دار المنظومة
DAR ALMANDUMAH
الرواد في قواعد المعلومات العربية

العنوان:	An Approach to High Precision Positioning and Measurement by Integrating Modern Simulation Tools
المؤلف الرئيسي:	Al Mousa, Abd Alrahman
مؤلفين آخرين:	Shetty, Devdas(Super)
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Chapter 1: Introduction

Positioning systems are widely used in many industrial applications such as actuation, CNC machining, automatic testing, calibration, inspection, and processes such as laser welding or cutting. Micropositioning refers to mechanical movement with positioning accuracy and resolution in the micron or high sub-micron range. Nano positioning refers to positioning with nanometer or sub-nanometer resolution range for high-precision nano positioning devices.

Applying design rules for motion systems with millimeter or sub-millimeter resolution do not always apply for the micron and sub-micron range. Resolution in the sub-micron realm cannot always be increased by simple means such as reducing the pitch of a leadscrew or increasing the gear ratio of a motor/gearhead unit. Stiction/friction, play, backlash, tilt, windup and, temperature effects, etc. will also limit accuracy and resolution. Sub-micron positioning systems require a great deal of attention in design, manufacturing and selection of materials.

These applications require that the positioning system have high accuracy and good repeatability. As a result, this project's purpose was to introduce

various ways to measure the actuation of the stage. The proposed measurements are very cost effective to implement in many organizations. The implementation and measurement of positioning was accomplished using four simulation tools and related software. The visual simulation software was used along with the software, which provided an example of hardware –in – the loop. The experiments also included three methods of position measurement. Amongst the methods implemented, interferometric method was adjudged to be the best case.

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Chapter 2: Overview of errors in measurement system

2.1 Contribution of errors

Total error is the cumulative effect of linear displacement error, angular error, and error due to straightness, parallelism, orthogonality, spindle thermal drift. Out of the above linear errors, displacement error is of prime importance in precision machine tools, for a sample linear stage in figure (2-1).

2.1.1 Linear Displacement Error

Linear displacement error is defined as translation error movement of a machine component along its axis of movement. In general, this type of error is caused by the geometric inaccuracies of the drive or encoder unit . The resolution of the encoder can result in this type of error; for example, if the resolution of the encoder is high than the linear displacement error will be low and the opposite is also true. Another cause can be leadscrew misalignment between its nut and rotation to the centerline.

2.1.2 Angular Error

Angular errors are rotational errors caused by geometric inaccuracies, feedback, and misalignment in the assemblies of the structural component of the machine tool. *Yaw error* is the rotational error of the slide around the axis perpendicular to the plane in which the axis of motion lies. *Roll error* is the

rotational error of the slide around the axis of motion, and *pitch error* is the rotational error of the slide around the third orthogonal axis of the slide.

2.1.3 Straightness, parallelism and orthogonality measurement

Straightness error is the translational error of the machine element that can occur in either of two directions orthogonal to a slide's axis of motion. *The parallelism error* would be the difference divided by the length between the axis of Z motion and the axis average line of the spindle. Several other errors can occur in the measurements such as the Z axis straightness error and the test arbor profile error.

2.1.4 Spindle Thermal Drift

Thermal drift is defined in the ANSI (America National Standard Institute) as "a changing distance between two objects, associated with a changing temperature distribution within the structural loop due to internal and external sources" from this definition of spindle error motions, three components for machine tool:

(1) *Axial thermal drift*, which is the displacement of the spindle along the Z axis.

(2) *Radial thermal drift*, which is the displacement perpendicular to the Z axis.

(3) *Tilt thermal drift*, which is the rotation of spindle in the X-Z plane of the machine.

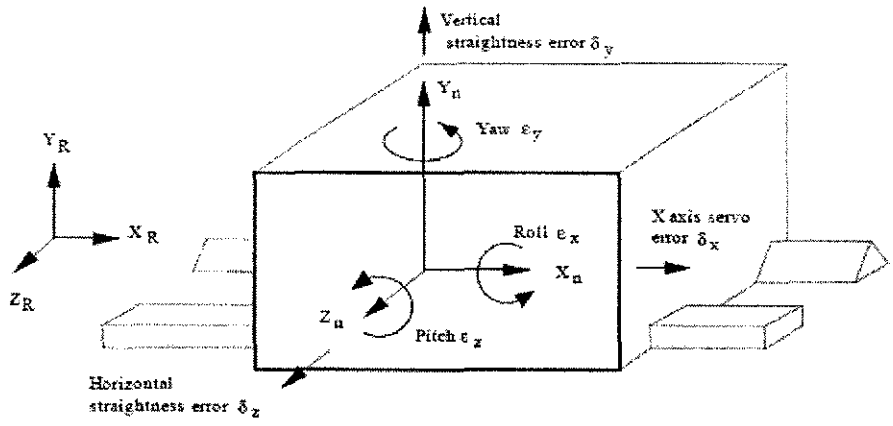

Figure (2-1) Homogeneous Transformation Matrix Model of a linear stage [6]

2.2 Homogeneous Transformation Matrix Model of a linear stage

In order to determine the effects of a component's error on the position of toolpoint or the workpiece, the spatial relationship between the two must be defined. To represent the relative position of a rigid body in three-dimensional space with respect to a given coordinate system, a 4x4 matrix is needed. This matrix represents the coordinate transformation to the reference coordinate system (X_R Y_R Z_R) form that of the rigid body frame (X_n Y_n Z_n), and it is called the Homogeneous Transformation Matrix (HTM). The first three columns of HTM are direction cosines (unit vectors I, j ,k) representing the orientation of the rigid body's X_n, Y_n and Z_n axes with respect to the reference coordinate frame, and their scale factors are zero[1]. The last column represents the position of the rigid body's coordinate system's origin

with respect to the reference coordinate frame. P_s is scale factor, which is usually set to unity to help avoid confusion.

$$ {}^{R}T_{n} = \begin{bmatrix} O_{ix} & O_{iy} & O_{iz} & P_x \\ O_{jx} & O_{jy} & O_{jz} & P_y \\ O_{kx} & O_{ky} & O_{kz} & P_z \\ 0 & 0 & 0 & P_s \end{bmatrix} \quad (2\text{-}1) $$

Thus the equivalent coordinates of a point in a coordinate frame n, with to a reference frame R, are

$$ \begin{bmatrix} X_R \\ Y_R \\ Z_R \\ 1 \end{bmatrix} = {}^{R}T_{n} \begin{bmatrix} X_n \\ Y_n \\ Z_n \\ 1 \end{bmatrix} \quad (2\text{-}2) $$

For example, if the $X_1 \quad Y_1 \quad Z_1$ coordinate system is translated by an amount x along the X axis, the HTM that transforms the coordinate of a point in the $X_1 \quad Y_1 \quad Z_1$ coordinate frame into the XYZ reference frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}3) $$

If the X_1 Y_1 Z_1 coordinate system is translated by an amount y along the Y axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into the XYZ reference frame is

$$ {}^{XYZ}T_{X_1Y_1Z_1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}4) $$

If the X_1 Y_1 Z_1 coordinate system is translated by an amount Z along the Z axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into the X Y Z reference frame is

$$ {}^{XYZ}T_{X_1Y_1Z_1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}5) $$

If the X_1 Y_1 Z_1 coordinate system is rotated by an amount θ_x about X axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into X Y Z frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta x & -\sin\theta x & 0 \\ 0 & \sin\theta x & \cos\theta x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}6) $$

If the X_1 Y_1 Z_1 coordinate system is rotated by an amount θ_y about Y axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into X Y Z frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} \cos\theta y & 0 & \sin\theta y & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta y & 0 & \cos\theta y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}7) $$

If the X_1 Y_1 Z_1 coordinate system is rotated by an amount θ_z about Z axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into X Y Z frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} \cos\theta z & -\sin\theta z & 0 & 0 \\ \sin\theta z & \cos\theta z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}8) $$

Equation (2-9) gives the position of the (Nth axis) in terms of the reference coordinates system, when N rigid bodies are connected in series and the relative HTMs between connection axes are known,

$$ {}^{R}T_{N} = \prod_{m=1}^{N} {}^{m-1}T_{m} = {}^{0}T_{1}\,{}^{1}T_{2}\,{}^{2}T_{3}.... \quad (2\text{-}9) $$

2.3 Linear Motion Errors

Consider the case of an ideal linear movement slide of a stage

$$ {}^{R}T_{n} = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}10) $$

For the stage, the HTM that describes the effects of errors on stage emotion can be found by multiplying Equations (2-1)-(2-8) in series with error terms $\delta_X, \delta_Y, \delta_Z, \varepsilon_X, \varepsilon_Y, and\ \varepsilon_Z$ for $x, y, z, \theta_x, \theta_x, and \theta_z$ respectively. The same result can be obtained in the following manner.

$$E_n = \begin{bmatrix} 1 & -\varepsilon z & \varepsilon y & \delta x \\ \varepsilon z & 1 & -\varepsilon x & \delta y \\ -\varepsilon y & \varepsilon x & 1 & \delta z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}11)$$

The first column describes the orientation of the stage's X axis by defining the positioning of the tip of a unit vector, parallel to the stage's X axis. The actual HTM for linear motion stage with errors is ${}^{R}T_{nerr} = {}^{R}T_{n}E_{n}$ [6].

$${}^{R}T_{nerr} = \begin{bmatrix} 1 & -\varepsilon z & \varepsilon y & a+\delta x \\ \varepsilon z & 1 & -\varepsilon x & b+\delta y \\ -\varepsilon y & \varepsilon x & 1 & c+\delta z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}12)$$

The most important step in assembling the error budget for a machine is the placement of the coordinate frames and the assignment of linear and angular errors for corresponding to the axes.

The relative error HTM is the transformation in the tool point coordinate system that must be done to the tool point in order to be at the proper position on the work piece

The error correction vector with respect to the reference coordinate frame can be obtained from equation (2-13)

$${}^{R}\begin{bmatrix} P_X \\ P_Y \\ P_Z \end{bmatrix}_{correction} = {}^{R}\begin{bmatrix} P_X \\ P_Y \\ P_Z \end{bmatrix}_{work} - {}^{R}\begin{bmatrix} P_X \\ P_Y \\ P_Z \end{bmatrix}_{tool} \quad (2\text{-}13)$$

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Chapter 3: Motion Control System Design

As the intelligent element that commands the motion, the controller may be visualized as the motion system brain that generates commands and requests status reports. "Motion controllers today are mostly digital devices that calculate motion trajectories, and compare them with the actual motor or actuator position," What explains the result is information (the reference input to the amplifier) that commands the amplifier to move the motor. Motion control systems consist of three main units:

- Motion controller
- Driver (motor or amplifier)
- Device as encoder

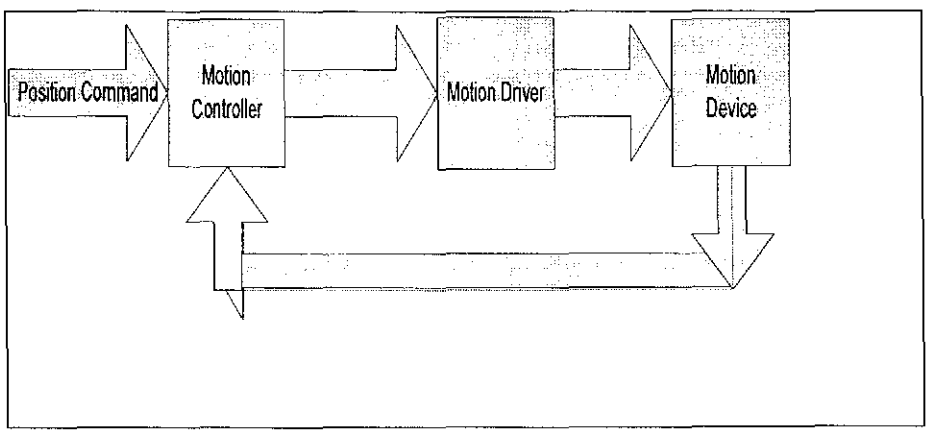

Figure (3-2) motion control systems

3.1 Motion controller

In a motion system, the motion controller is used to control motion devices such as stages and actuator so that the motion controller acts as the brain of the of the system by taking the desired target positions and motion profiles and creating the trajectories for the motors

3.1.1 Control System Components

Application software – You can use application software to command target positions and motion control profiles.

Amplifier or drive – Amplifiers (also called drives) take the commands from the controller and generate the current required to drive or turn the motor.

Feedback device or position sensor – A position feedback device is not required for some motion control applications (such as controlling stepper motors), but is vital for servo motors. The feedback device, usually a quadrature encoder, senses the motor position and reports the result to the controller, thereby closing the loop to the motion controller.

