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DETERMINING ALIGNMENT IN MEASUREMENT OF A LARGE-DIAMETER THREAD BY MEANS OF DEVICES FOR PROFILE MEASUREMENT

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An analytic estimation of the inaccuracy of the alignment of a thread gauge on a device that must be taken into account in the measurement of the accumulated error of the thread pitch is given. For an M170×6 thread, the measurement error of the accumulated pitch reaches 0.008 mm on a length of 200 mm.

Key words: *thread, pitch, alignment.*

The use of two-coordinate measuring devices [1], for example, DIP-1 or DIP-6U, is a standard method of measuring the pitch of a thread. However, in measuring large-size threads with increased thread length and with M170 diameter and greater, there arises a number of technical difficulties that hinder the application of standard measurement techniques. The several difficulties that are the most important should be especially noted:

- a thread possessing increasing thread length is not accommodated in the range of measurement of DIP-type devices (200 mm);
- the weight of go gauges with M170 thread and greater reaches 20 kg. This increases the maximally attainable weight of the article being measured on DIP-type devices (to 15 kg at the centers);
- because of structural features of the binocular extension of DIP-type devices, it is not possible to place large gauges on such devices.

These technical difficulties force us to search for other methods of measuring such threads under the conditions of factory laboratories. In particular, different types of devices specialized only for the measurement of thread (for example, MSXL 300 from the firm of IAC) as well as coordinate-measuring tools may be used to measure a profile [2]. In certain cases even "improvised" tools are used to measure form in the course of operations [3] (the article says nothing, however, about the accuracy of measurements).

Below, we will consider one aspect discussed in [4] of the difficulty involved in the measurement of the pitch of large threads by means of devices used to measure profile. This aspect must be considered as an additional source of error in the development of techniques for performing measurements.

The Crux of the Problem. The problem referred to in the title arises in the measurement of the pitch of a thread by means of large-diameter thread gauges. The measurement of the pitch of a thread with a symmetric profile may be carried out by means of a coordinate device for profile measurement through the production of a profile diagram. This is followed by mathematical inscription of spheres corresponding in terms of diameter to values taken from the recommendations of [1] into the turns of the loops that have been scanned in the profile diagram. In order to measure the turns of a thread in axial profile, the object that is to be measured must be placed with the thread on the working plate of the device in such a way that the thread axis lies in the same plane as the axis along which the device's measurement needle travels. To meet this requirement, the following alignment procedure is usually performed on the particular object.

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A special stage with micro-feed units that realize transverse displacement and rotation about its center is mounted on the device's working granite plate. A prism in which the thread gauge to be measured is mounted is placed on the stage. The gauge is fixed in position by its own weight and no additional anchoring is needed.

Since the surface of the crests of the turns of a thread in a thread gauge is cylindrical in shape, to turn the gauge in the plane required for carrying out the measurements. the axis of this cylinder should lie in the plane in which the device's measuring needle travels. The profilometer itself or an indicator may be used to solve this problem. The measuring needle must be brought into contact with the cylindrical surface and then with the two transverse sections of the gauge (the two profiles must be the greatest distance apart along the axis of the gauge) and through the use of the microfeed unit of the stage the extremal points are then found, i.e., points at which the profilometer exhibits maximal (for an outer thread) or minimal (for an inner thread) value. Next, the axis of the gauge will lie in the required plane. Let us estimate how accurate, in principle, is such an alignment procedure.

Analytic Estimate of Alignment Accuracy. Let us construct dependences that will make it possible to arrive at an analytic estimate of the dependence of the accuracy of the alignment described above on the sensitivity of the device. In the case of alignment, the value of the device's vertical sensitivity D is related to the dimension of the dead zone by the Pythagorean theorem:

$$(D/2)^2 = \Delta^2 + (D/2 - \delta)^2;$$

$$\Delta = \sqrt{(D/2)^2 - (D/2 - \delta)^2},$$

where D is the nominal thread diameter, mm; Δ, dead zone, mm; and δ, sensitivity of device along the Z-axis, mm.

