A figure after the letter shows a **grade of tolerance** that determines the value of tolerance (Table 7-2). **Tolerance** is the total permissible variation of a size. It is the difference between the maximum and minimum limits of size. Numbers 6 and 7 grades of tolerance are accuracy and are obtained by grinding, accuracy turning processing, etc. Numbers 8,9,10 are middle accuracy; 11, 12 are rugged enough; 14 is very rugged.

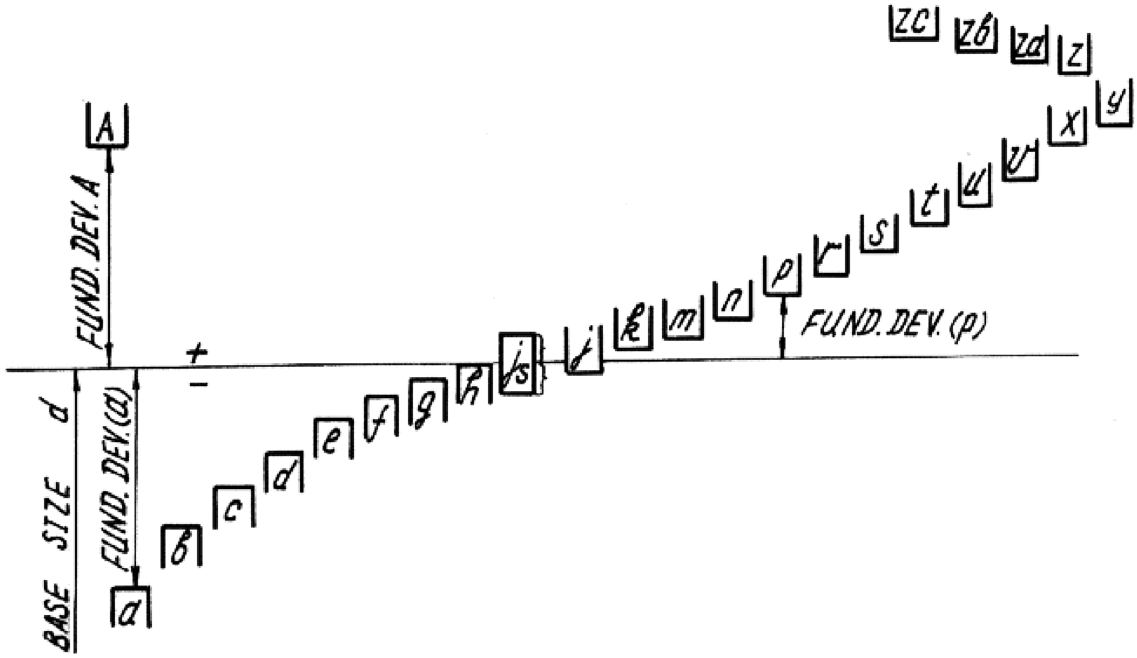


Fig. 7-4. A scheme of fundamental deviations of shafts.