Configuration: - One of the first things to do is configure your system. For this, National Instruments offers Measurement and Automation Explorer, an interactive tool for configuring not only motion control, but all other National Instruments hardware. For motion control, Measurement and Automation Explorer offers interactive testing and tuning panels that help you verify your system functionality before you program.

3.2 Motors and Mechanical Elements

Motors are designed to provide torque to some mechanics. These include linear slides, robotic arms, and special actuators. Motor selection and mechanical design is a critical part of designing your motion control system. Many motor companies offer assistance in choosing the right motor, so we have servo motor for our project. After determining which technology you want to use, you need to determine the torque and inertia at the motor shaft.

Additional factors to consider when selecting your motor and other mechanics are whether an off-the-shelf actuator (such as a stage) might work for your application. Stages offer the power transmission to obtain useful rotary or linear motion without designing it yourself.

3.3 Feedback Devices

Feedback device helps the motion controller know the motor location. The most common position feedback device is the quadrature encoder, which gives positions relative to the starting point. Most motion controllers are designed to work with these types of encoders. Other feedback devices include potentiometers that give analog position feedback, tachometers that provide velocity feedback, absolute encoders for absolute position measurements, and resolvers that also give absolute position measurements. When using National Instruments motion controllers, you can use quadrature encoders and potentiometers.

3.3.1 Motion I/O

Other I/O that is important in motion control includes limit switches, as shown in Figure (3-4) home switches, position triggers, and position capture inputs. Limit switches provide information about the end of travel to help you avoid damaging your system. When a motion system hits a limit switch, it typically stops moving. Home switches, on the other hand, indicate the system home position to help you define a reference point. This is very important for applications such as pick-and-place and where you might want to trigger a system to take measurements at a series of prescribed position.

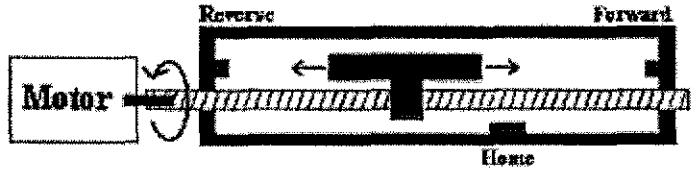

Figure (3-4) Limit and home switches in a motion control system

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Chapter 4: Components of the motorized stage

The components of the motorized stage are shown in Figure (4-1). These components were used to develop the positioning system. This system was implemented to measure the actuation and the stage movement.

Figure (4-1) Motorized Stage

Motor Connector Pin Assignments:	
Motor Type:	MTR-10-E
Connector Type:	Dual Row IDC
Mating Part:	Panduit P/N 057-010-115 (male pin socket)

Table (4-1) Motorized Stage Description

Pin #	**Name**		**Pin #**	**Name**
1	Motor +		6	Motor -
2	Encoder +V		7	Limit Ground
3	Encoder Ch. A		8	No Connection
4	Encoder Ch. B		9	Reverse Limit
5	Ground (case)		10	Forward Limit

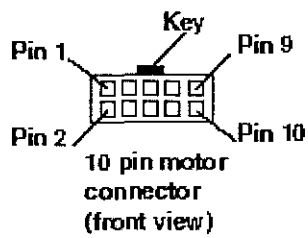

Table (4-2) 10-pin motor connecter

Electrical Specifications:	
Supply Voltage Nom. (Volts)	6
Armature Resistance (Ohm) ±12%	20.1
Max Power Output (Watts)[2]	0.46
Max Efficiency (%)[2] [2]	68
No-Load Speed (rpm) ±12%[2]	17,600
Friction Torque (at no-load speed)(oz-in)	0.004
No-Load Current (mA) ±50%[3]	10
Stall Torque (oz-in)[2]	0.15
Velocity Constant (rpm/Volt)	2.854
Back EMF Constant (mV/rpm)	0.350
Torque Constant (oz-in/Amp)	0.48
Armature Inductance (mH)	0.060

Table (4-3) Motorized stage electrical specifications

4.1 Drive Mechanisms

This section will introduce most of the more common types of drive mechanisms found in linear motion machinery. Ideally, a drive system should not support any loads, with all the loads being handled by a bearing system. Topics discussed will include, but not be limited to, the mechanism of actuation, efficiency, accuracy, load transfer, speed, pitch, life cycle, application and maintenance.

4.1.1 Leadscrew

Leadscrew is a device that converts rotary motion to linear motion. The Figure (4-2) shows a sample leadscrew. The two major parts are the stage slider and the lead screw. The more adjusted the thread zone, the higher the resolution of the actuation.

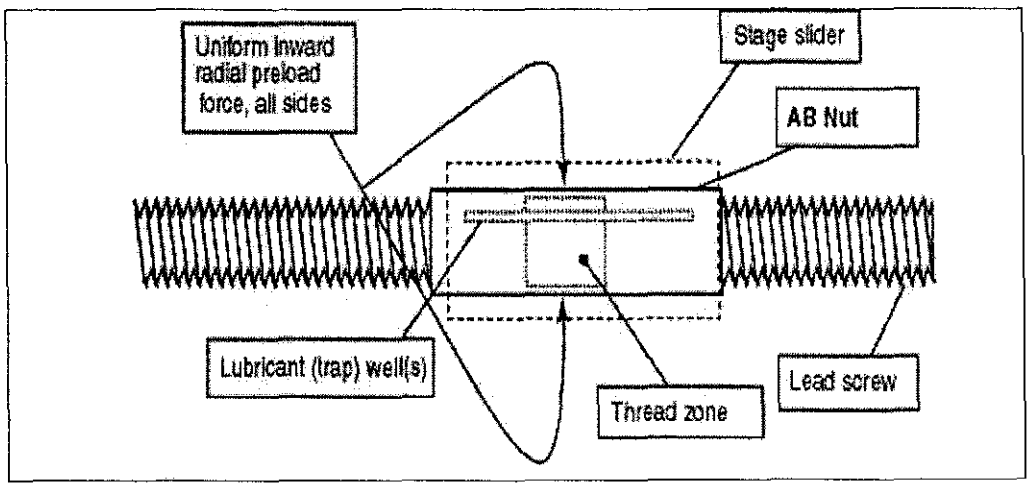

Figure (4-2) Leadscrew

4.1.2 Constant Preload

The sliding contact thread should be as close as possible to minimize the backlash as demonstrated in the Figure (4-3). Some resent leadscrews went from standard 25-50 micrometers to 2-4 micrometers.

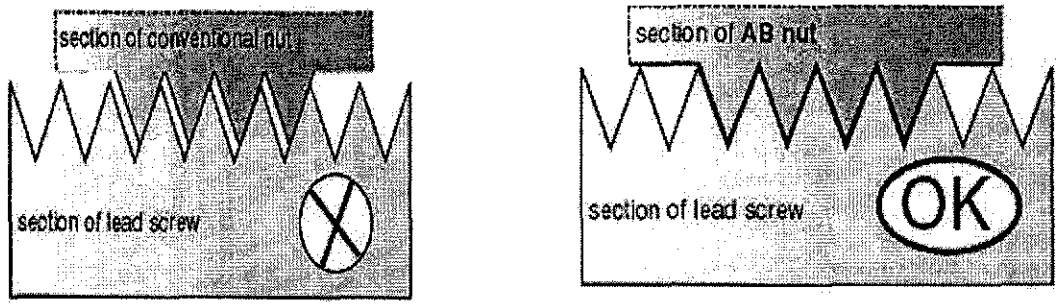

Figure (4-3) Using thread conventional AB nut-using engagement thread

4.2.1 Motor

A motor driver receives input signals from a controller and converts them into power to drive a motor, Motors turn electrical energy into mechanical energy and produce the torque required to move to the desired target position.

4.2.2 Servo motors are more robust than stepper motors, but pose a more difficult control problem. They are primarily used in applications where speed, power, noise level as well as velocity and positional accuracy are important. Servo motors are not functional without sensor feedback, they are designed and intended to be applied in combination with encoders (closed loop), resolvers, or tachometers as shown in the Figure (4-4).

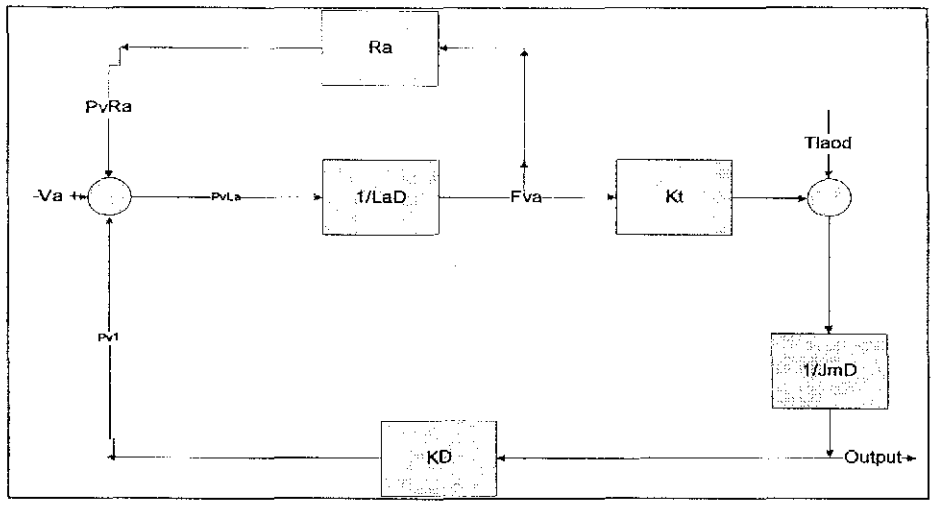

Figure (4-4) Block diagram for the motor

Mechanical Specifications (Motor):	
Mechanical Time Constant (ms) [2]	9
Armature Inertia (x 10^{-6} oz-in-sec^2) [2]	0.085
Angular Acceleration (x 10^3 rad/sec^2) [2]	193
Rotor Temperature Range	-30°C to 125°C (-22°F to +257°F)
Bearing Play (measured at bearing)	
Radial	Less than 0.03mm (0.0012")
Axial	Less than 0.02mm (0.0079")
Thermal Resistances ($^{\circ}$C/W)	
Rotor to Case	10
Case to Ambient	65
Max Shaft Load (oz)	
Radial at 3,000 rpm (3mm from bearing)	1.8 (51 grams)
Axial	72 (2,041.2 grams)
Weight (oz)	0.23 (6.5 grams)
* Specified at nominal supply voltage.	
** Specified with shaft diameter = 0.8mm at no-load speed.	

Table (4-4) Motor's mechanical specifications

4.2.3 Motor DC Electric (brush type)

Advantages	Disadvantages
Fast and accurate	Inherently high-speed, low-torque devices (usually needing a gear ,which increases cost)
Small in size	Commutator and brushes limit life
Reversible by changing input polarity	Not self locking (brake required)
Good for position and velocity control	High current at stall leads to heat generations
Inexpensive	The motor performance may suffer inefficiencies.
Easily controlled using feedback, agreeable to complicated control strategies	The brushed motor will require maintenance, as the brushes will wear and need replacement.

Table (4-5) Characteristic for servo brush type motor

4.3 Encoder (feedback)

Encoder Specifications:	
Supply Voltage	5 VDC Nom.
Max Supply Voltage	15 VDC
Operating Current	5 mA Nom. @ 5VDC
Signal Phase Shift	90°
Max Signal Frequency	7.2 Khz
Operating Temp. Range	-20°C to +85°C (-20°F to +185°F)
Storage Temp. Range	-40°C to +110°C (-40°F to +230°F)
Max Asymmetry	10%
Output Signal Type	Square wave
Signal Rise Time	Less than 5µs
Phase Relationship	Ch. A leads Ch. B when motor rotation is clockwise as viewed from shaft end.
Pulses Per Revolution	10 (2 channels)
Quadrature	40 encoder counts

Table (4-5) Encoder specifications

A feedback device's basic function is to transform a physical parameter into an electrical signal for use by a motion controller. Common feedback devices are encoders for position feedback. The location in the motion system from which the feedback device performs its measurements directly affects the quality of the data fed back to the controller. The closer the feedback device is to the parameter being controlled, the more effective it will be in helping the controller achieve the desired result. When controlling position, for example, measuring the linear position of the stage carriage directly provides higher quality feedback than measuring the angular position of the leadscrew.