Since the dead zone may be situated on either side of the profile because of the symmetry of the section, the alignment accuracy

$$U = 2\Delta = 2\sqrt{(D/2)^2 - (D/2 - \delta)^2} = 2\sqrt{D\delta - \delta^2}.$$

Since the vertical sensitivity of the device δ is very low, the quantity δ^2 in the radicand may be ignored. The expression then assumes the form

$$U = 2\sqrt{D\delta}.$$

Let us perform standard calculations for the threads M50, M100, and M170, setting the sensitivity of the device $\delta = 0.001$ mm:

$$U_{\mathrm{M50}} = 2\sqrt{50 \cdot 0.001} \approx 0.447 \text{ mm};$$

$$U_{\mathrm{M100}} = 2\sqrt{100 \cdot 0.001} \approx 0.632 \text{ mm};$$

$$U_{\mathrm{M170}} = 2\sqrt{170 \cdot 0.001} \approx 0.825 \text{ mm}.$$

The results that we find are quite unexpected. For example, with $\delta = 0.001$ mm, even with measurement of a thread of one-fourth the diameter, the error decreases only half and amounts to 0.4 mm. With threads of low diameter, this is not so important, since it is better to control such gauges by means of a standard method, though it will be a problem for large-diameter threads.

The asymptotic expression

$$\omega(U(D)) = 0.063\sqrt{D} \tag{1}$$

may be used under ordinary conditions to simplify the estimation of this quantity with $\delta = 0.001$ mm.

The deviation of the values of (1) from the values of the function $U(D)$ for thread diameters D in the range 10–200 mm is not more than 0.4% (0.005 mm in absolute value). Moreover, the (1) function does not exceed $U(D)$ on this segment of the values of D.

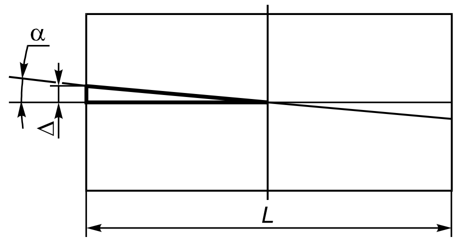

Fig. 1. Diagram to determine the location of the section being measured.

Estimate of Influence of Alignment Accuracy on Results of Measurement of Thread Pitch. In measuring the thread pitch, because of the deviations calculated in the preceding section, the device's probe will perform measurements not in the axial section, but instead in a section rotated towards the axial section by some angle. Let us determine this angle from the diagram in Fig. 1.

Using the trigonometric equalities, we obtain an expression of the form

$$\alpha = \arctan[\Delta/(L/2)] = \arctan(2\Delta/L) = \arctan(U/L), \tag{2}$$

where α is the desired slope of the section, deg; Δ, dead zone, mm; and L, actual length of thread (distance between sections in alignment), mm. Here and below, we will assume that the distance between the sections in the alignment is equal to the actual length of the grooved thread, since it is best to use the greatest acceptable length in order to arrive at the most accurate alignment.

Substituting into (2) the value of U found above, we determine

$$\alpha = \arctan(U/L) = \arctan(2\sqrt{D\delta}/L).$$

Let us find the value of the angle α fort the metric threads M50, M100, and M170, setting the length of alignment equal to the thread diameter (i.e., $L = D$):

$$\alpha_{M50} = \arctan\frac{2\sqrt{50\cdot 0.001}}{50} \approx 0.512°;$$

$$\alpha_{M100} = \arctan\frac{2\sqrt{100\cdot 0.001}}{100} \approx 0.362°;$$

$$\alpha_{M170} = \arctan\frac{2\sqrt{170\cdot 0.001}}{170} \approx 0.278°.$$

Using the diagram in Fig. 2, we will consider the parameters θ and P'.

Here $\theta = \arctan(\pi D/P)$ is the helix angle of the thread and P the nominal thread pitch, mm. For an M170×6 thread, we obtain $\theta = \arctan(170\pi/6) \approx 89.356°$.