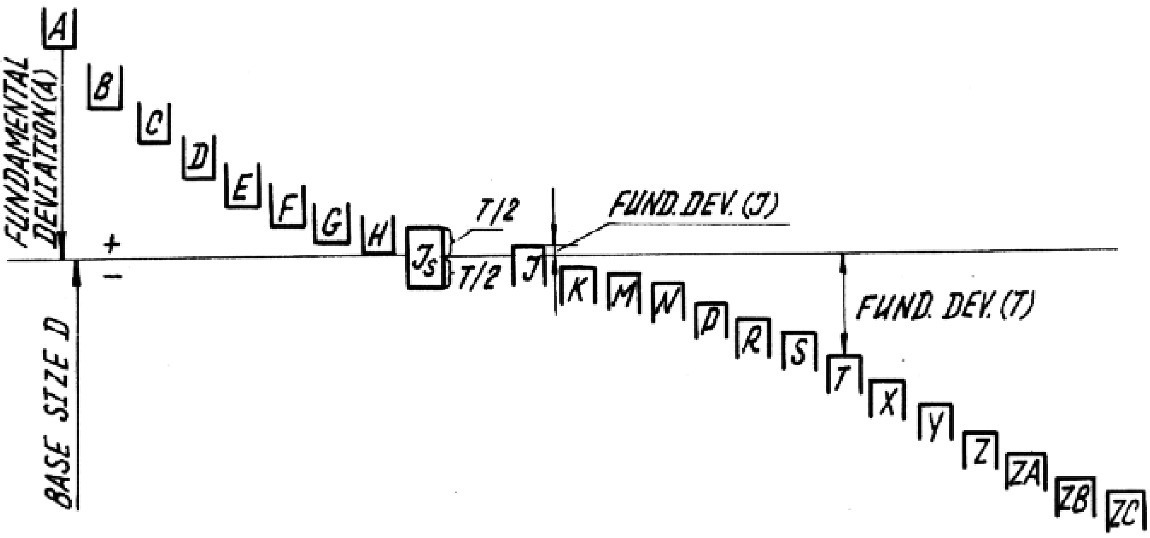


Fig. 7-5. A scheme of fundamental deviations of holes.

The values of tolerance and fundamental deviation depend on the part size. All the range of sizes is divided into intervals of sizes within which the values of tolerance and fundamental deviation are equal. In tables the values of tolerance and fundamental deviation are written in micrometers.

In our example 30g6 the fundamental deviation **fd** in accordance with the letter **g** is -7μm = -0.007mm (Table 7-1). The size tolerance is T_d=13μm in accordance with the number **6** of the grade of tolerance (Table 7-2). The upper deviation **es** is equal to the fundamental deviation **fd** in this example: es=-7μm, Fig. 7-6. We define the lower deviation **ei**: ei=-7-13=-20μm. A lower limit of the tolerance zone corresponds to the lower deviation. An upper limit of the tolerance zone corresponds to the upper deviation. We can write: $30g6\left(^{-0.007}_{-0.020}\right)$ or $30^{-0.007}_{-0.02}$ mm. The maximum limit of the size: $d_{max}=d_{basic}+es=30+(-0.007)=29.993$mm.

The minimum limit of the size: $d_{min}=d_{basic}+ei=30+(-0.02)=29.98$ mm. The right size is settled between 29.98 and 29.993 mm, including size limits.

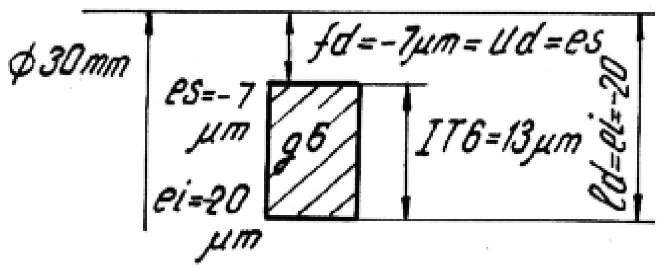


Fig. 7-6. A scheme of the tolerance zone 30g6.

If the fundamental deviation proves positive we will draw analogy between what we have written before.

For example 30s7: the fundamental deviation **fd** in accordance with the letter **s** is +35μm = +0.035mm (Table 7-1). The size tolerance is T_d=21 μm in accordance with the number 7 of the grade of tolerance (Table 7-2).The lower deviation **ei** is equal to the fundamental deviation **fd** in this example ei=+35μm. We define the upper deviation **es**: es=+35+21=+56μm. We can write: $30s7\left(^{+0.056}_{+0.035}\right)$ or $30^{+0.056}_{+0.035}$ mm. The maximum limit of size: $d_{max}=d_{basic}+es=$ 30+(+0.056)=30.056 mm. The minimum limit of size: $d_{min}=d_{basic}+ei=30+(+0.035)=30.035$ mm. The right size is settled between 30.035 and 30.056 mm including size limits.

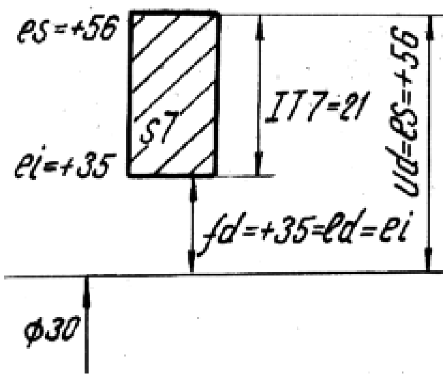


Fig. 7-7. A scheme of the tolerance zone 30s7.