4.3.1 Quadrature Encoders

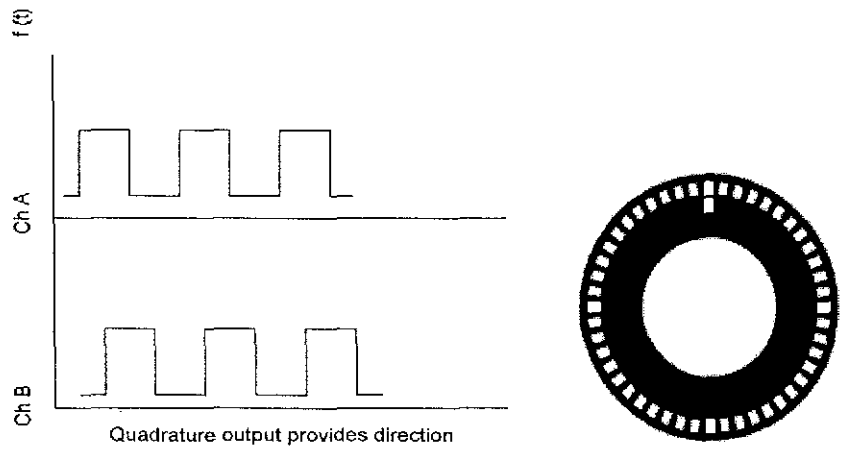

Figure (4-5)

Quadrature encoders are a particular kind of incremental encoder with of at least two output signals, commonly called channel A and channel B. As shown in Figure (4-5), channel B is offset 90 degrees from channel A. The

addition of a second channel provides direction information in the feedback signal. The ability to detect direction is critical if encoder rotation stops on a pulse edge. Without the ability to decode direction, the counter may count each transition through the rising edge of the signal and lose position.

Another benefit of the quadrature signal scheme is the ability to electronically multiply the counts during one encoder cycle. In the times-one mode, all counts are generated on the rising edges of channel A. In the times-two mode, both the rising and falling edges of channel A are used to generate counts. In the times-four mode, the rising and falling edges of channel A and channel B are used to generate counts. This increases the resolution by a factor of four.

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Chapter 5: Simulation of Positioning System

5.1 Visual Simulation using VisSim

VisSim is a Windows-based program for the modeling and simulation of complex nonlinear dynamic systems. VisSim combines an intuitive drag & drop block diagram interface with a powerful simulation engine. The visual block diagram interface offers a simple method for constructing, modifying and maintaining system models. The simulation engine provides fast and accurate solutions for linear, nonlinear, continuous time, discrete time, time varying and hybrid system designs.

VisSim provides a fully integrated control system design environment where all design and simulation tasks can be completed without writing a line of code. Furthermore, VisSim offers unprecedented ease-of-use and consequently a shorter learning curve than competitive systems. Less time training -- more time engineering!

Professional VisSim includes the VisSim Viewer, a run-time, view only version of VisSim. The VisSim Viewer enables users to distribute VisSim models and simulations to individuals not licensed to use VisSim. Model integrity is preserved by prohibiting recipients from changing wiring and model structure. However, recipients of the Viewer are able to change block and simulation

parameters, optimize gains, perform interactive "what -if " scenarios and customize histogram, plot and stripChart blocks.

VisSim/Real-Time lets you connect to your VisSim model directly to the external world through digital and analog I/O blocks. VisSim/Real-Time supports analog and digital I/O boards from National Instruments. No code generation or programming is required to configure and use VisSim/Real-Time.

VisSim/Real-Time is used successfully in a wide variety of industries to:

- Develop and validate control strategies
- Perform off-line tuning of controllers against a real-time plant
- Perform real-time control of actual plant
- Operator training against a real-time plant simulation

With VisSim/Real-Time, applications can perform real-time simulation, data acquisition and control directly from Windows 9x/NT/2000/XP. There is no code generation or programming involved. There is virtually no difference between running a regular VisSim simulation and a real-time HIL system.

5.2 MATLAB

- MATrix LABoratory, Cleve Moler founder.

- Integrates mathematical computing, visualization, and extensible programming language
- Command line as well as Graphic interface
- Interactive and batch processing
- Widely used in science and engineering

5.2.1 MATLAB Key Features

Numeric computing for quick and accurate results.

- Graphics to visualize and analyze data.
- Discipline specific toolboxes.
- Tools for building custom GUIs.
- Interfaces to External Languages: C/C++, Fortran, Java, LabVIEW.
- Support for wide range of Input/Output.
- Conversion of MATLAB applications to C/C++ with the MATLAB Compiler for speed and dissemination.
- MATLAB programs platform independent.
- Relatively easy to learn programming language

5.2.2 MATLAB Applications

- Data analysis and exploration.

- Visualization and image processing.
- Algorithm prototyping and development.
- Modeling and simulation.
- Programming and application development.

5.3 SIMULINK

SIMULINK is a software package for modeling, simulation, and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled-time or hybrid of two. Systems can also be multirate, i.e., have different parts that are sampled or updated at different rates.

For modeling, SIMULINK provides a graphical user interface (GUI) for building models as block diagrams, using click and drag mouse operations. With this interface, you can draw the models just as you would with pencil and paper.

SIMULINK includes comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. You can also customize and create your own blocks. After you define a model, you can simulate it, using a choice of integration methods, either from the SIMULINK menus or by entering commends in matlab commend windows. The simulation results can be put in the MATLAB workspace for post processing and visualization.

Model analysis tools include linearization and trimming tools, which can be accessed from the MATLAB command line, plus the many tools in MATLAB and its application toolboxes. And because MATLAB and SIMULINK are integrated, you can simulate, analyze, and revise your models in either environment at any point.

The other method MATLAB uses to numerically differentiate (integrate) is via SIMULINK. SIMULINK is a program for simulating dynamic systems. It has two phases of use: model definition and model analysis, which means you, need to first define your model and then use modeling analysis to understand the system's dynamic behavior. SIMULINK has a new class of windows called block diagram windows. After a model is defined, it can be analyzed either using the SIMULINK menus or using MATLAB's command window (workspace).

Defining the model is easiest if one visualizes the loop for calculating the output as an approximate integration solution for small time steps.

5.4 LabVIEW

LabVIEW is a fully featured programming language produced by National Instruments. It is a graphical language relatively unique in the method by which code is constructed and saved. There is no text based code as such, but a diagrammatic view of how the data flows through the program. Thus

LabVIEW is a much respected tool of the scientist and engineer who can often visualize data flow rather than how a text based conventional programming language must be built to achieve a task, also the development of data acquisition software. LabVIEW can acquire data and control devices via IEEE-488 (GPIB), RS-232/422 and modular (VXI or CAMAC) instruments as well as plug-in I/O boards.

LabVIEW programs, called "virtual instruments" (VIs), are created using icons instead of conventional, text-based code. A VI consists of a front panel and a block diagram. The front panel (with knobs, switches, graphs, and so on) is the user interface. The block diagram, which is the executable code, consists of icons that operate on data connected by wires that pass data between them. Controls are knobs push buttons dials and other input devices.

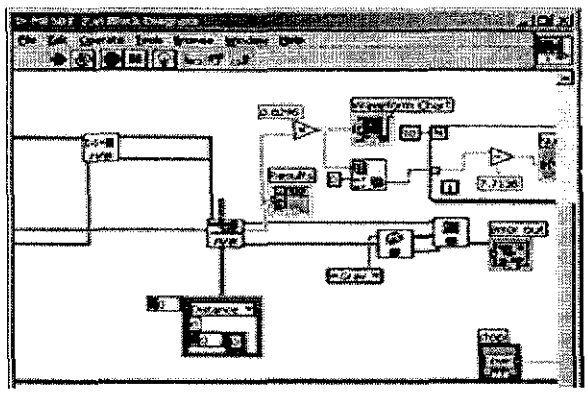

Figure (5-1) Sample LabView Program

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Chapter 6: Experiment validation of micro positioning

Precision actuation is a complicated task. The project had to be modified to accommodate the challenges. One of the challenges the project faced was the power of the data acquisition system. As a result, an amplifier was implemented to strengthen the power of data acquired as shown in Figure (6-1).

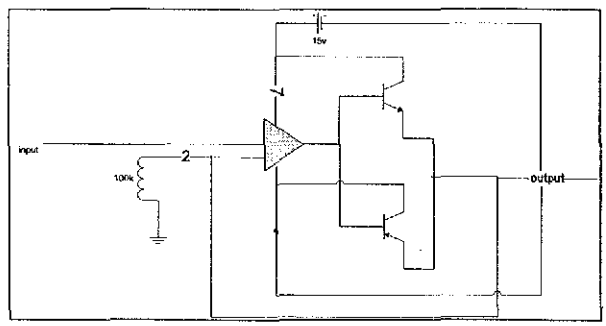

Figure (6-1) Amplifier

6.1 Experiment set up

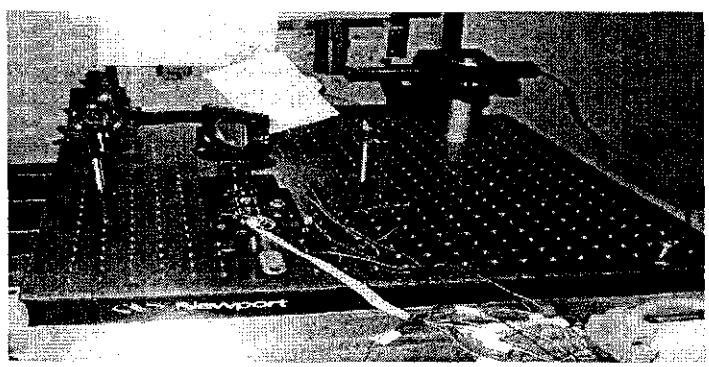

Figure (6-2) Setup

A block diagram is constructed to control the stage actuation as shown in Figure (6-3)

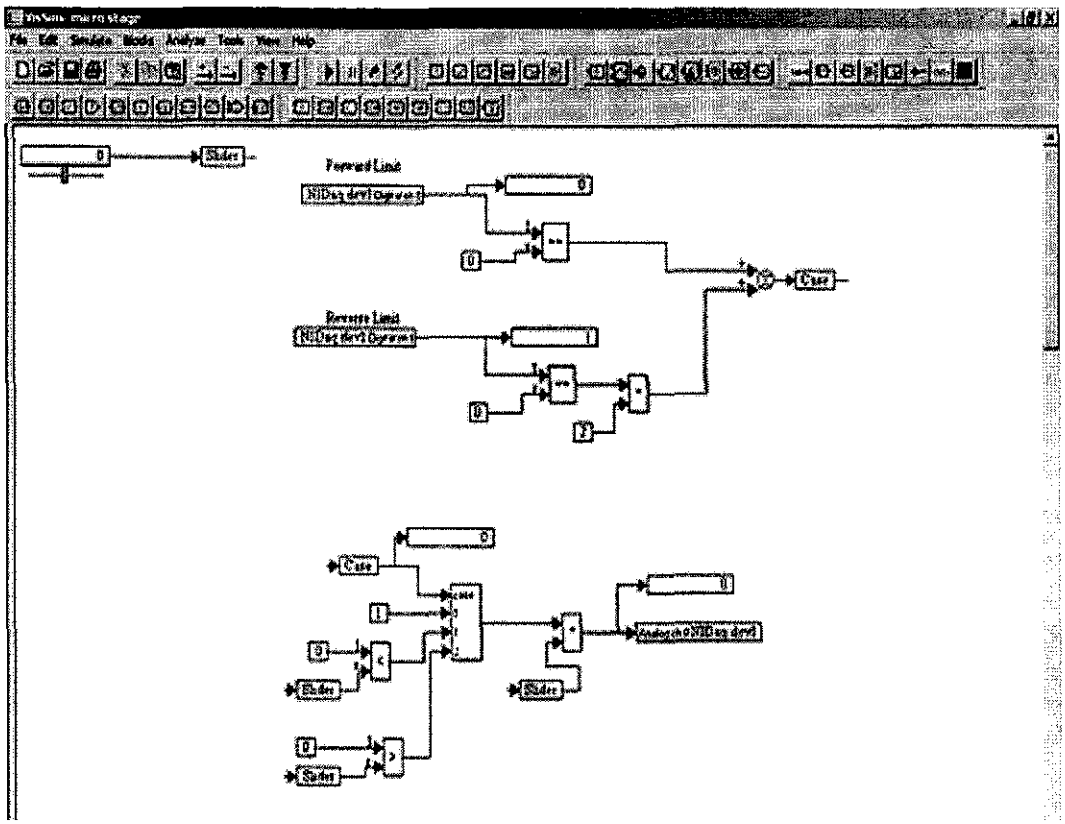

Figure (6-3) VisSim diagram for the stage

Linear Motion: 80 TPI Lead Screw

Gearhead Ratio	Resolution		Max Travel Rate	
	µInch/count	µm/count	Inch/sec	mm/sec
16:1	19.5313	0.4960	0.260	6.60

Table (6-1) Encoder resolution calculations

Encoder counts per shaft revolution = 40 encoder counts x Gearhead ratio

Distance per micrometer = encoder counts x resolution (µm/count)

We setup a counter for encoder with Labview.

