determined. The measurement is 2-dimensional, hence the true radius, velocity and acceleration can be determined.

Major features and benefits

Non-contact, no cables to worry about, no friction of bearings
Radius can be varied continuously from 3" to 0.1"
High data rate, up to 1000 data/sec
No need for centering
No need for special parts program
Measures true radius, velocity and acceleration
NIST traceable laser accuracy



LD-71

Major applications

Dynamic testing and tuning of CNC machine tools, CMMs and precision machines
Check radius shrinkage at small radius and high feed rate, replacing expensive cutting tests
Check machine contouring capability at high feed rate
Check dynamic compensation, look-ahead, feed forward performance

LD-69

Configuration

Laser calibration system	MCV-500
Flat mirror target 6" length	LD-71
Optical adapter	LD-69
Magnetic base and post	LD-03P
PC interface card and cable	IPC5-1000
Windows software	W-500LB
Diagnostics software (Polarcheck)	W-500PC

LD-03P

W-500LB
W-500PC

Capability

Data rates	1-1000 Hz
Maximum data points per record	10,000 points
Radius	3" to 0.1" (75 mm to 2 mm)
Resolution	1 microinch (0.01 um)

IPC5-1000

SQ-500 Squareness and straightness measurement


LD-42

This is an add-on package to the MCV-500 laser calibration system for the measurement of squareness and straightness. The package includes a quad-detector and an optical square. The quad-detector is a precision position sensor, and the optical square is a precision penta-prism to bend the laser beam 90 degree. A laser produces an intense beam of red light which is a straight line of the greatest accuracy in a vacuum. In atmosphere, the straightness of a laser beam may be changed by temperature gradients or air currents. For a typical indoor condition, the stability of the laser beam is in the order of 0.0001"/ ft or a few µm/m. Longer average time may reduce the effect of turbulence or air current.

Major features and benefits

Easy to align and setup
Compact and light-weight
Measures both squareness and parallelism


LD-16

Major applications

Check squareness and straightness of CNC machine tools, CMMs, and other precision machines
Alignment of guide ways for parallelism or perpendicularity

Configuration

Laser calibration system	MCV-500
Quad-detector	LD-42
Optical square	LD-16
Squareness/straightness program	W-104

Capability

Resolution	0.00001" (0.1 um)
Range	16 ft (5 m)
Deviations	+/- 0.02" (0.5 mm)
Linearity	<5%


W-104

Applications

Periodic check and predictive maintenance

To reduce machine downtime and to assure maximum performance, manufacturers are increasingly employing predictive maintenance (PDM) programs. The objective of PDM is to predict when a machine will fail or go out of tolerance in order to reduce unplanned downtime. The objective is achieved by monitoring the machine with a combination of measurement instruments, such as Optodyne's laser volumetric calibration system and dynamic contouring testing equipment. In a typical PDM program, each machine is checked twice a year for accuracy and dynamic characteristics. Then an analysis is made by comparing the baseline data, past data and new data. Finally, a prediction is made for when the machine should be calibrated and serviced.

A on-machine inspection

Manufacturing process control has long been recognized as an important and necessary milestone on the road to reduce cost, improve throughput and superior quality product. On-machine probing is growing widespread application for process improvement. It yields time, quality and productivity improvement. However, the major objection for on-machine probing is that the part is measured on the same machine, which made it. Any positioning errors that occurred during machining are very likely to be repeated during inspection.

Using Optodyne's volumetric calibration system the volumetric positioning errors can be measured and a lookup table can be generated for the on-machine measurement software to compensate the machine positioning errors volumetrically. Therefore, it improves the accuracy of on-machine probing and makes it a viable process. The system can be operated by a machine operator and measure the volumetric errors in 2 to 4 hours for a working volume about 1 cubic meter.

Measurement of servo error

For a circular contour of radius R, at a constant feed rate F, and a response lag T, the decrease in radius is proportional to the feed rate and response lag squared, and is inversely proportional to the radius. Hence for small radii or high feed rates, the radius shrinkage may becomes large. For example, for a CNC machine with response lags of 28 msec, at a radius of 50 mm and a feed rate of 80 mm/sec, the measured radius shrinkage is -52 µm, which is larger than the non-roundness or circularity error of 29 µm. Furthermore, at the same feed rate but reduce the radius to 12.5 mm the measured radius shrinkage is -216 µm and the non-roundness is about the same 31 µm. This result agrees with the theory very well.

There are many techniques to reduce the radius shrinkage, such as bell-shaped acceleration/deceleration, feed forward and corner function controls. It is very important to measure the radius shrinkage with various servo compensation techniques to verify the effectiveness of the compensation.

Service and support

Full operator hands on training are available either at your site or at Optodyne training centers. A comprehensive document to help operators quickly learn how to install, setup and operate the Optodyne laser calibration systems is in the user's guide. The laser system comes with a standard 1-year warranty. 3-year and 5-year warranty are available. Optodyne's calibration laboratory provides calibration traceable to NIST. For the latest information on Optodyne's laser systems, visit Optodyne's web site at www.optodyne.com.

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