Forming high-precision angular measuring structures by the laser pattern generators with circular scanning

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Abstract. *Metrological performances of raster scanning technology are analyzed using high-precision angular scales formed by laser pattern generator CLWS-300/C. It is shown that the raster scanning technology allows forming the angular measuring structures with error about ±1″. Improvement of some auxiliary procedures will make it possible to increase the accuracy of synthesis of structures and decrease the error of topology up to 0,5″– 0,3″.*

Keywords: angular scale, raster scanning technology, accumulated errors

1. Introduction

At the present time, for production high-precision angular measuring structures a technology based on the projection photolithography is predominantly used. It was created by German firm Heidenhain [1] and universally known as the Diadur technology. The important peculiarity of it is an effect of space averaging of errors in the initial fragment, which makes it possible to increase the accuracy of structures to be synthesized.

A technology of raster scanning developed at the Siberian Branch of USSR Academy of Sciences has a similar effect of space-time averaging of external actions in synthesis of angular measuring structures [2, 3].

These technologies of synthesis of angular measuring structures differ fundamentally from each other. Therefore, it is of interest to compare their major characteristic parameters.

2. An experimental comparison of scale-plate errors formed by two technologies

The first experimental comparison of errors of scale-plates formed by two alternative technologies was made by specialists of Ural Optical Mechanical Plant [4] using an AS-700 unit manufactured at this plant. Figure 1 shows the results of measurement of the accumulated error for two rasters with a number of graduations N=36 000. One raster was manufactured for a ROD – 800 encoder by the Heidenhain Company (Germany), and the other one was made on a laser pattern generator CLWS-300/C by TDI SIE. The results of measurements have shown that for the raster manufactured using the Diadur technology the accumulated error is by a factor of 1,5 greater than that for the raster produced on the basis of the alternative technology. The former error constitutes ± 2,2″ (Fig. 1a). Besides, an error type that is specific for this technology has been recorded. Specifically, there is a discontinuity at the interface between the scale beginning and end that constitutes 2,2″.

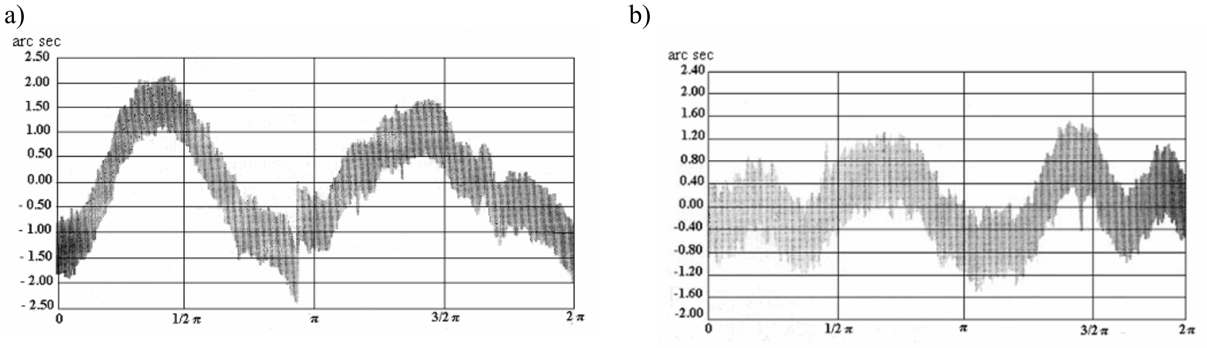


Fig. 1. Errors of rasters manufactured using the alternative technologies.

For the raster made using the raster scanning technology, the maximum value of accumulated error does not exceed ± 1,5″, and no discontinuities are observed. The result obtained shows that the technology of raster scanning in problems of synthesis of high-precision angular measuring structures holds much promise.

3. Principle of formation of structure by the raster scanning

A simplified schematic diagram of formation of angular measuring structures using the raster scanning method is presented in Fig. 2. *A scale-plate blank* covered by a photosensitive layer is located on the rotary table of a *spindle*, which is set in the mode of continuous rotation. With the help of a *carriage* of linear displacements, laser radiation is fixed at a given distance from the spindle rotation center. With the help of the *microobjective* of a writing head, the radiation is focused on the surface of the photosensitive layer. The topology of the element is formed in this layer by using two motions (a rapid rotation of the blank and a slow displacement of the laser beam in the radial direction) and by controlling the power of the laser radiation put to the photosensitive laser with the help of an acousto-optical *modulator*.