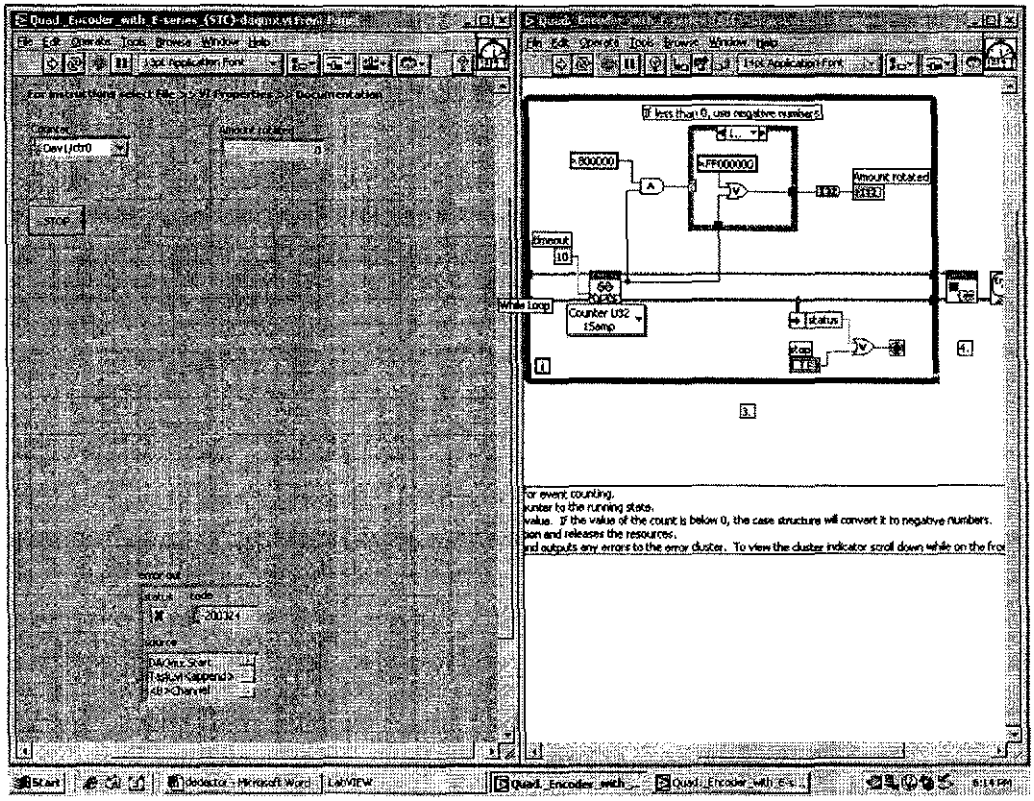

Figure (6-4) Design counter for the Encoder

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Chapter 7: Position Measurement

7.1 Interferometer

Interferometer is a device that uses interference between two beams of collimated light to make measurements. In principle, these measurements can be made to great precision, typically on the order of nanometer, since interferometric technique uses the interference of nanometer wavelengths. For this experiment, one of the mirrors constituting one of two arms of the interferometer is attached to a motorized stage. The stage is attached to the micrometer which is attached to the translation stage. As the mirror is moved, observation of the changes in the interference pattern can be used to determine how far the mirror actually moved.

Theory:

$$\Delta l = \frac{n\lambda}{2} \quad (7\text{-}1)$$

Where Δl is the distance that one the mirrors moves relative to the other mirror.

λ is the wavelength of the laser source

n is an integer (not zero)

The previous equation comes with the following argument; when the mirror mounted on the translation stage is moved ($\lambda/2$) then the light in that arm of

interference will move one whole wavelength and the interference pattern changes from a maximum to a minimum and then back to a maximum. This means if the bright center of circular interference pattern as the translation stage is slowly moved ($\lambda/2$) the central bright region should turn to a dark minimum and then back to a bright maximum. This is what is termed the movement of one fringe, with n=1, or better $\Delta n=1$.

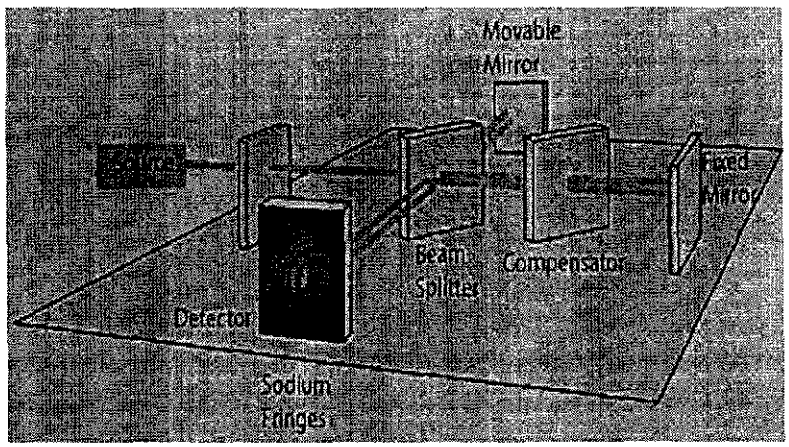


Figure (7-1) Michelson Interferometer

7.1.1 Interferometer Setup:

As in table of lab a Michelson interferometer is constructed using precision laboratory components as shown in Figure (7-2)

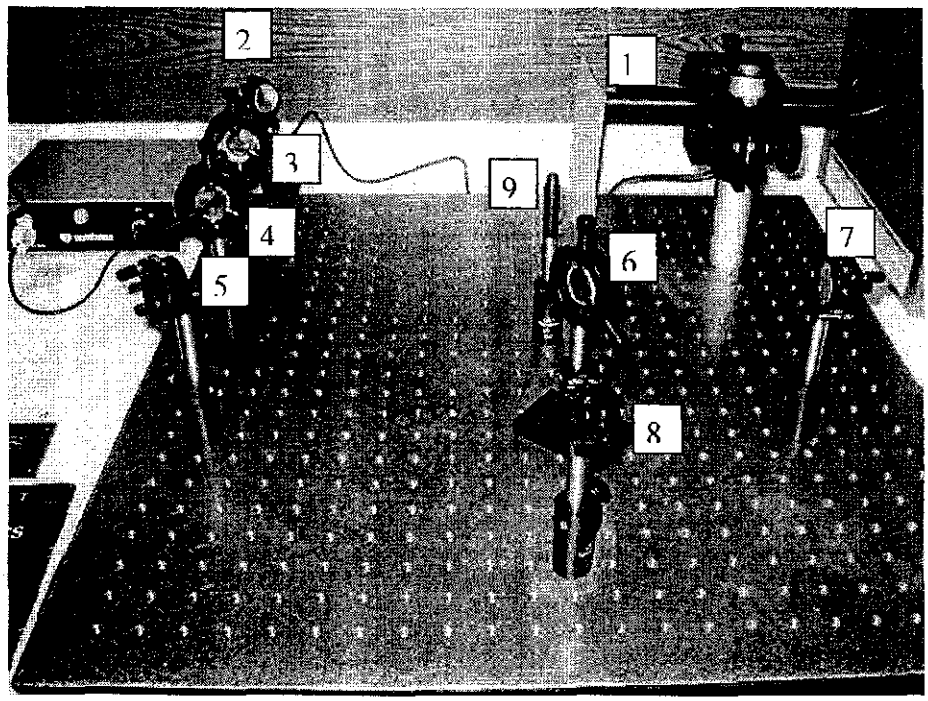


Figure (7-2) the interferometer setup

The interferometer components:-

1. The laser and mount, so the laser what we used is HeNe has wavelength of 632.8 nm as shown in table (7-1)
2. Mirror mount.
3. Two lenses to the expander.
4. Lens
5. Mirror #2.
6. Splitter.
7. Mirror #3.

8. Mirror (movable).

9. Observation Screen.

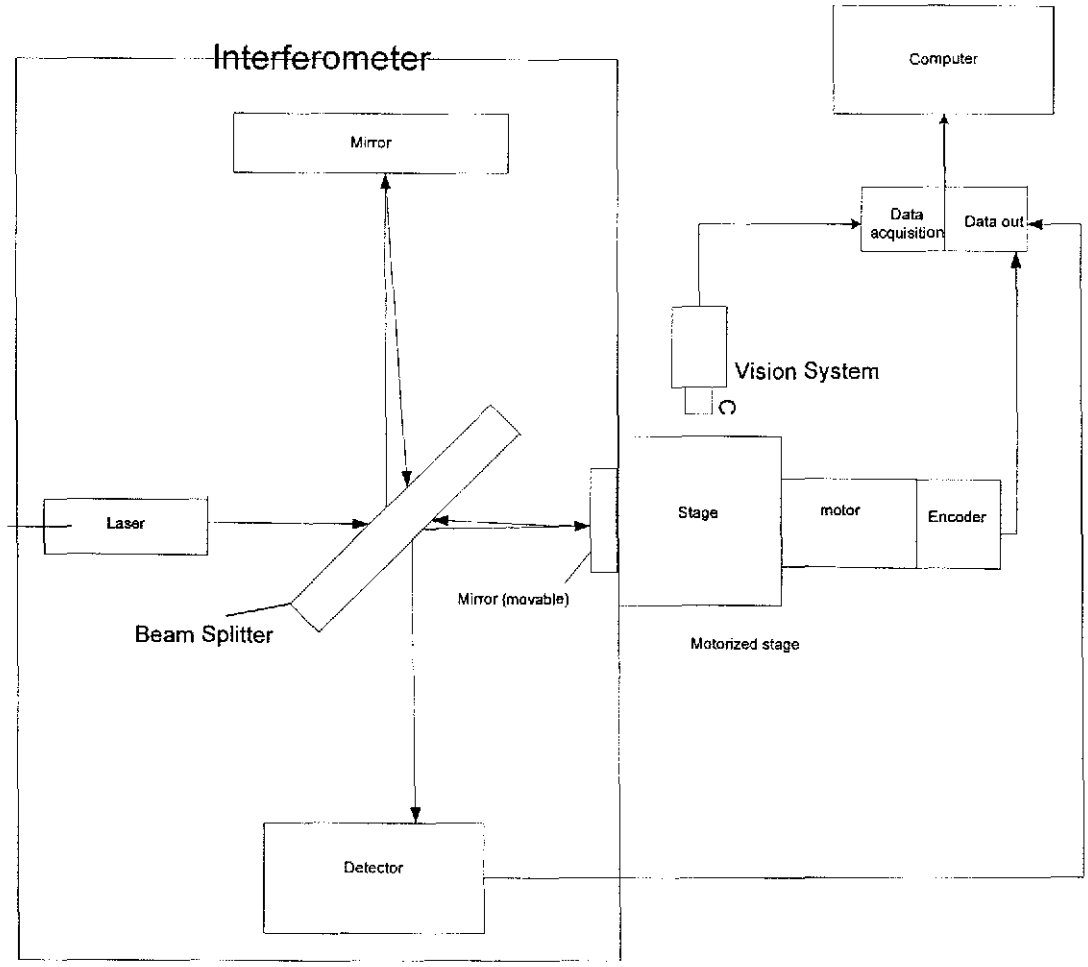


Figure (7-3) Experiment Setup for actuation

7.1.2 Experimental Procedure:

Once the interferometer is constructed, align the beams of the two arms so that they overlap on the observation screen. The fringes should follow the following image.

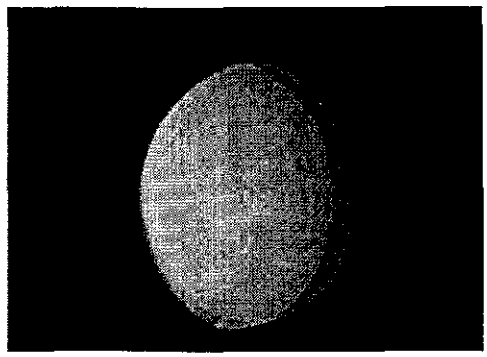


Figure (7-4) two overlapping beams

Align the interferometer so that the circular interference fringes are achieved. So when the two beams are identical, the small diffraction patterns within the beams due to the collimating lens and the beam expander can be used to overlap the beams in order to achieve the desired interference pattern as shown in Figure (7-5). One should be able to adjust the mirror on the translation stage by a small amount and count the fringes that go by. Somewhat a more elaborate experiment requires a light detector such as a photocell or phototransistor, so we used phototransistor to count the fringes as shown in figure (6-7).

