Computer Controlled Automatic Calibration System for Dial Gauges

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Abstract: The calibration of dial gauges is a time consuming, cumbersome and monoton process. Due to monotonety the probality of human errors is large both in capturing the measuring data and in it's evaluation. In order to maintain competitivness automation became compulsory. The present paper describes the design and implementation of an automatic calibration system applying advanced computer technologies and a high precision positionings system based on novel piezo motors providing submicron accuracy.

Keywords: dial gauge calibration, piezo servo, pattern recognition, evaluation software, error computation

1 Introduction

Gauge management is an inherent part of current days quality management systems, meeting the requirements of the ISO standards. The calibration of gauges is a time consuming task, requiring considerable human skill and high precision. The time and the related costs are especially high in case of dial gauges where the accuracy and the standard deviation has to be determined at every 0,1th mm of the measuring range. Therefore it was decided to automate the process and develop a computer controlled system.

2 The Mechanical Construction

The mechanical construction [Fig. 1] consists of a natural stone column on which a cylindrical guideway is mounted. The slide has high precision linear ball bearings on both ends and can move up and down. It is driven by two piezo-motors [5] placed on both side of the slide. The measuring element, a Heidenhain linear scale [3], is mounted on the front face of the slide and is coaxial with the axis the dial gauge. The tip of the dial gauge rests on a hard metal inserts on the slide. The slide is made out of light metal (aluminum alloy) in order to minimize the weight and the ceramic driving plates are fixed by double sided adhesive paper strip and two small epoxy drops. The epoxy is needed to avoid creep. The sensor head of the measuring system is mounted in a bridle in front of the system. Hereby the electronic connection and the adjustment of the sensor head was made easy.

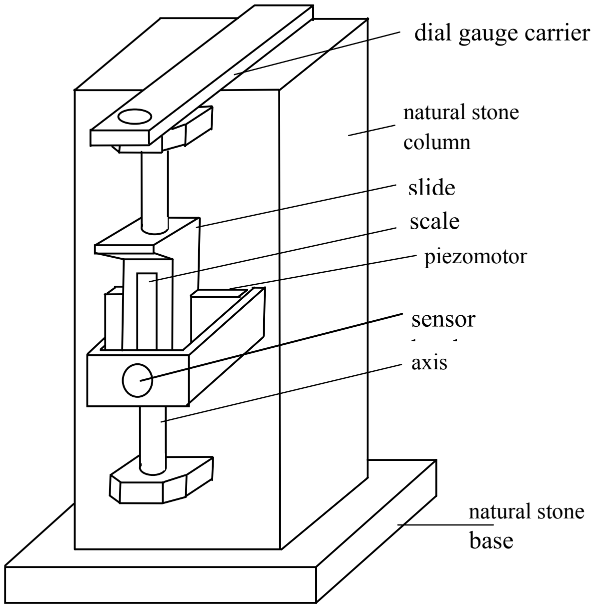

Figure 1
The mechanical construction (dismantled)

3 The Measuring System

The measuring system consists of a 70 mm long Heidenhain LP 481A linear scale on Zerodur glasceramics [3] with grating pitch of 4µm without a reference mark. A reference signal is generated by a high precision capacitive gauge sensing a predetermined position of the slide itself.

The Zerodure body ensures a thermal expansion of nearly null. The zero position for the measuring cycle can be set in software and therefore it can be fitted to the individual dial gauges. By electronically subdividing the signals a resolution of 0,005 µm can be reached, which is satisfactory for our purposes. The interface electronics responsible for the subdivision is implemented by a microcontroller and allows a 16m/min approach speed.

4 The Control Loop

The total control loop implemented is given in Fig. 2. The components applied are:

- Nanomotion piezomotor
- AB2 driver box
- Advantech D/A converter
- Position controller in software
- Digitizing and interpolating electronics
- LP 481A optical scale

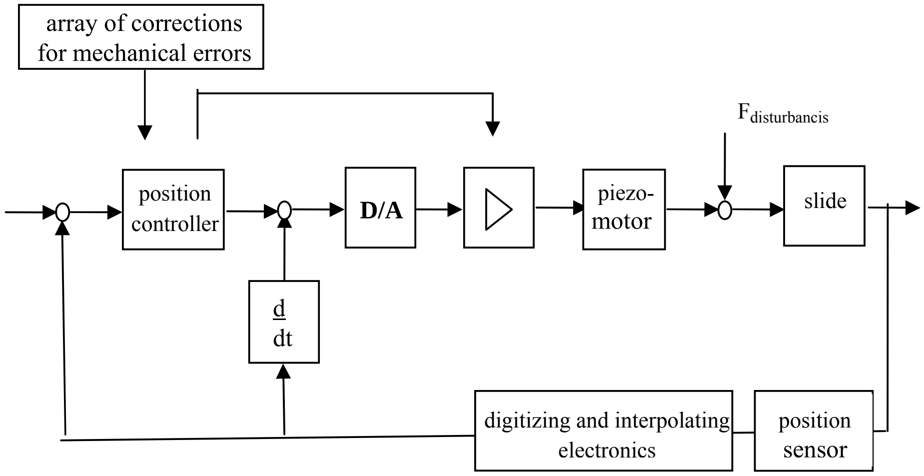

Figure 2
The control loop

In piezoceramics in the one dimensional case the mechanical strain and stress relates to the electrical and displacement field according to the following equations:

$$S_x = s_{11}T_x + d_{31}E_x$$

$$D_z = d_{31}T_x + \varepsilon_{33}E_x$$

Where:

S_x = strain in the x-direction

T_x = stress in the x-direction

E_z = electric field in the z direction

S_{11} = elastic constant

d_{31} = piezoelectric constant

ε_{33} = dielectric constant

D_z = electric displacement field

A simplified one dimensional model is expressed by the following equation:

$$\rho.\frac{\partial^2 U}{\partial t^2} = \frac{1}{s^E{}_{11}}.\frac{\partial^2 U_x}{\partial x^2}$$

Where:

U_x = displacement in the x-direction

ρ = material density

This is a wave equation describing a longitudinal extension standing wave with resonant frequency:

$$f = \frac{1}{2L}.\sqrt{\frac{E}{\rho}}$$

Where:

L = plate length

E = Young modulus of the material

Under special excitation, drive and ceramic geometry, it is possible to excite a traverse bending vibration mode at close frequency to the longitudinal mode. A special implementation of this concept is the dual mode standing wave motor. The exitation of the two modes creates a small elliptical trajectory of the ceramic edge. The periodic nature of the driving force at frequencies much higher than the mechanical resonance of the slide allows continuous smooth motion for unlimited travel, while maintaining high resolution and positioning accuracy [2] [4].

The intrinsic friction of the piezomotor offres an interesting solution for vertical applications, where the gravity functions as a permanent load. This application is asymmetric, where much larger forces are required to move the slide upwards then downwards. In vertical operations the subsequent points should be considered:

- Intrinsic friction
- Shearing
- Vibration

The static holding force is 8N, which may be slightly reduced with the time due to a number of enviromental influences. The effect of shearing on the positioning accuracy can be neglected if proper gluing (epoxi) is used. The effect of vibration should be considered in details. Assuming a vibration spectra $A_z(\omega)$ in the gravitational direction, the vibration force F_v is given by:

$$F_v = m.\int\omega^2 A_z(\omega)d\omega$$

Where ω is the radial frequency.

As the the vibration is symmetrical but the gravity is not, the system will be stable when the following inequality holds:

$$F_v + mg < F_h$$

Based on the vibration levels given in reference books lead to that a piezomotor can maintain vertical position for a mass which is about ⅓ of the nominal holding force. In our case the spring force of the dial gauge acts as an additional component:

$$F_v + mg + F_{gauge} < F_h$$

The AB2 driver box is operated in one of the following two modes: Velocity (AC) mode, in which the motor is drive continuously and in DC mode, in which the motor works as a piezoactuator [7]. In velocity mode by applying the analog command voltage (±10V) the motor is driven continuously. The velocity is proportional with the command voltage. In DC mode the driver enables the motor to converge to 10 nm and less. The travel available in this mode is 300 nm from the point reached by the motor while operating in the regular velocity mode. The position is a linear function of the command voltage, with certain hysteresis and some asymmetry (Fig. 3).

The controller, implemented in software is working dual mode. The driver box is switched into velocity mode and a point 200 nm from the target position is approached following a trapezional velocity pattern. The stationary velocity, the accelaration and the deceleration distances can be introduced as control system parameters. Than the last 200 nm is covered in DC mode.

The parameters of the controller used in velocity mode were determined by mean of simulator taking into account the mechanical properties of the system.

