The Japan Society for Precision Engineering

Introduction of JSPE Best Paper Awards 2011

1. An evaluation of a modulated laser encoder

Susumu MAKINOUCHI, Akihiro WATANABE, Masahisa TAKASAKI, Tetsuo OHARA, JinHock ONG, Shinji WAKUI

Precision Engineering, Vol.35, No.2, pp.302-308

This paper introduces a new method of interpolation for sub-nanometer-resolution linear encoders. This method, called SPPE (scanning position probe encoder), uses high-order harmonics information obtained by a sinusoidal scanning pickup located on a periodic grating surface. The proposed encoder uses a current-modulated laser diode with diffractive grating optics. Since the electrical current changes the laser-diode wavelength, the interference light intensity is modulated as a sinusoidal scanning pickup on the scale grating. Phase-detection circuits can decode the position information in the pickup signal by using phase-locked loop techniques. The decoder achieves an interpolation rate of over 1/40,000 with interpolation errors of less than ±1 nm. A new interpolation-error measuring system was developed for the encoder. Finally, the evaluation results reveal that the presented encoder shows both high resolution and strong robustness.

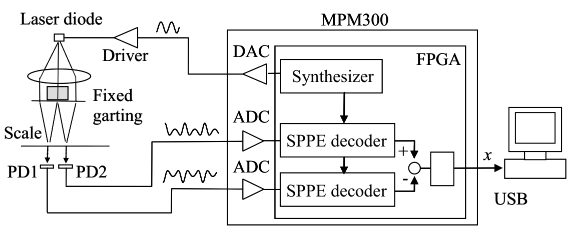

Fig. 1 System configuration

2. Experimental analysis and simulation of nonlinear microscopic behavior of ball screw mechanism for ultra-precision positioning

Shigeo FUKADA, Bin FANG and Akira SHIGENO

Precision Engineering, Vol.35, No.4, pp.650–668

In this paper, microscopic behavior of a preloaded ball screw supported by ball bearings is discussed based on experimental results and simulation. An experimental apparatus is specially designed and constructed to independently measure the torques of ball screw, ball bearings supporting the screw shaft and driving motor. It is clarified experimentally that the nonlinear microscopic behavior of a positioning mechanism driven by a ball screw is affected not only by the ball screw itself, but also considerably by the ball bearings supporting the screw shaft. Moreover, the ball screw and the ball bearing have their own properties within the deferent limit of the elastic region, and their contribution ratios to the total apparent property of the mechanism change in a complicated manner according to the driving range. To demonstrate the elastic property, a simulation model for the nonlinear microscopic behavior is proposed using a viscous-elastic-plastic model, and procedure of identifying the model parameters is shown. The simulation results on micro-step positioning agree with the experimental results, and the availability of the simulation model proposed is verified. Moreover, the simulation model obtained is compared with previous analytical models of nonlinearity based on elliptic contact under torsion, and the advantage of the proposed model is demonstrated.

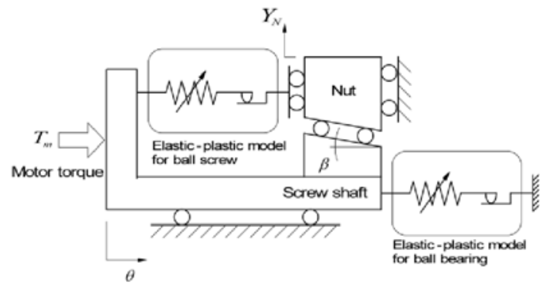

Fig. 2 Schematic mechanical model

3. Ultra-flat and ultra-smooth Cu surfaces produced by abrasive - free chemical – mechanical planarization /polishing using vacuum ultraviolet light

Okiharu KIRINO and Toshiyuki ENOMOTO

Precision Engineering, Vol.35, No.4, pp.669–676

The new bonding technologies utilizing intermolecular bonding forces have been developed and attracting attention recently. Cu is known to be a suitable material for the bonding substrate due to its excellent physical properties. And an ultra flatness and an ultra smoothness over a relatively large area are strongly required for the Cu substrate surface.

Chemical–mechanical planarization/polishing (CMP) with abrasives is widely adopted for planarizing and smoothing Cu surfaces. But this method has serious problems resulting from abrasives in CMP slurry. Hence, we have developed an abrasive-free polishing (AFP) method that utilizes vacuum ultraviolet (VUV) light in the previous study and an ultra-smooth Cu surface was achieved. However, the problems about a low removal rate and a small finished area remained.

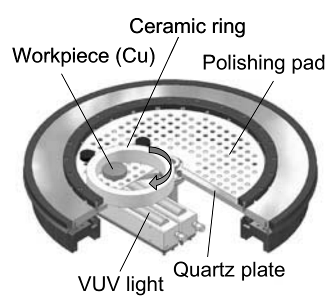

Fig. 3 Schematic of the experimental setup

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To overcome the problem, a new manufacturing process, namely, the process of combining CMP with abrasives and the AFP method was newly developed. First, an ultra-flat surface is achieved using CMP with abrasives. Next, the AFP method is applied for the final polishing step in order to achieve an ultra-smooth surface. As a result, utilizing VUV in situ irradiation and electrolyzed reduced water in the AFP process, the ultra-flat and the ultra-smooth surface produced has a roughness average of <1 nm with a peak value of <10 nm over a relatively large area of 700 μm 500 μm.