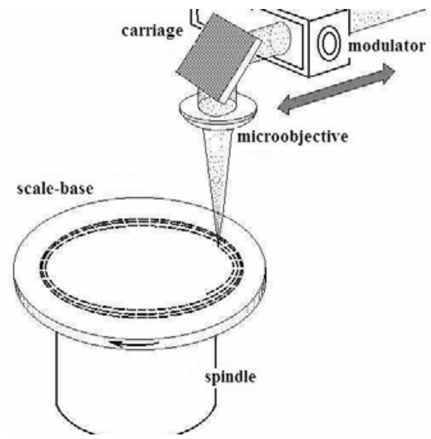


Fig. 2. Schematic diagram of formation of structures by the raster scanning method.

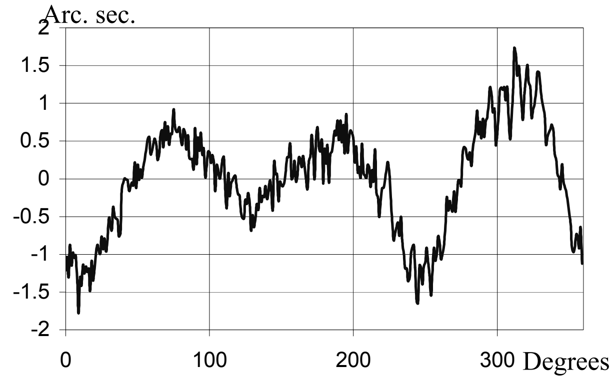
4. Problems of precision in the recording of structures

Analysis [2, 3] has shown that for the external perturbations which effective spectrum width exceeds the rotation speed of the scale-plate blank, the error variance in the applying of graduations decreases by a factor of M in comparison with the variance of active perturbations. Here M is the number of scale-plate revolutions during its formation. The contribution of the perturbing factors that are synchronous with the rotation speed of the scale-plate is more significant. The action of these factors is possible both at the stage of formation of the scale-plate itself and at the stage of recording of the data about the quality of the scale. In the first case, the operating factors distort the structure itself. In the second case, they distort the results of measurements. Therefore, while estimating the potentialities of the new technology it is important to distinguish between the contribution of the perturbing factors that distort the results of measurements and that of the factors that distort the topology of elements.

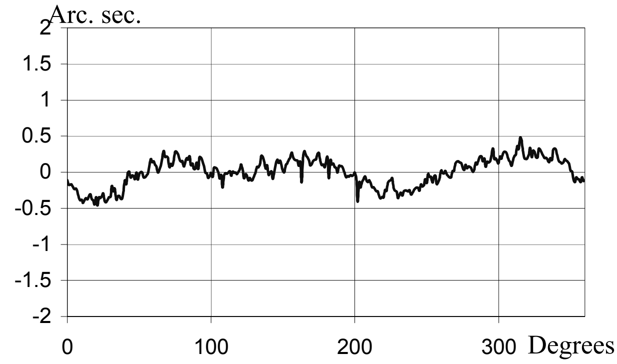
5. Results of measuring the contribution of technological equipment to the structure error

To define the real contribution of technical equipment to the error structure formation the structures of the same type were recorded on 25 specimens (scales with a number of graduations of 360; the graduation width was 2 μm; the length was 2,0 mm; the graduation that coincided with the CLWS-300 origin was broadened by 5″). A typical result of an individual measurement of the accumulated error of a scale synthesized at the CLWS – 300 unit and obtained by the standard method at the AS-700 unit is shown in Fig. 3a. This plot represents the contributions of at least three sources of error: the reference scale, the CLWS-300/C unit and the bases on which the inspected scales were recorded. It has been found that for individual measurements the maximal values of the scale error did not exceed ± 1,6″ (Fig. 3a).

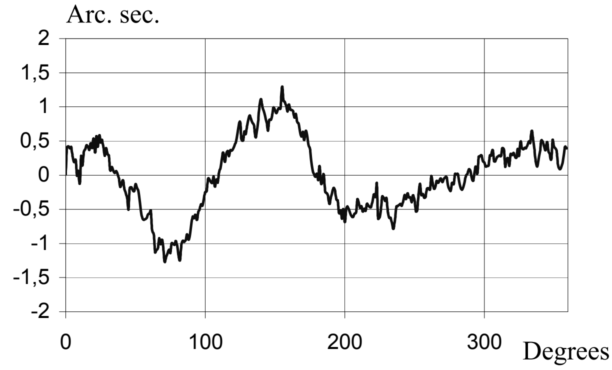
a) Result of measuring the scale error by the standard method (individual measurement)