We next find P', i.e., the thread pitch in a section rotated by the angle α relative to the axial section:

$$P'/\sin\theta = P/[\sin(180° - \alpha - \theta)];$$

$$P' = P\sin(\theta)/\sin(\alpha + \theta). \tag{3}$$

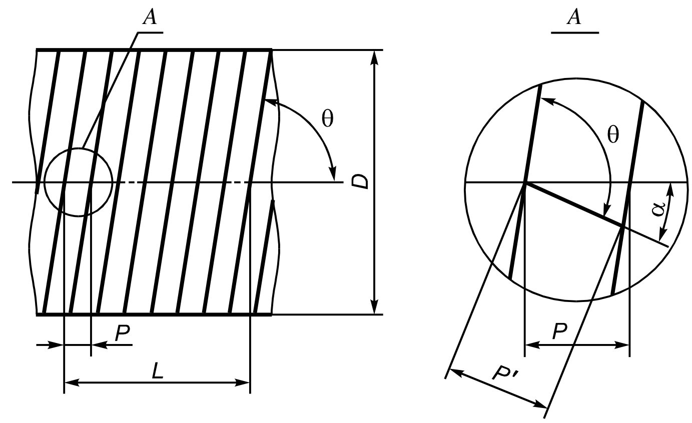

Fig. 2. Diagram to determine the position of the thread parameters.

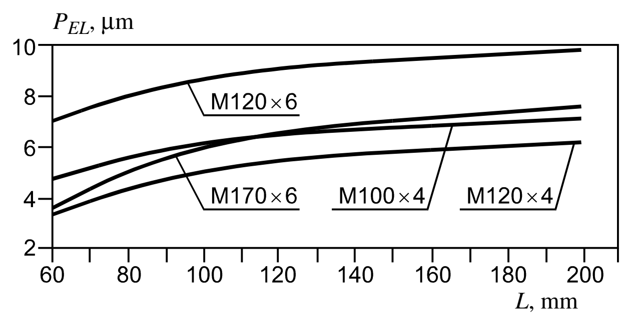

Fig. 3. P_{EL} expressed as a function of the parameters P, D, and L.

The value of the angle α may be substituted into (3) with either a positive or negative sign. A positive sign denotes rotation of the measured section in the clockwise direction. Substituting into (3) the value for the parameters α and θ, we obtain

$$P' = P\sin(\arctan(\pi D/P))/\sin(\arctan(U/L) + \arctan(\pi D/P)).$$

The error in the measurement of the thread pitch accumulated over the entire length of the thread will be as follows:

$$P_{EL} = LP_E/P = L(P' - P)/P.$$

The error in the measurement of the thread pitch grows more rapidly in threads of lesser diameter. Now let us determine how different values of the length over which the alignment and measurement are performed affect the result of measurements of the thread pitch (Fig. 3). The accumulated error in the thread pitch reaches high values and, for example, for an M170×6 thread 200 mm in length amounts to 0.008 mm. This must be taken into account in carrying out measurements of the corresponding threads on these types of devices.

Experimental Data. We wish to experimentally determine the value of U. For this purpose, clock-type indicators are mounted on the stage in such a way as to measure the displacements of the probe perpendicular to the trajectory of the motion. The Mahr Perthometer Concept XC20 was used as the profile measurement device. A thread gauge probe with M170×6-6g thread was placed on the stage of the device and alignment performed along a 196 mm length in accordance with the method described above. Next, the screw of the stage's angular microfeed unit was rotated, which induced a variation in the readings

TABLE 1. Determination of Dead Zone

Device	Values of U and Z-coordinate, mm						
Indicator	8.0	8.2	8.4	8.6	8.8	9.0	9.2
Profilometer	0.013	0.008	0.002	–0.003	–0.006	–0.010	–0.014
Indicator	9.4	9.6	9.8	10.0	10.1	10.2	10.4
Profilometer	–0.017	–0.019	–0.021	–0.022	–0.023	–0.023	–0.023
Indicator	10.6	10.8	10.9	11.0	11.2	11.4	11.6
Profilometer	–0.023	–0.023	–0.023	–0.021	–0.020	–0.017	–0.015
Indicator	11.8	12.0	12.2	12.4	12.6	12.8	13.0
Profilometer	–0.012	–0.008	–0.004	0.000	0.005	0.011	0.017

TABLE 2. Influence of Turning Angle of Section on Error in the Measurement of Thread Pitch

Δ, mm	α, deg	P_{EL}, mm	$P' - P$, mm
–2.5	–1.461	180.081	0.00248
–2.0	–1.169	180.046	0.00141
–1.5	–0.877	180.026	0.00080
–1.0	–0.585	180.006	0.00018
–0.8	–0.468	180.000	0
–0.6	–0.351	179.997	–0.00009
–0.4	–0.234	179.991	–0.00028
–0.2	–0.117	179.988	–0.00037
0	0	179.985	–0.00046
0.2	0.117	179.983	–0.00052
0.4	0.234	179.982	–0.00055
0.6	0.351	179.981	–0.00058
0.8	0.468	179.982	–0.00055
1.0	0.585	179.983	–0.00052

of the indicator. The readings of the indicator and values of the Z-coordinate of the profile exhibited by the profilometer were written in discrete steps. The values obtained from the indicator and the profilometer are summarized in Table 1.

