A New Photo-Electronic Length Measuring Instrument with 0.1 nm Resolution and 110 mm Range

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Instruction

Authors and their colleagues have been working on the field of manufacturing metrological gratings for more than forty years. We have developed kinds of dividing machines based on photo-electronic control principle to produce metrological gratings [1, 2, 3, 4, 5]. These metrological grating can have up to 1,000~2,000 lines per millimeter. The position accuracy of such grating lines is about ± (20~100) nm [6]. We also developed several series of photo-electronic length gauges with resolution of up to one nanometer and measuring range of 10~100mm [7, 8]. For the calibration of these series of length gauges, we built the instrument described by this paper.

Instrument

The exterior view of the instrument is shown in Fig.1 and the working principle is illustrated in Figure 2. There is a very big and steady iron base filled with special oil. On top of it, there fixed a special ultra-precision guide mechanism developed by us, what we call "optical guide". The straightness of the slideway is less than one sixth of wavelength within 310mm, and the uncertainty of this motion guide mechanism is 30nm within 110mm stroke. Moving resistance is about 0.02N when slideway is moved forward. Torque motor driven by control circuit rotates the leadscrew to push the working table forward continuously by passing through a special coupling mechanism. The nano-grating is supported upon the working table according to the principle of "Bessel point", and the reading system fixed on the base acquires four signals with phase-difference 90° to one another. The signals are passed through differential amplifier, flip-flop, direction distinguishing circuit, counter and are sent to computer to count the total number of moiré fringes. The signals are also passed through A/D converters and are sent to computer to get interpolation number of moiré fringe [9]. In order to get ultra-high accuracy, the photo-electronic signal is not formed by a few lines of nano-grating but by four thousand of lines of grating. Thus the random error and local error of grating are greatly reduced. However, careful mechanical construction and signal processing are important as well.

Environment

The temperature around the instrument must be highly controlled. We built the laboratory in three "layers", one enveloped inside another. The temperature is controlled better and better from outer room to inner ones. The smallest room is actually a glass room. It consists of two layers of glass plates. The instrument described by the paper is put in it. The temperature around the instrument is controlled to 20±0.005°C. All operations must be done outside the glass room. The instrument must be free from various vibrations. So the instrument and its base weigh about twelve tons altogether and are supported on a special vibration-free system developed by us.

Experiments

Because there is no higher accurate length standard available in China, we use a laser interferometer HP 5529A to make a relative comparison with our instrument temporarily. Although our instrument can work while continuously moving, the resolution of 5529A is 10nm when it moves continuously. Thus we have to make stationary comparison since the resolution of 5529A is 1nm only when it is stationary. We chose 10mm reading intervals to avoid spending too much time for each measurement. Fig. 3 shows the connection of our instrument and HP 5529A. Our instrument is not sensitive to air refraction index, air pressure, humidity and flow of air, and so that 0.1 nanometer steady reading can be got. But laser interferometers are different. Especially, when we tried to get steady reading data of magnitude order of nanometer, the laser interferometer is extremely sensitive to the flow of air. For this purpose, when the adjustment and alignment of these two kinds of instrument shown in Fig. 3 had been done, we still have to wait at least 24 hours for steady mechanism and steady air.

Fig. 4 shows the difference of reading data between our instrument and HP5529A. Fine solid line shows the first set of comparison, and fine dotted line shows the second set of comparison. Coarse solid line shows the average value of these two sets. The above-mentioned repeatability of measurement is obviously better when we use our nano-grating sensor instead of laser interferometer, and in this case, the repeatability of measurement, is $\sigma \leq 0.4$nm. Because the random error is comparatively small, if there is an enough accurate length standard, the systematic error of the instrument is easy to be corrected by computer technology.