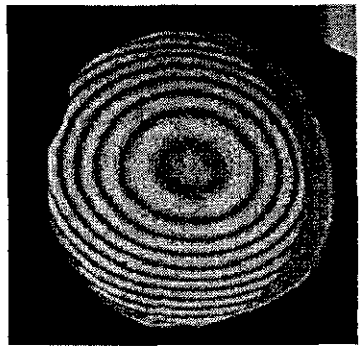


Figure (7-5) Interference fringes

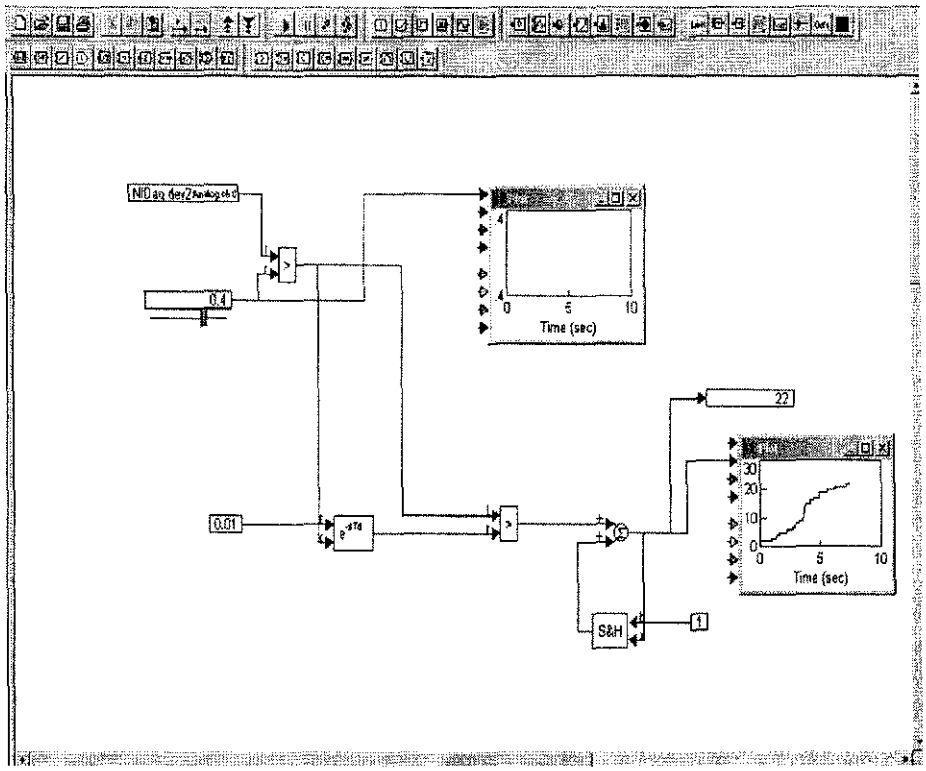


Figure (7-6) Phototransistor reading for fringes in VisSim

It was very complicated to count the fringes with bare eye, so it is very important to create counter to get the number of fringes as shown in Figure (7-6)

Parameter	1101/P	1103/P	1107/P	1108/P	1122/P	1125/P	1135/P	1137/P	1144/P	1145/P	Unit
Optical											
Min. output power (TEM00)	1.5	2.0	0.8	0.5	2.0	5.0	10.0	7.0	15.0	22.5/21.0	mW
Wavelength	632.8	632.8	632.8	632.8	632.8	632.8	632.8	632.8	632.8	632.8	nm
Mode purity (TEM00)	>95	>95	>95	>95	>95	>95	>95	>95	>95	>95	%
Beam diameter (1/e2 points, ±3%, TEM00)	0.63	0.63	0.48	0.48	0.63	0.81	0.68	0.81	0.70	0.70	mm
Beam divergence (TEM00, ±3%, mrad- full angle)	1.3	1.3	1.7	1.8	1.3	1.0	1.2	1.0	1.15	1.15	mrad
Polarization ratio (minimum, P versions)	N/A /500:1	N/A /500:1	N/A /500:1	N/A /500:1	N/A /500:1	N/A /500:1	N/A /500:1	N/A /500:1	N/A /500:1	N/A /500:1	-
Longitudinal mode spacing (nominal)	730	730	1090	1090	730	435	320	435	257	257	MHz
Maximum noise (rms, 30 Hz to 10 MHz)	0.1	0.1	0.1	0.1	0.1	0.2	1.0	0.2	0.5	0.5	%
Max. drift (mean power measured over 8 hours)	±2.5	±2.5	±2.5	±2.5	±2.5	±2.5	±3.0	±2.5	±2.0	±2.0	%
Max. mode sweeping contribution	3	3	10	20	3	2	2	2	1	1	%
Max. warm-up time (minutes to 95% power)	10	10	10	10	10	10	15	10	20	20	min.
Beam pointing stability (from cold start, 25 °C)	N/A	N/A	N/A	N/A	<0.10	<0.10	<0.10	<0.10	<0.20	<0.20	mrad
Beam pointing stability (after 15 minutes warm-up)	N/A	N/A	N/A	N/A	<0.10	<0.10	<0.02	<0.02	<0.05	<0.05	mrad
Operating voltage (V DC ±100)	1700	1700	1250	1250	1800	2300	3100	2300	3800	3800	V DC
Operating current (±0.1 mA)	4.9	4.9	4.0	4.0	6.5	6.0	6.5	6.0	6.5	6.5	mA

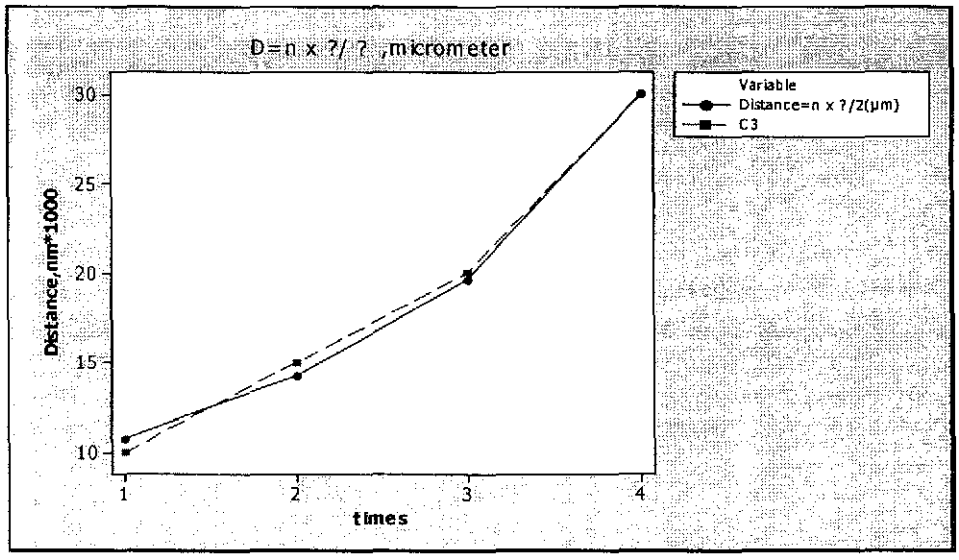
Table (7-1) Specification of Laser source

7.1.3 Interferometer Results:

After the experiment was completed, the resulting values were very close to the micromere measurement values. The table and the graph below demonstrate the closeness of these measurements.

Number of fringes	Distance=n x λ/2(μm)	micrometer(μm)
34	10.757	10
45	14.238	15
62	19.616	20
95	30.058	30

Table (7-2) Compare the experiment results and the micrometer measurements



Graph (7-1) to demonstrate the experiment results and the micrometer measurements

7.2 Optical System for the vision

A vision system can be classified in a broad sense as a noncontact optical sensor system that obtains geometric information about a part such as

position, orientation, size, shape, or surface contour. For precision engineering applications, vision systems are useful for mapping the shape of a tool. Everyday applications are found in the form of optical comparators. The machine vision process can be divided into four basic steps: image formation, image preprocessing, image analysis, and image interpretation. IMAQ Vision Builder is a tool for prototyping and testing image processing applications. IMAQ Vision Builder uses the IMAQ Vision Library, but it is a standalone executable that you can use independently of other programs. The IMAQ Vision Builder is an invaluable tool for prototyping vision systems and for learning how different image processing functions perform The IMAQ Vision Builder interface makes prototyping your application easy and efficient. The Vision Builder is also used for the measurement of motion as we have done in our experiment.

7.2.1 Optical System Procedure:

1: Set the camera over the stage

2: Connect the camera with the computer (device from National Instruments)

3: Open the program for the IMAQ Vision Builder

4: Choose the channel (0)

5: Press the Acquire Continuous Images button

6: Press Store Acquire Image in Browser

7: Press Return

8: Choose from Machine Vision>edge detector

9: Select what you want to measure

10: Click Apply, and then Close

11: Click Machine Vision, then click Caliper

12: Click the two points you want to measure

13: Choose from Options menu Distance, and then click Measure

14: Lastly save the results

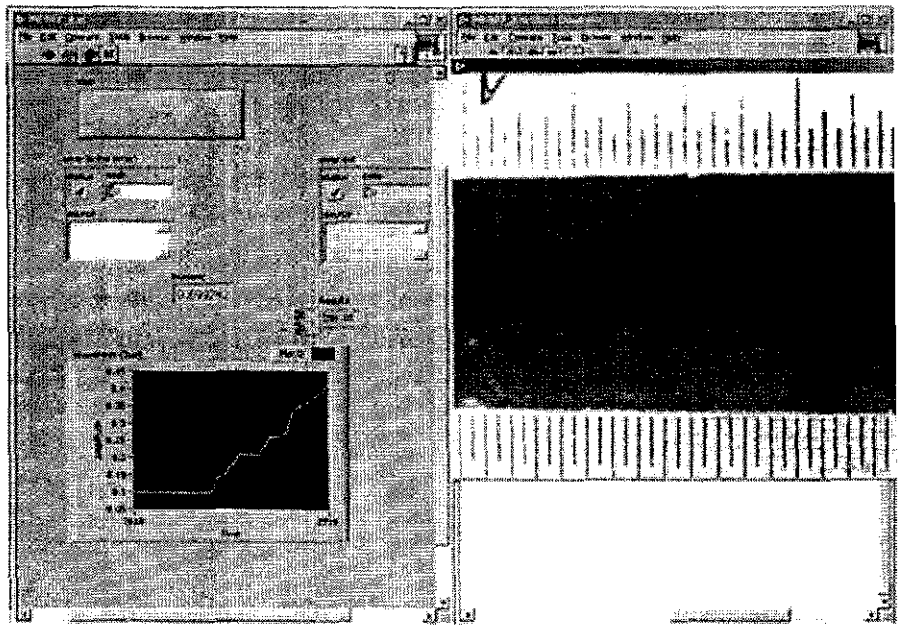


Figure (7-6) Measure simulation

7.2.2 Vision System Results:

the distance between the camera and the stage to get a highly accurate measurement was reduced. The result which we came up with was a pixel

unit. We converted the pixel to millimeters using the certificate of accuracy (see figure below). We took the diameter of the pixel from our experiment (25.25) and divided it by the dot diameter on our certificate of accuracy (0.75),which gave us the result of 0.0297 as the converter, which we will use for the LabView program.