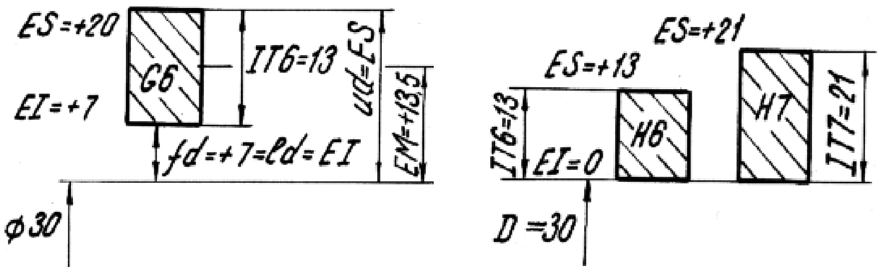
Holes standard is analogous to shafts standard but the arrangement of fundamental deviations is like a mirror and fundamental deviations are marked with a capital letter (Fig.7-5).

For example, for 30G6 the fundamental deviation is +7μm likely -7μm for the shaft 30g6. Lower deviation coincides with the fundamental deviation: EI=+7μm. The size tolerance is T_D=13μm. The upper deviation is ES=+7+13=+20μm. We can write: $30G6(^{+0.020}_{+0.007})$ or $30^{+0.020}_{+0.007}$ mm.

There are standards where deviations are already defined. First of all we find the standard for a hole or a shaft, then we find the necessary grade of a tolerance number.

After that we find the necessary letter of the fundamental deviation (for example, g6). On an intersection letter column with a size line we obtain both deviations (for example, 30g6: $^{-7}_{-20}$ μm).

Sometimes we can use the mean deviation: em=(es+ei)/2 or EM=(ES+EI)/2. For example, for 30G6$\left(^{+0.020}_{+0.007}\right)$ EM=(+0.02+0.007)/2=+0.0135 mm.



A B

Fig. 7-8. A scheme of tolerances zones 30G6 (A) and basic holes H6 and H7 (B).

In order to reduce quantity of tolerance zone we have to use a tolerance zone for the preferable application. These zones are marked in standards.

It is better if the lower deviation of a hole will be equal to 0 to reduce the number of cutting tools such as drills, reamers and others. If the lower deviation is not equal to 0 we must have cutting tools of several sizes, for example, 10.1mm, 10.2mm, 10.3mm, etc. When we use the hole tolerance zone with a zero lower deviation we can use only the tools with whole millimeters, for example, 10mm, 11mm, 12mm, etc. These tolerance zones are H6, H7, H8, etc. This hole is called a **basic hole**.

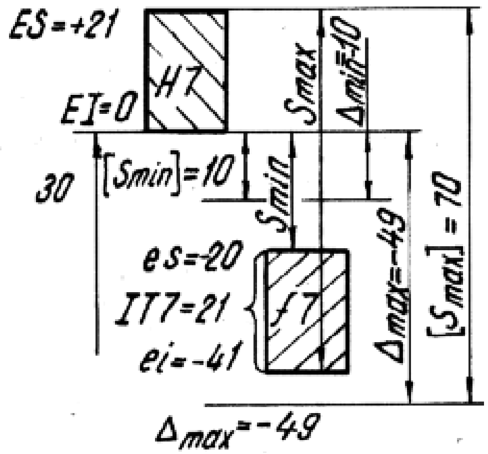


Fig. 7-9. A scheme of the clearance fit.

A hole together with a shaft makes a fit. Fits are divided into: 1) clearance fits; 2) interference fits; 3) transition fits.

When we deal with clearance fits a shaft is always smaller then a hole and we obtain only clearances between minimum clearance and maximum clearance (Fig. 7-9). We can define the tolerance of the fit: T_F=T_S= S_{max}-S_{min}= T_D+T_d.