Introduction of JSPE Numata Memorial Paper Awards 2011

1. Studies on Continuous Chip Disposal and Chip-Pulling Cutting − Challenge to Chip Control by Changing Shape of Rake Face—

Eiji SHAMOTO, Koichiro YASUDA, Tomoya AOKI, Norikazu SUZUKI and Tomio KOIDE

J. JSPE, Vol.77, No.5, pp.520-524

Chips are generally assisted to curl and then broken into pieces by chip breakers. This conventional concept sometimes fails especially when the workpiece is highly ductile or the chip is thin and flexible. Contrary to this conventional method, a new concept of continuous chip disposal is proposed in the present research, where the chip is controlled not to curl and guided to a chip disposer. The key to this concept is chip control to suppress the curl and to guide the chip to desired direction. The continuous chip disposal can also be combined easily with chip-pulling cutting. It is known that the cutting process is improved drastically by pulling the chip, i.e. cutting force, energy and heat are all reduced remarkably. Therefore, new chip control methods are developed as basic technologies to realize the continuous disposal and the chip-pulling. A chip control method is proposed to suppress the up-curl by convex tool geometry, i.e. curved rake face with inverse curvature to the up-curl. Tools with the inversely curved rake faces are developed, and it is confirmed that the up-curl can be suppressed at a certain inverse curvature. Another chip control method is proposed to suppress the side-curl and to control the chip flow direction at the same time by forming guide grooves on the rake face. The tools with the guide grooves and a guide tunnel are developed, and it is demonstrated that the chip can be guided successfully along the guide grooves into the guide tunnel over a fairly wide range of conditions.

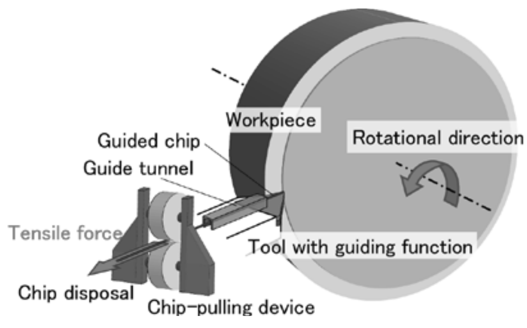

Fig. 4 Concept of continuous chip disposal to improve machinability

2. Multi-probe scanning system comprising three laser interferometers and one autocollimator for measuring flat bar mirror profile with nanometer accuracy

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Precision Engineering, Vol.35, No.4, pp.686–692

This paper describes a multi-probe scanning system comprising three laser interferometers and one autocollimator to measure a flat bar mirror profile with nanometer accuracy. The laser interferometers probe the surface of the flat bar mirror that is fixed on top of a scanning stage, while the autocollimator simultaneously measures the yaw error of the scanning stage. The flat bar mirror profile and horizontal straightness motion error are reconstructed by an application of simultaneous linear equations and least-squares method. Measurement uncertainties of the flat bar mirror profile were numerically evaluated for different installation distances between the laser interferometers. The average measurement uncertainty was found to be only 10 nm with installation distances of 10 and 21 mm between the first and second, and first and third interferometers, respectively. To validate the simulation results, a prototype system was built using an X–Y linear stage driven by a stepper motor with steps of 1 mm along the X direction. Experiments were conducted with fixed interferometers distances of 10 and 21 mm, as in the simulation, on a flat bar mirror with a profile known to an accuracy of λ = 632.8 nm. The average value of two standard deviations (95%) of the profile calculated over ten experiments was approximately 10 nm. Other results from the experiment showed that the system can also measure the yaw and horizontal straightness motion errors successfully at a high horizontal resolution. Comparing with the results measured by ZYGO's interferometer, our measured data excluding some edge points showed agreement to within approximately 10 nm. Therefore, we concluded that our measurement profile has an accuracy in the nanometer range.

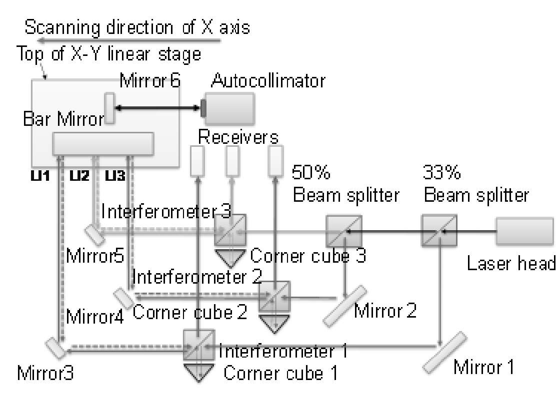

Fig. 5 Block diagram of experimental setup