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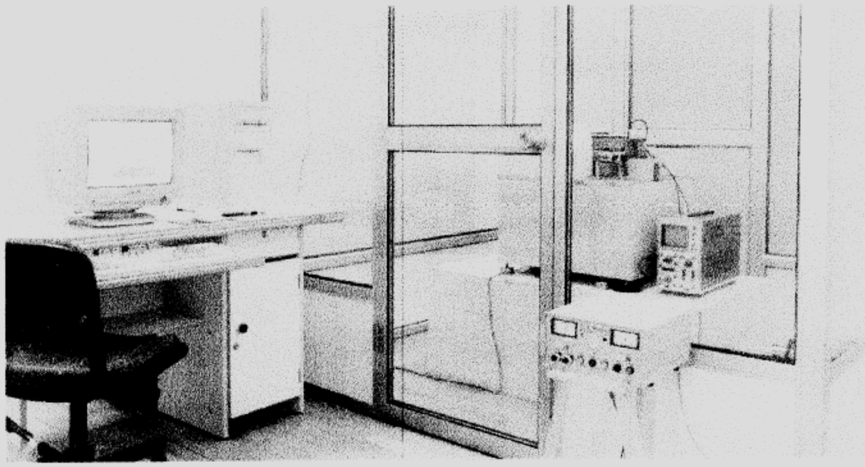