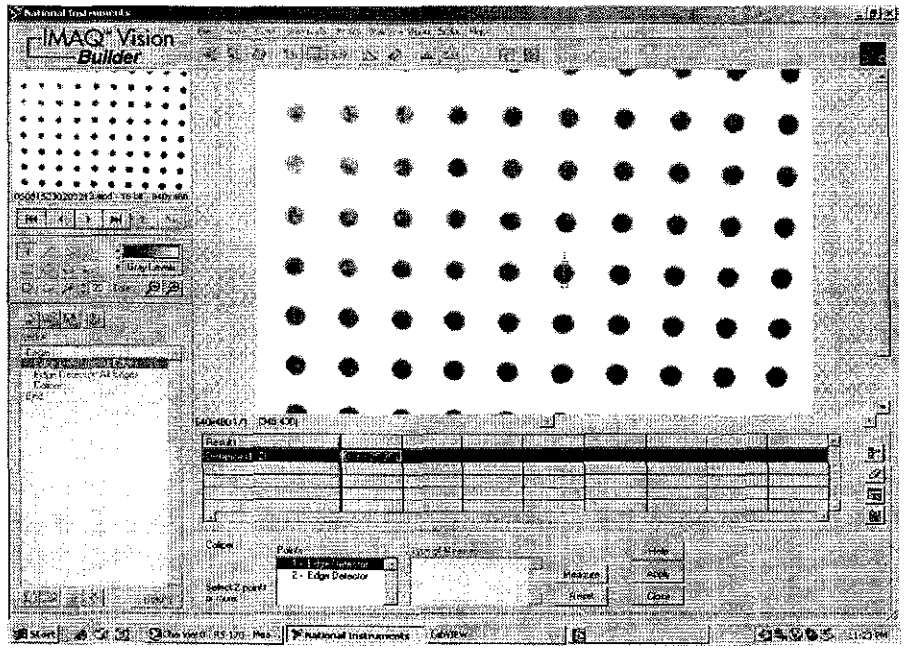
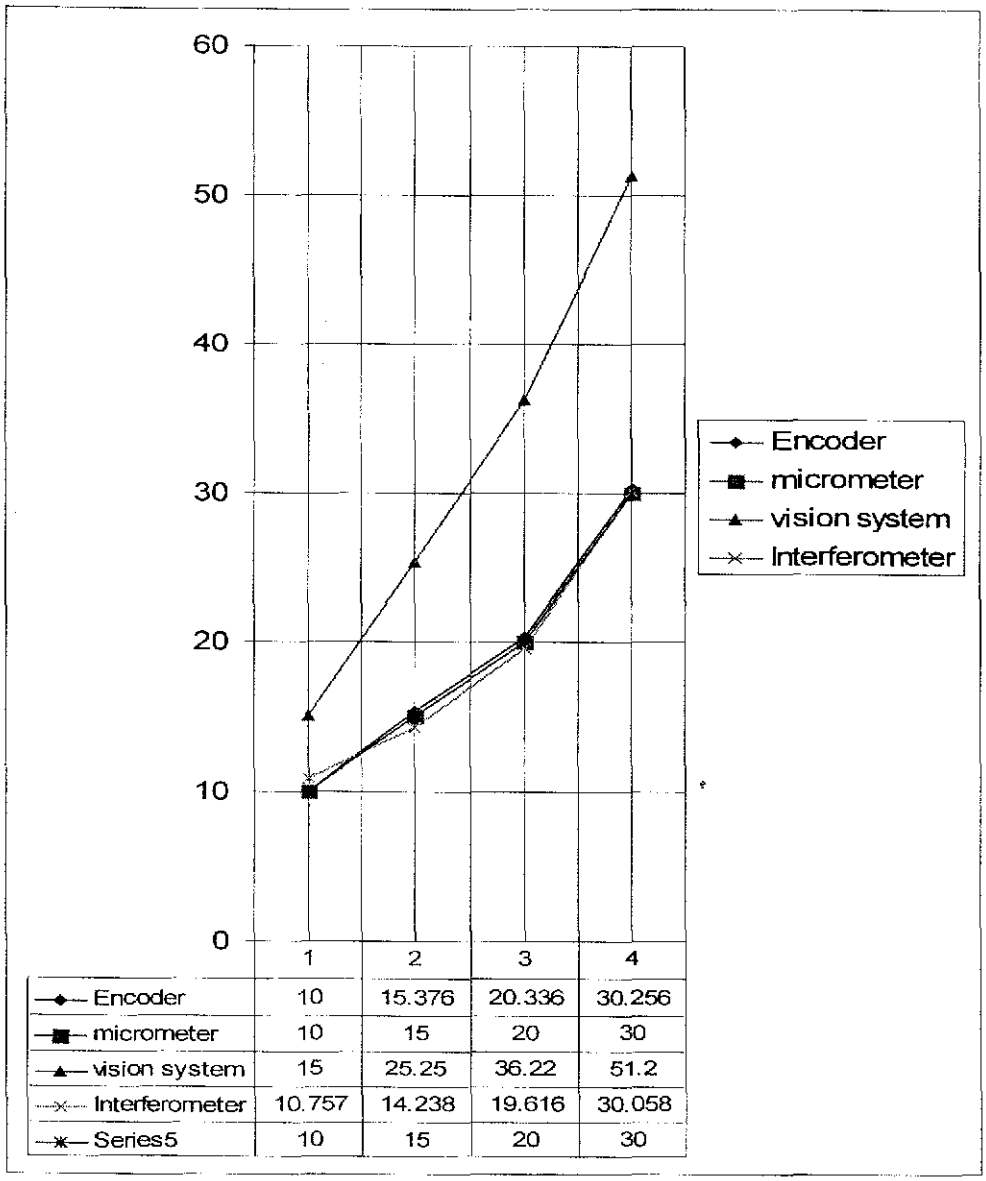


Figure (7-7) Measurement conversion sampler

The project used three methods to measure this motorized stage as we mentioned before.

1. encoder
2. Michelson interferometer
3. optical system

7.3 Summary for the four methods



	1	2	3	4
Encoder	10	15.376	20.336	30.256
micrometer	10	15	20	30
vision system	15	25.25	36.22	51.2
Interferometer	10.757	14.238	19.616	30.058
Series5	10	15	20	30

Figure (7-8) Comparison for the four methods

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مؤلفين آخرين:	Shetty, Devdas(Super)
التاريخ الميلادي:	2003
موقع:	هارتفورد كونيكت
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الجامعة:	University of Hartford
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An Approach to High Precision Positioning and Measurement by Integrating Modern Simulation Tools

By

Abdulrahman Almousa

Presented to the faculty of the College of Engineering, Technology &

Architecture

University of Hartford

As partial requirement for the Degree of Masters of Engineering

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Abdulrahman Almousa

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APPENDIX

Chapter 1: Introduction

Positioning systems are widely used in many industrial applications such as actuation, CNC machining, automatic testing, calibration, inspection, and processes such as laser welding or cutting. Micropositioning refers to mechanical movement with positioning accuracy and resolution in the micron or high sub-micron range. Nano positioning refers to positioning with nanometer or sub-nanometer resolution range for high-precision nano positioning devices.

Applying design rules for motion systems with millimeter or sub-millimeter resolution do not always apply for the micron and sub-micron range. Resolution in the sub-micron realm cannot always be increased by simple means such as reducing the pitch of a leadscrew or increasing the gear ratio of a motor/gearhead unit. Stiction/friction, play, backlash, tilt, windup and, temperature effects, etc. will also limit accuracy and resolution. Sub-micron positioning systems require a great deal of attention in design, manufacturing and selection of materials.

These applications require that the positioning system have high accuracy and good repeatability. As a result, this project's purpose was to introduce

various ways to measure the actuation of the stage. The proposed measurements are very cost effective to implement in many organizations. The implementation and measurement of positioning was accomplished using four simulation tools and related software. The visual simulation software was used along with the software, which provided an example of hardware –in – the loop. The experiments also included three methods of position measurement. Amongst the methods implemented, interferometric method was adjudged to be the best case.

Chapter 2: Overview of errors in measurement system

2.1 Contribution of errors

Total error is the cumulative effect of linear displacement error, angular error, and error due to straightness, parallelism, orthogonality, spindle thermal drift. Out of the above linear errors, displacement error is of prime importance in precision machine tools, for a sample linear stage in figure (2-1).

2.1.1 Linear Displacement Error

Linear displacement error is defined as translation error movement of a machine component along its axis of movement. In general, this type of error is caused by the geometric inaccuracies of the drive or encoder unit . The resolution of the encoder can result in this type of error; for example, if the resolution of the encoder is high than the linear displacement error will be low and the opposite is also true. Another cause can be leadscrew misalignment between its nut and rotation to the centerline.

2.1.2 Angular Error

Angular errors are rotational errors caused by geometric inaccuracies, feedback, and misalignment in the assemblies of the structural component of the machine tool. *Yaw error* is the rotational error of the slide around the axis perpendicular to the plane in which the axis of motion lies. *Roll error* is the

rotational error of the slide around the axis of motion, and *pitch error* is the rotational error of the slide around the third orthogonal axis of the slide.

2.1.3 Straightness, parallelism and orthogonality measurement

Straightness error is the translational error of the machine element that can occur in either of two directions orthogonal to a slide's axis of motion. *The parallelism error* would be the difference divided by the length between the axis of Z motion and the axis average line of the spindle. Several other errors can occur in the measurements such as the Z axis straightness error and the test arbor profile error.

2.1.4 Spindle Thermal Drift

Thermal drift is defined in the ANSI (America National Standard Institute) as "a changing distance between two objects, associated with a changing temperature distribution within the structural loop due to internal and external sources" from this definition of spindle error motions, three components for machine tool:

(1) *Axial thermal drift*, which is the displacement of the spindle along the Z axis.

(2) *Radial thermal drift*, which is the displacement perpendicular to the Z axis.

(3) *Tilt thermal drift*, which is the rotation of spindle in the X-Z plane of the machine.

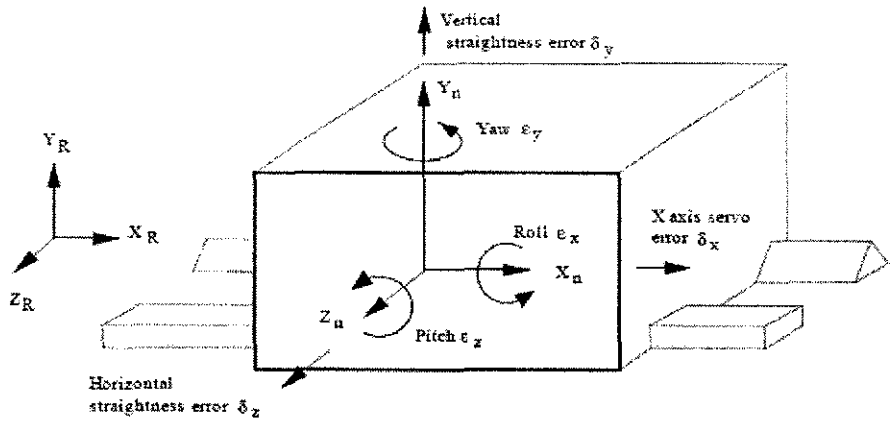

Figure (2-1) Homogeneous Transformation Matrix Model of a linear stage [6]

2.2 Homogeneous Transformation Matrix Model of a linear stage

In order to determine the effects of a component's error on the position of toolpoint or the workpiece, the spatial relationship between the two must be defined. To represent the relative position of a rigid body in three-dimensional space with respect to a given coordinate system, a 4x4 matrix is needed. This matrix represents the coordinate transformation to the reference coordinate system (X_R Y_R Z_R) form that of the rigid body frame (X_n Y_n Z_n), and it is called the Homogeneous Transformation Matrix (HTM). The first three columns of HTM are direction cosines (unit vectors I, j ,k) representing the orientation of the rigid body's X_n, Y_n and Z_n axes with respect to the reference coordinate frame, and their scale factors are zero[1]. The last column represents the position of the rigid body's coordinate system's origin

with respect to the reference coordinate frame. P_s is scale factor, which is usually set to unity to help avoid confusion.

$$ {}^{R}T_{n} = \begin{bmatrix} O_{ix} & O_{iy} & O_{iz} & P_x \\ O_{jx} & O_{jy} & O_{jz} & P_y \\ O_{kx} & O_{ky} & O_{kz} & P_z \\ 0 & 0 & 0 & P_s \end{bmatrix} \quad (2\text{-}1) $$

Thus the equivalent coordinates of a point in a coordinate frame n, with to a reference frame R, are

$$ \begin{bmatrix} X_R \\ Y_R \\ Z_R \\ 1 \end{bmatrix} = {}^{R}T_{n} \begin{bmatrix} X_n \\ Y_n \\ Z_n \\ 1 \end{bmatrix} \quad (2\text{-}2) $$

For example, if the $X_1 \quad Y_1 \quad Z_1$ coordinate system is translated by an amount x along the X axis, the HTM that transforms the coordinate of a point in the $X_1 \quad Y_1 \quad Z_1$ coordinate frame into the XYZ reference frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}3) $$

If the X_1 Y_1 Z_1 coordinate system is translated by an amount y along the Y axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into the XYZ reference frame is

$$ {}^{XYZ}T_{X_1Y_1Z_1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}4) $$

If the X_1 Y_1 Z_1 coordinate system is translated by an amount Z along the Z axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into the X Y Z reference frame is

$$ {}^{XYZ}T_{X_1Y_1Z_1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}5) $$

If the X_1 Y_1 Z_1 coordinate system is rotated by an amount θ_x about X axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into X Y Z frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta x & -\sin\theta x & 0 \\ 0 & \sin\theta x & \cos\theta x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}6) $$

If the X_1 Y_1 Z_1 coordinate system is rotated by an amount θ_y about Y axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into X Y Z frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} \cos\theta y & 0 & \sin\theta y & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta y & 0 & \cos\theta y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}7) $$