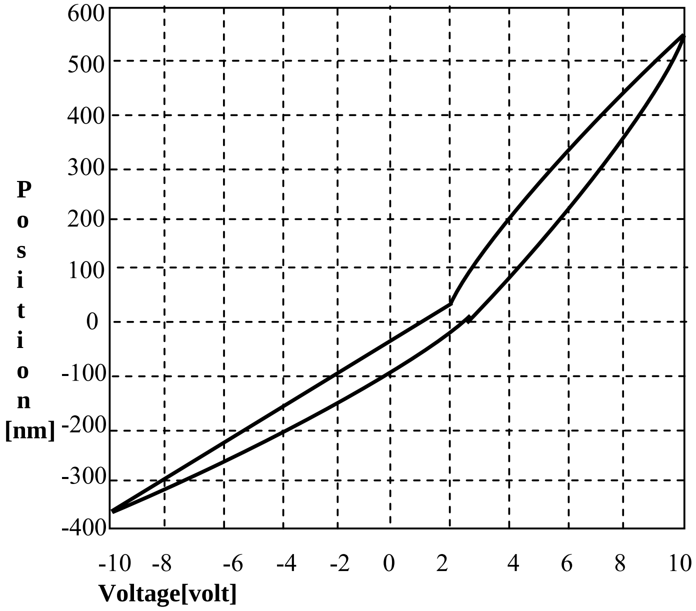

Figure 3

The position as a function of the command voltage in DC mode

5 Dial Gauge Calibration Procedure

The gauge calibration follows two differen motion patterns:

- Unidirectional approach of the measurement point
- Bidirectional approach of the measurement point

In the unidirectional mode the targe position is approached from one direction and the deviation from the nominal value is determined. This procedure is repeated from both direction several times [8]. From the captured values maximum deviation, repeatibility and backslash are derived by the software and printed in the calibration document.

6 The Data Collection Modul

The data collection can be done either manually or automatically, either through an available electronic connection or using a pattern recognition system.

In case of the manual data entry mode the motion of the slide stops at every measuring point and after keying in the data, the process is continued on human intervention.

In automatic mode when the gauge has a digital output its value is entered on the fly at each predefined point. When no electronic connection is available a pattern recognition module acts as a „human eye". The detection of the pointer's position on a conventional gauge is relatively simple. When the output is in numeric form, character recognition techniques, known from the literature are used.

The only problem is caused by the low contrast of the LCD displays. This was solved by contrast enhancing techniques implemented in software and by appropriate shielding from ambient light.

7 The Software Implementation

The system is menu driven [7] and the structure of the main menu is given below:

File	**Gauge data**	**Measurement**	**Processing**	**Help**	**Info**
Save data	Identification	Standard	Show data		
Load data	Interface	Set zero point	Create certificate		
Printer setup	Measuring range	Start			
Print	Resolution	Stop			
Exit		Reset			

The names of the entry points under File speaks for themselfs. Under Gauge data the operator can identify the gauge to be calibrated by given it's factory code, manufaturer's and customer's name. Using the menu points Interface, Measuring range and Resolution one can select the appropriate values describing the properties of the gauge. Under Measurement the user selects the calibration standard, defines the Zero position of the calibration cycle, Starts and Stops the calibration and can Reset the system. Data collected during the last calibration cycle can be viewed under the menu point Show data and a Calibration cerificate can be produced by selecting Create certificate.

8 Calibration of the System

The dial gauge calibration system in turn is calibrated in situ using a plane mirror interferometer. The single beam interferometer enables a displacement measurement of 100 mm along one axis with a resolution of 1 nm [6] (under ideal environmental conditions). By this procedure the length measurement becomes directly traceble to the national length standard.

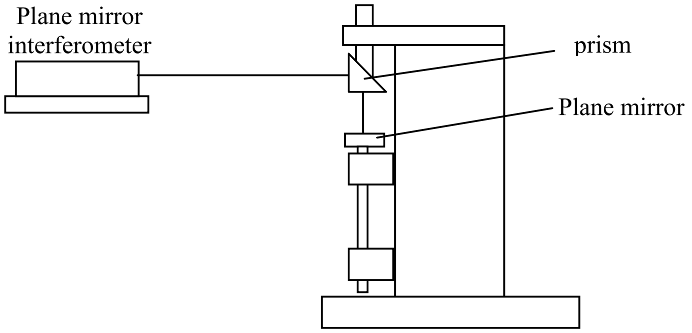

Figure 4

Setup for calibration

Because of the rotational errors of the slide the calibration has to be performed in the extension of the dial gauge axis in order to eliminate the Abbe error. The system is calibrated by mounting a plane mirror on the slide. A 45º prism, mounted in the dial gauge holder, directs the laser beam towards this mirror. Deviations measured are used by the system software for error corrections. The nominal values and the correcponding deviations are entered in an Excel table, which forms an input to the control software.

Conclusions

The increased demand for calibration initiated the automation of the processes and the application of computer. In the present paper the design and construction of a computer based system for calibration of dial gauges was described involving the application novel piezo-motor based drive. The capturing of the values displayed by the gauge is implemented using visual pattern recognition technique. The system meets all of the requirements posed by the calibration of current dial gauges.

Acknowledgment

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Prüfanweisungen zur Prüfmittelüberwachung

Prüfanweisungen für Messuhren Blatt 11