From the results of the experiment, it follows that there exists a dead zone in the interval of profilometer readings 10.1–10.9 mm, i.e., the accuracy of the alignment cannot be greater than the value $U = 10.9 - 10.1 = 0.8$ mm, which is in good agreement with the theoretically calculated value for this thread (0.825 mm).

To test the hypothesis that the alignment affects the accuracy of measurements of the accumulated error of the thread pitch, we performed an experimental determination of the dependence $P'(\alpha) - P$ a graph of which is presented in Fig. 4. For this purpose, we place the thread on the device's plate in such a way that its axis forms an angle with the device's measurement axis (this angle will also be the angle α). The stage is then turned in discrete steps with the gauge, while following each rotation a measurement of the total length of 30 thread turns (i.e., a 180-mm segment) is performed. We establish the numerical value of the rotation from the indicator (from the indicator we determine the magnitude of the linear shift in the end face

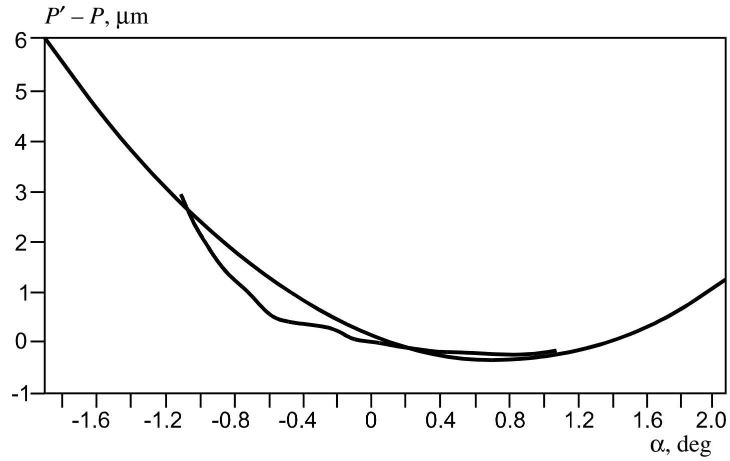

Fig. 4. Experimental dependence of error in thread pitch on slope of section.

of the gauge in a direction perpendicular to the measurement axis), which measures the displacement of one of the end faces of the gauge, i.e., the indicator gives the value of Δ while the Perthometer, that of P_{EL}. The results of the measurements are summarized in Table 2.

The values of α and of $P' - P$ may be compared with the theoretical values given in Fig. 4. But for this purpose it is necessary to recall that in performing the experiment the "null" section cannot be precisely adjusted with the thread axis (due to the dead zone U). To solve the problem of comparing the experimental and theoretical values, the experimental graph must be shifted along the α-axis to the right so that the characteristically expressed extremum of experimental values of $P' - P$ (with $\alpha = 0.351$) coincide with the theoretical extremum (with $\alpha = 0.65$). The magnitude of the shift will then amount to $S = 180\tan(0.65 - 0.351) = 0.94$ mm. We may compare this result with the size of the dead zone for the given gauge (0.825 mm). The combined graphs thus obtained are presented in Fig. 4.

Five repeated measurements of the accumulated error in the thread pitch on 30 turns of an M170×6-6g thread yielded the following results: 0.011, 0.015, 0.016, 0.013, and 0.016 mm (with actual dimensions 179.989, 179.985, 179.984, 179.987, and 179.984 mm). The scatter of the readings, which was equal to 0.005 mm, is in sufficiently good agreement with the theoretically calculated error in the measurement of thread pitch $S = 180[P'(6, 170, 196) - 6]/6 = 0.0069$ mm.

Thus, the accumulated error of the measurement of thread pitch induced by the inaccuracy of the alignment of a thread gauge on the device may reach values on the order of 0.005–0.008 mm for large-diameter threads. This must be taken into account when performing high-precision measurements by this type of device.

A number of other questions of accuracy that arise in studying profile measurement devices are touched on in [6].

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