If the X_1 Y_1 Z_1 coordinate system is rotated by an amount θ_z about Z axis, the HTM that transforms the coordinate of a point in the X_1 Y_1 Z_1 coordinate frame into X Y Z frame is

$$ {}^{XYZ}T_{X1Y1Z1} = \begin{bmatrix} \cos\theta z & -\sin\theta z & 0 & 0 \\ \sin\theta z & \cos\theta z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2\text{-}8) $$

Equation (2-9) gives the position of the (Nth axis) in terms of the reference coordinates system, when N rigid bodies are connected in series and the relative HTMs between connection axes are known,

$$ {}^{R}T_{N} = \prod_{m=1}^{N} {}^{m-1}T_{m} = {}^{0}T_{1}\,{}^{1}T_{2}\,{}^{2}T_{3}.... \quad (2\text{-}9) $$

2.3 Linear Motion Errors

Consider the case of an ideal linear movement slide of a stage

$$ {}^{R}T_{n} = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}10) $$

For the stage, the HTM that describes the effects of errors on stage emotion can be found by multiplying Equations (2-1)-(2-8) in series with error terms $\delta_X, \delta_Y, \delta_Z, \varepsilon_X, \varepsilon_Y, and\ \varepsilon_Z$ for $x, y, z, \theta_x, \theta_x, and \theta_z$ respectively. The same result can be obtained in the following manner.

$$E_n = \begin{bmatrix} 1 & -\varepsilon z & \varepsilon y & \delta x \\ \varepsilon z & 1 & -\varepsilon x & \delta y \\ -\varepsilon y & \varepsilon x & 1 & \delta z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}11)$$

The first column describes the orientation of the stage's X axis by defining the positioning of the tip of a unit vector, parallel to the stage's X axis. The actual HTM for linear motion stage with errors is ${}^{R}T_{nerr} = {}^{R}T_{n}E_{n}$ [6].

$${}^{R}T_{nerr} = \begin{bmatrix} 1 & -\varepsilon z & \varepsilon y & a+\delta x \\ \varepsilon z & 1 & -\varepsilon x & b+\delta y \\ -\varepsilon y & \varepsilon x & 1 & c+\delta z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2\text{-}12)$$

The most important step in assembling the error budget for a machine is the placement of the coordinate frames and the assignment of linear and angular errors for corresponding to the axes.

The relative error HTM is the transformation in the tool point coordinate system that must be done to the tool point in order to be at the proper position on the work piece

The error correction vector with respect to the reference coordinate frame can be obtained from equation (2-13)

$${}^{R}\begin{bmatrix} P_X \\ P_Y \\ P_Z \end{bmatrix}_{correction} = {}^{R}\begin{bmatrix} P_X \\ P_Y \\ P_Z \end{bmatrix}_{work} - {}^{R}\begin{bmatrix} P_X \\ P_Y \\ P_Z \end{bmatrix}_{tool} \quad (2\text{-}13)$$

Chapter 3: Motion Control System Design

As the intelligent element that commands the motion, the controller may be visualized as the motion system brain that generates commands and requests status reports. "Motion controllers today are mostly digital devices that calculate motion trajectories, and compare them with the actual motor or actuator position," What explains the result is information (the reference input to the amplifier) that commands the amplifier to move the motor. Motion control systems consist of three main units:

- Motion controller
- Driver (motor or amplifier)
- Device as encoder

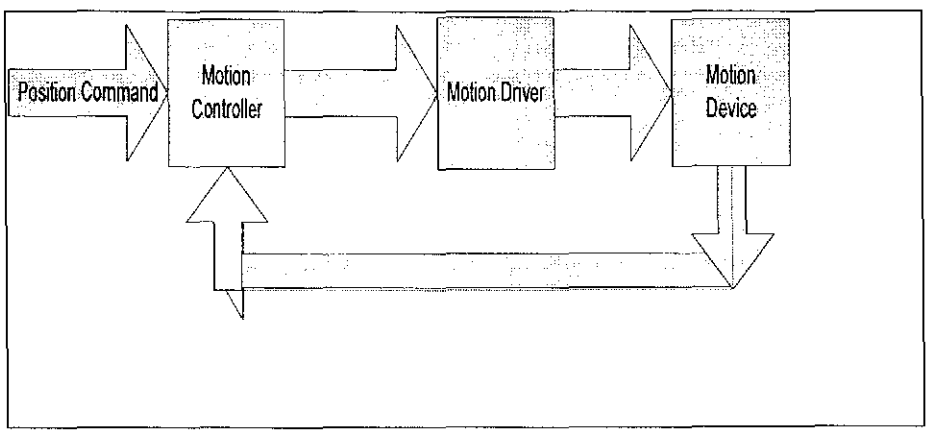

Figure (3-2) motion control systems

3.1 Motion controller

In a motion system, the motion controller is used to control motion devices such as stages and actuator so that the motion controller acts as the brain of the of the system by taking the desired target positions and motion profiles and creating the trajectories for the motors

3.1.1 Control System Components

Application software – You can use application software to command target positions and motion control profiles.

Amplifier or drive – Amplifiers (also called drives) take the commands from the controller and generate the current required to drive or turn the motor.

Feedback device or position sensor – A position feedback device is not required for some motion control applications (such as controlling stepper motors), but is vital for servo motors. The feedback device, usually a quadrature encoder, senses the motor position and reports the result to the controller, thereby closing the loop to the motion controller.

Configuration: - One of the first things to do is configure your system. For this, National Instruments offers Measurement and Automation Explorer, an interactive tool for configuring not only motion control, but all other National Instruments hardware. For motion control, Measurement and Automation Explorer offers interactive testing and tuning panels that help you verify your system functionality before you program.

3.2 Motors and Mechanical Elements

Motors are designed to provide torque to some mechanics. These include linear slides, robotic arms, and special actuators. Motor selection and mechanical design is a critical part of designing your motion control system. Many motor companies offer assistance in choosing the right motor, so we have servo motor for our project. After determining which technology you want to use, you need to determine the torque and inertia at the motor shaft.

Additional factors to consider when selecting your motor and other mechanics are whether an off-the-shelf actuator (such as a stage) might work for your application. Stages offer the power transmission to obtain useful rotary or linear motion without designing it yourself.

3.3 Feedback Devices

Feedback device helps the motion controller know the motor location. The most common position feedback device is the quadrature encoder, which gives positions relative to the starting point. Most motion controllers are designed to work with these types of encoders. Other feedback devices include potentiometers that give analog position feedback, tachometers that provide velocity feedback, absolute encoders for absolute position measurements, and resolvers that also give absolute position measurements. When using National Instruments motion controllers, you can use quadrature encoders and potentiometers.

3.3.1 Motion I/O

Other I/O that is important in motion control includes limit switches, as shown in Figure (3-4) home switches, position triggers, and position capture inputs. Limit switches provide information about the end of travel to help you avoid damaging your system. When a motion system hits a limit switch, it typically stops moving. Home switches, on the other hand, indicate the system home position to help you define a reference point. This is very important for applications such as pick-and-place and where you might want to trigger a system to take measurements at a series of prescribed position.

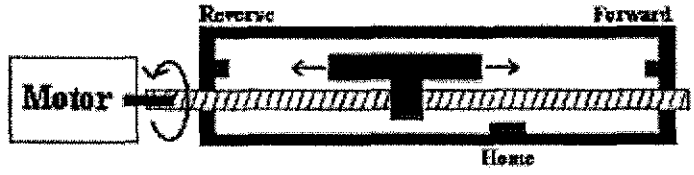

Figure (3-4) Limit and home switches in a motion control system

Chapter 4: Components of the motorized stage

The components of the motorized stage are shown in Figure (4-1). These components were used to develop the positioning system. This system was implemented to measure the actuation and the stage movement.

Figure (4-1) Motorized Stage

Motor Connector Pin Assignments:	
Motor Type:	MTR-10-E
Connector Type:	Dual Row IDC
Mating Part:	Panduit P/N 057-010-115 (male pin socket)

Table (4-1) Motorized Stage Description

Pin #	**Name**		**Pin #**	**Name**
1	Motor +		6	Motor -
2	Encoder +V		7	Limit Ground
3	Encoder Ch. A		8	No Connection
4	Encoder Ch. B		9	Reverse Limit
5	Ground (case)		10	Forward Limit

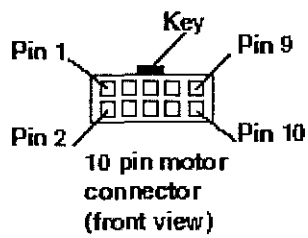

Table (4-2) 10-pin motor connecter

Electrical Specifications:	
Supply Voltage Nom. (Volts)	6
Armature Resistance (Ohm) ±12%	20.1
Max Power Output (Watts)[2]	0.46
Max Efficiency (%)[2] [2]	68
No-Load Speed (rpm) ±12%[2]	17,600
Friction Torque (at no-load speed)(oz-in)	0.004
No-Load Current (mA) ±50%[3]	10
Stall Torque (oz-in)[2]	0.15
Velocity Constant (rpm/Volt)	2.854
Back EMF Constant (mV/rpm)	0.350
Torque Constant (oz-in/Amp)	0.48
Armature Inductance (mH)	0.060

Table (4-3) Motorized stage electrical specifications

4.1 Drive Mechanisms

This section will introduce most of the more common types of drive mechanisms found in linear motion machinery. Ideally, a drive system should not support any loads, with all the loads being handled by a bearing system. Topics discussed will include, but not be limited to, the mechanism of actuation, efficiency, accuracy, load transfer, speed, pitch, life cycle, application and maintenance.

4.1.1 Leadscrew

Leadscrew is a device that converts rotary motion to linear motion. The Figure (4-2) shows a sample leadscrew. The two major parts are the stage slider and the lead screw. The more adjusted the thread zone, the higher the resolution of the actuation.

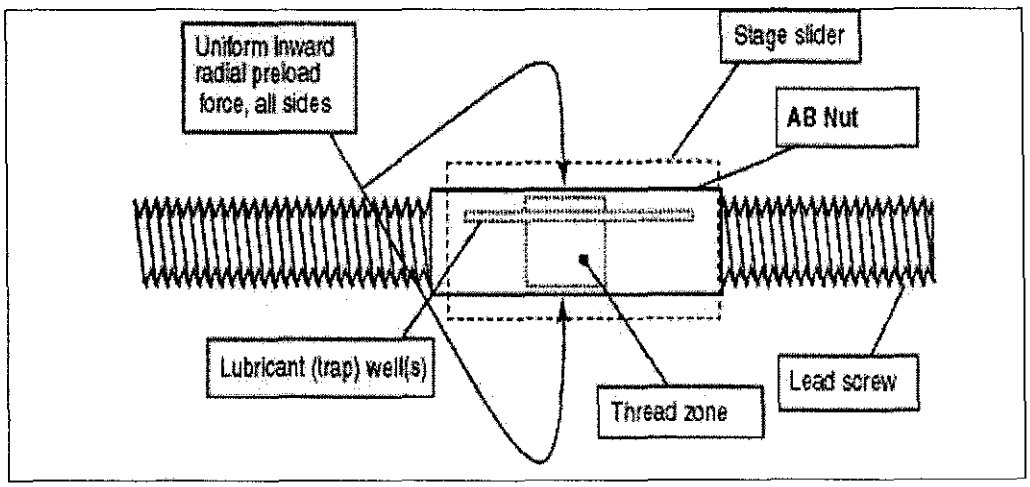

Figure (4-2) Leadscrew

4.1.2 Constant Preload

The sliding contact thread should be as close as possible to minimize the backlash as demonstrated in the Figure (4-3). Some resent leadscrews went from standard 25-50 micrometers to 2-4 micrometers.

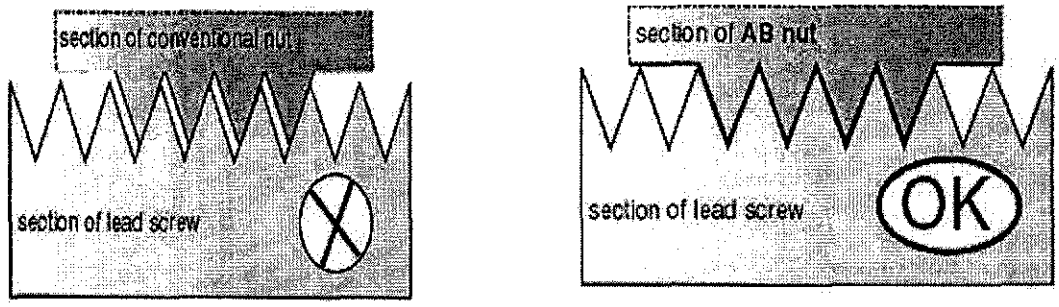

Figure (4-3) Using thread conventional AB nut-using engagement thread

4.2.1 Motor

A motor driver receives input signals from a controller and converts them into power to drive a motor, Motors turn electrical energy into mechanical energy and produce the torque required to move to the desired target position.