b) Result of separating the error component of the reference scale



c) Final result: the technological process error



d) Magnitude of the distortions contributed by the base to the final result

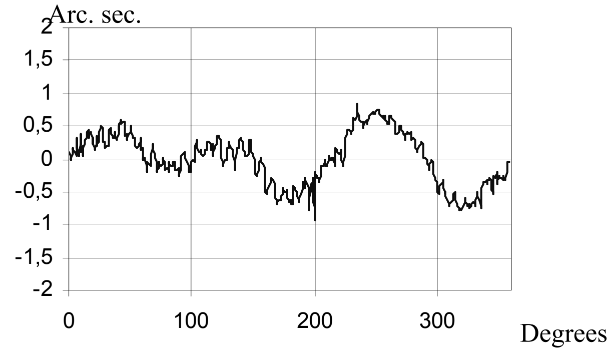


Fig. 3. Results of measurements and separation of scale errors.

In accordance with the measurement method used, data files for 18 relative positions spaced uniformly around a circle with a step of 20° were recorded for each scale. A total file, $\overline{F}_r$, was formed from these files. This file characterized the accumulated error of the AS-700 reference limb (Fig. 3b). It has been found that the maximum error of the reference scale reaches ± 0,4″.

To determine the angular error of structures synthesized on the CLWS – 300/C unit, a special smoothing procedure was applied to all initial files to «reference» the data to the CLWS – 300/C rotation start. A total file $\overline{F}_{mes}$ was formed for each scale. It was obtained by averaging of the files processed for each of the 18 locations. Then a new file $\hat{F}_{mes}$ was formed from the total files $\overline{F}_{mes}$ obtained for each manufactured scale. It was produced by averaging of the files $\overline{F}_{mes}$ for all measured scales. It characterizes with the highest reliability the sought-for scale error produced by the CLWS – 300/C unit using the raster scanning method in the recording of structures (Fig. 3c). It has been shown that the maximum error of the raster scanning method does not exceed ± 1,1″, and its root-mean-square value is 0,5″. It has also been found that the distortions caused by the base reach ± 0,7″ (Fig. 3d). Figure 4a shows an intermediate result produced by this method. The result was obtained after the processing of 180 files produced by 10 one-type specimens. Figure 4b shows the Fourier spectrum harmonics (FSH) of this error curve.

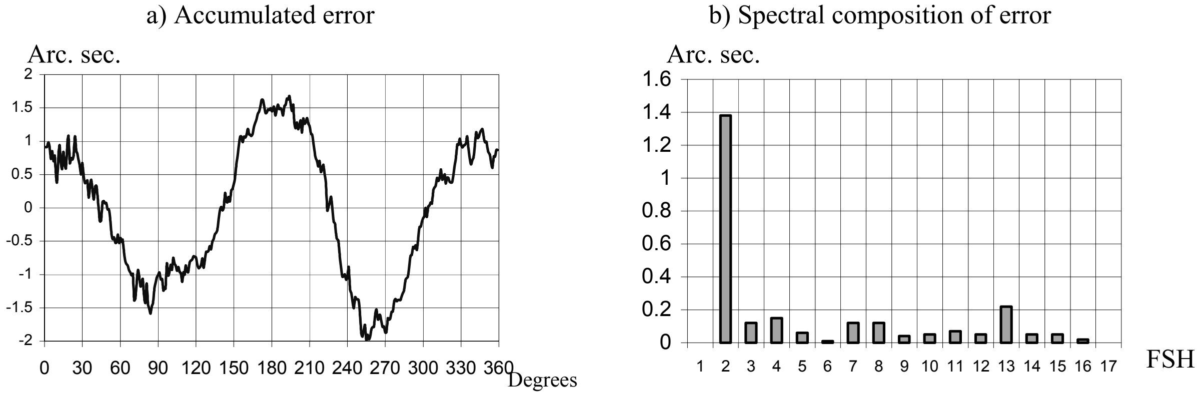


Fig. 4. Result of measurement of scale error introduced by CLWS-300/C unit.

The predominant contribution of the second harmonic indicated that the spindle rotary table is not balanced. Once the rotor had been balanced (as far as this was possible) the error of synthesis decreased by a factor of 1,5 and constituted ± 1,1″ (a plot of the error is shown in Fig. 3c).

6. Conclusion

The technology of synthesis of angular measuring structures by laser pattern generators with circular scanning provides the formation of scale-plates, limbs, and rasters with a number of marks of the order of 36 000 and more, with an scale error that does not exceed ± 1,0″. Improvement of some auxiliary procedures (the balancing or centering of blanks) will make it possible to increase the accuracy of synthesis of structures and decrease the error of topology up to 0,5″ – 0,3″.

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