Figure 1. Exterior View

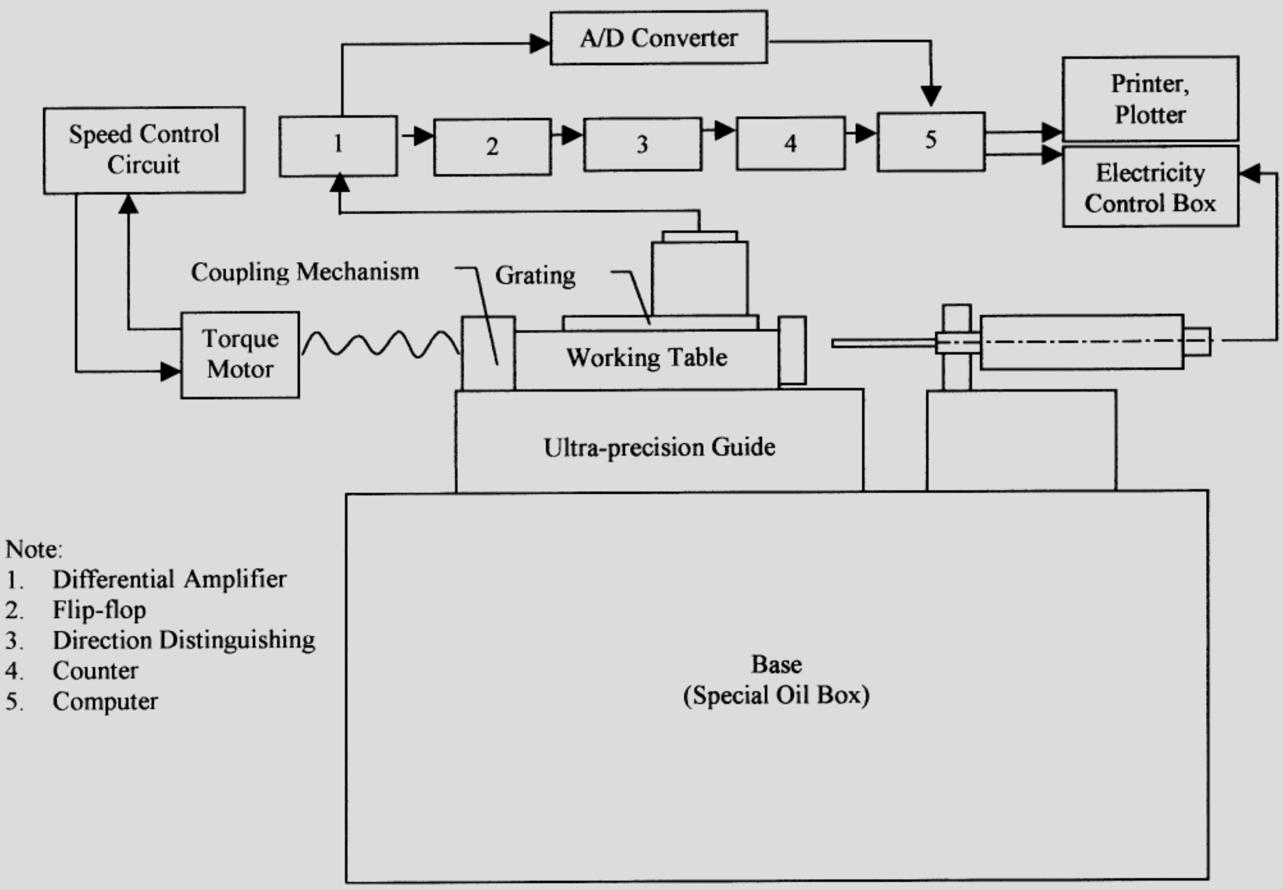

Figure 2. Working Principle Draft

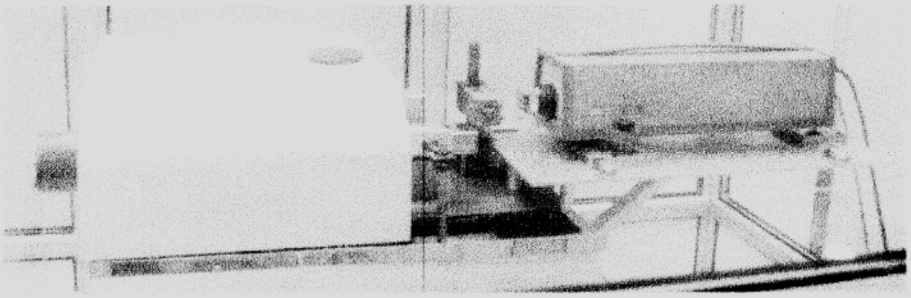

Figure 3. Comparison with HP5529A

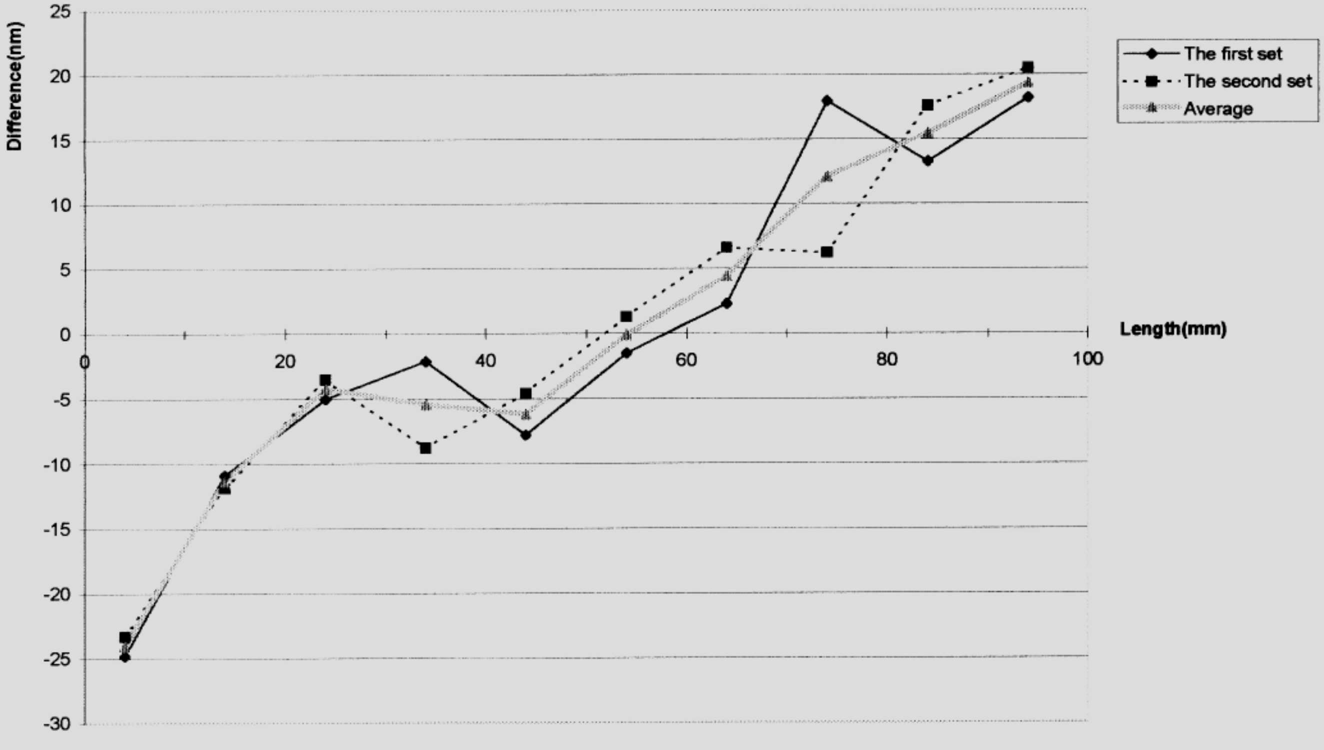

Figure 4. Comparison Result