4.2.2 Servo motors are more robust than stepper motors, but pose a more difficult control problem. They are primarily used in applications where speed, power, noise level as well as velocity and positional accuracy are important. Servo motors are not functional without sensor feedback, they are designed and intended to be applied in combination with encoders (closed loop), resolvers, or tachometers as shown in the Figure (4-4).

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مؤلفين آخرين:	Shetty, Devdas(Super)
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Conclusion

The main focus of this research was to examine various visual simulation tools that are of importance for modeling, simulation and precision actuation .Additional goals were to develop precision control mechanism, independent measurement tool and integration of the actuation and the measurement into one unit. The results of the project proved that the interferometer is the best option to measure the actuation movement. This study recommends that a controller be used to control the movement of the stage, using an enhanced vision system. It is also suggested that SIMULINk software be explored for such applications. Use of vibration isolation table will provide accurate results.

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Objective

- To develop a method of high precision movement (actuation) and measure.
- To investigate simulation tools as Matlab/Simulink/Labview/Vissim for precision actuation.
- To evaluate errors in measurement.
- Different techniques for measurement.
- To develop an unique, simple method of precision actuation and display.

Introduction

- Developed an accurate and precise positioning system using three methods.
  - Use of computer vision
  - Use of encoder
  - Use of interferometer
- Positioning systems have a wide range of applications in the modern world.
- They are used in calibration, inspection, Laser welding and automatic testing etc.
- The details of all the methods will be explained as we move on.

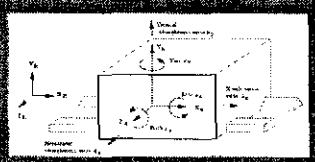
State of the art

- Machine tool metrology (Alexander Slocum 1992)
- Micro-Motion Positioning Systems (Ernest Doebelin 2003)
- Simulation and Block Diagrams (Devdas Shetty , Richard Kolk 1997)
- Design Examples (Ernest Doebelin 1998)
- Vissim User Book (version 4.5 2000)

Overview of errors in measurement system

- **Linear Displacement Error**
- **Angular Error**
- **Straightness, parallelism, and orthogonality measurement**
- **Spindle Thermal Drift**

Motion and errors in a single-axis linear motion stage



Most machine tools have only translational axis, and thus the error correction vector RP correction with respect to the reference coordinate frame can be obtained from:

The HTM for a linear stage with a small errors is:

Motion Control System

As the intelligent element that commands the motion. The controller can be visualized as the motion system's brain that generates commands and requests status reports.

Motion control systems consist of three main units: the motion controller, the driver (motor or amplifier) and a device acts as the encoder.

Adaptation of Simulation Tools

- MATLAB
- Simulink
- Labview
- Vissim

MATLAB

- MATrix LABoratory(full form)
- Integrating mathematical computing, visualization, and extensible programming language
- Command line as well as Graphic interface
- Algorithm prototyping and development.
- Modeling and simulation.
- Interfaces to External Languages: C/C++, Fortran, Java, LabVIEW.
- Support for wide range of Input/Output.

Simulink

- Interactive Tool for modeling, simulating, and analyzing dynamic systems.
- Visual programming using graphical block diagrams.
- Simulation applications include control systems, and communication systems design.

Labview

- LabVIEW is a fully featured programming language produced by National Instruments.
- It is a graphical language relatively unique in the method by which code is constructed and saved.
- There is no text based code as such, but a diagrammatic view of how the data flows through the program.

Vissim

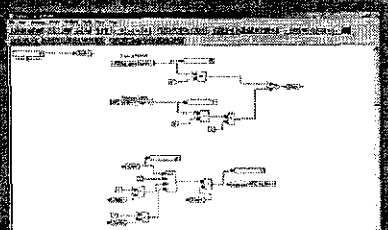
- VisSim is a Windows-based program for the modeling and simulation of complex nonlinear dynamic systems.
- VisSim combines an intuitive drag & drop block diagram interface with a powerful simulation engine.
- VisSim provides a fully integrated control system design environment where all design and simulation tasks can be completed without writing a line of code.

Components

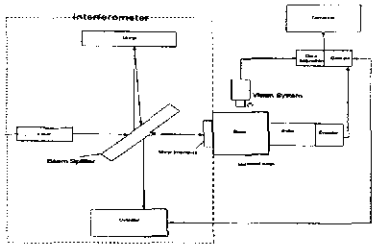
- Motor
- Encoder
- Leadscrew
- Stage
- Nut
- Base

Figure A

Vissim movement



Experiment Set up for actuation



Interferometer

Interferometer is a device that uses interference between two beams of collimated light to make measurements.

In principle, these measurements can be made to great precision, typically on the order of nanometer, since interferometric technique uses the interference of nanometer wavelengths.

Components for the interferometer

1. The laser and mount
2. Mirror mounts
3. Two lenses to expander
4. Mirror #2
5. Splitter
6. Mirror #3
7. Mirror (movable)
8. Observation Screen

Michelson Interferometer

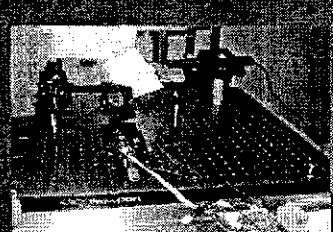
interferometer

Once the interferometer is constructed, align the beams of the two arms so that they overlap on the observation screen. They should look like this:

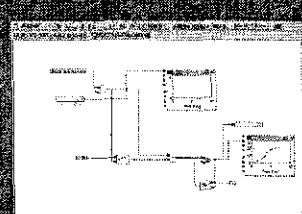
interferometer

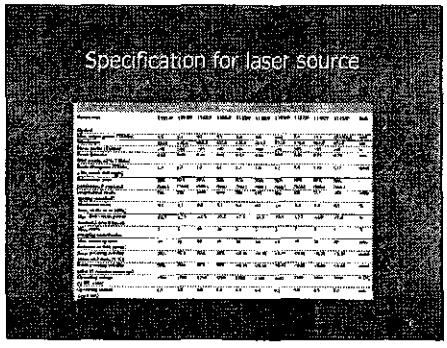
When the two beams are identical, the small diffraction patterns within the beams due to the collimating lens and the beam expander can be used to overlap the beams in order to achieve the desired

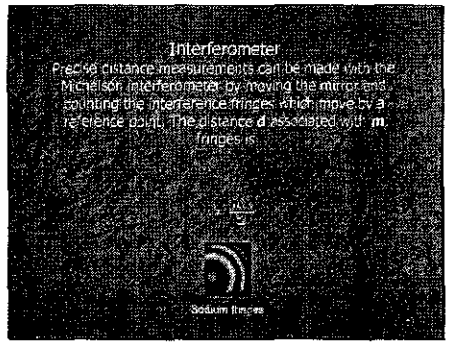
interferometer

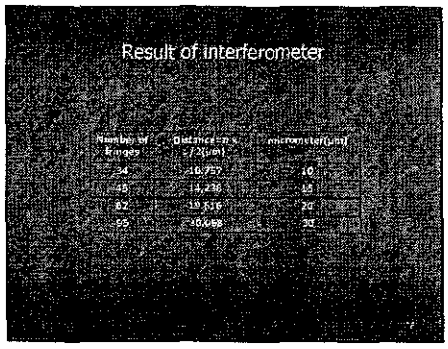


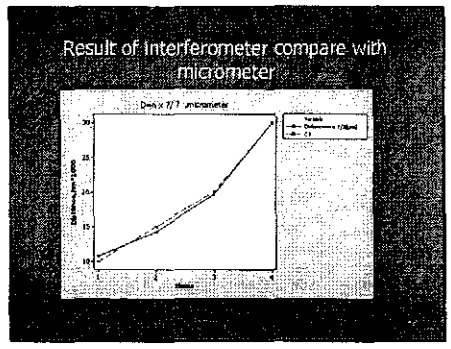
Design counter system for interferometer

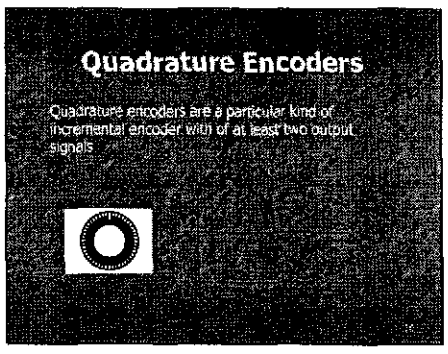


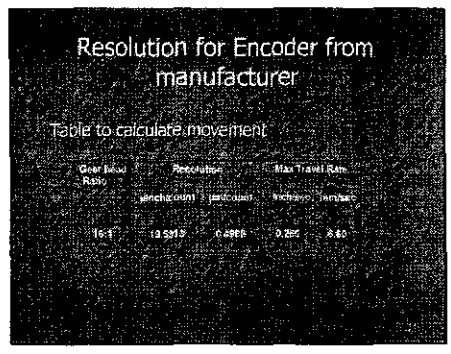

Specification for laser source

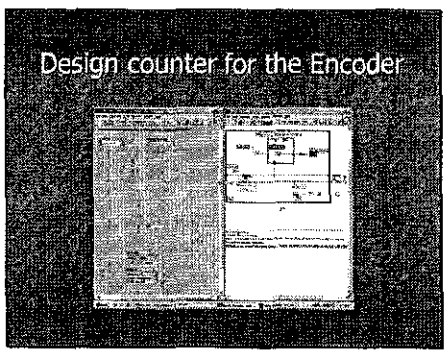

Interferometer
Precise distance measurements can be made with the Michelson interferometer by moving the mirror and counting the interference fringes which move by a reference point. The distance d associated with m fringes is
Sodium fringes

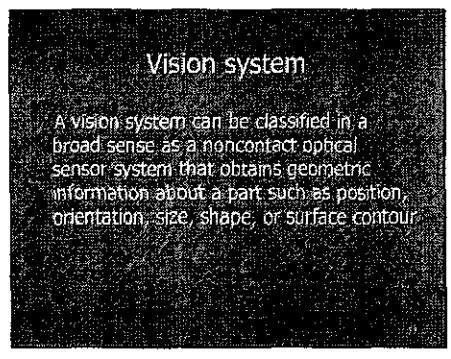

Result of interferometer
Number of fringes
Distance = n x 5 / 2(μm)
micrometer(μm)
34
10.757
10
48
15.236
15
62
19.616
20
65
20.668
30


Result of interferometer compare with micrometer


Quadrature Encoders
Quadrature encoders are a particular kind of incremental encoder with of at least two output signals


Resolution for Encoder from manufacturer
Table to calculate movement
Gear Head Ratio
Resolution
Max Travel Rate
μinch/count
μm/count
inch/sec
mm/sec
16:1
0.4986
0.285
8.60

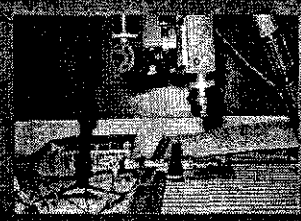

Design counter for the Encoder


Vision system
A vision system can be classified in a broad sense as a noncontact optical sensor system that obtains geometric information about a part such as position, orientation, size, shape, or surface contour

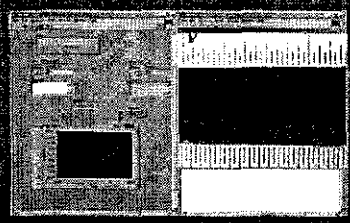
The machine vision process can be divided into four basic steps

- image formation
- image preprocessing
- image analysis
- image interpretation.

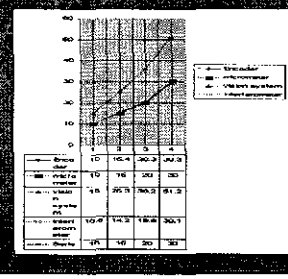
Vision System



Measurement set up stage movement with Labview-IMAQ system



Comparison of four methods



Conclusion

Developed visual simulation to actuate and measure at the same time.

Developed a precise control mechanism to the order 10 micron.

Developed three independent measurement methods.

Integrated the actuation and the measurement into one system.

Future Recommendations

The motion of the stage should be controlled and a controller should be used for this purpose.

Enhance the vision system.

Simulink should be used because it is more common and easy to understand than other software.

Vibration- elimination (use breadboard vibration isolation)

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By

Abdulrahman Almousa

Presented to the faculty of the College of Engineering, Technology &

Architecture

University of Hartford

As partial requirement for the Degree of Masters of Engineering

August 2005