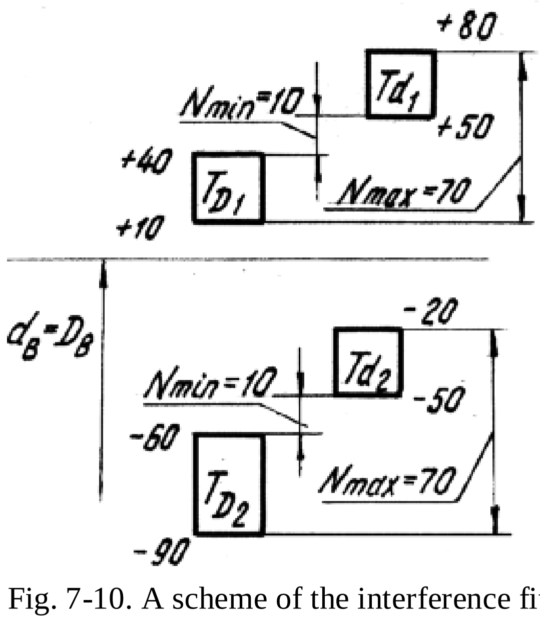


Fig. 7-10. A scheme of the interference fit.

When we deal with interference fits a shaft is always larger then a hole and we obtain only interferences between the minimum interference and maximum interferences (Fig. 7-10). We can define a tolerance of the fit: T_F=T_N= =N_{max}-N_{min}= T_D+T_d.

When we deal with transition fits we can obtain clearances or interferences dependent on an actual size of a hole and a shaft (Fig. 7-

11). These fits have S_{max} and N_{max}. We can define a tolerance of the fit: $T_F= N_{max}+S_{max}= =T_D+T_d$.

We can nominate a fit using the **hole-basis system** of fits or **shaft-basis system** of **fits**.

When we nominate a fit using the hole-basis system of fits the hole is made as the basic hole (H) and we select (pick out) a shaft tolerance zone to this basic hole in order to obtain the necessary fit.

When we nominate a fit using the shaft-basis system of fits, the shaft is made as the basic shaft (h) and we select a hole tolerance zone to this basic shaft in order to obtain the necessary fit.

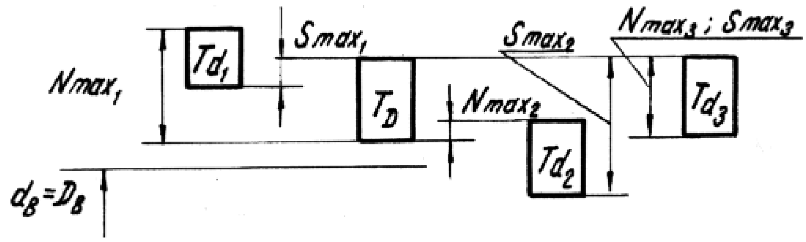


Fig. 7-11. A scheme of transitions fits: 1) T_D/T_{d1}; 2) T_D/T_{d2}; 3) T_D/T_{d3}.

The hole-basis system of fits is more preferable than the shaft-basis system of fits.

For example, it is necessary to pick out a fit if the basic size of the fit is 30 mm, the maximum clearance must be less than 70 μm ($S_{max}<70 \mu m$), the minimum clearance must be more than 10 μm ($S_{min}>10 \mu m$).

$d_b=30$ mm, $[S_{max}]=70 \mu m$, $[S_{min}]=10 \mu m$.

1. We define an approximate tolerance of the fit: $T_F =T_S=[S_{max}] - [S_{min}] = 70-10=60 \mu m$.
2. We define an approximate tolerance of the hole and shaft considering $T_D= T_d$: if $T_D+ T_d=T_F$, that is $T_D=T_F/2=60/2=30 \mu m$. $[T_D]=30 \mu m$.
3. We define the grade of tolerance: a tolerance must be less than 30 μm. For d=30 mm that is number 7 (IT7=21 μm). For number 8 IT8=33 $\mu m>[T_D]=30 \mu m$.
4. We draw the tolerance zone for the hole 30H7. The letter H we have nominated as we use the basic hole (a hole-basis system). The lower deviation is 0, the upper deviation is +21 μm.
5. We lay $[S_{max}]=70 \mu m$ and $[S_{min}]=10 \mu m$ as it is shown in Fig.7-12.

6. The fundamental deviation must be less than -10 μm and the lower deviation must be larger than -49 μm. A shaft tolerance zone must settled between -10 μm and -49 μm, Fig. 7-12.

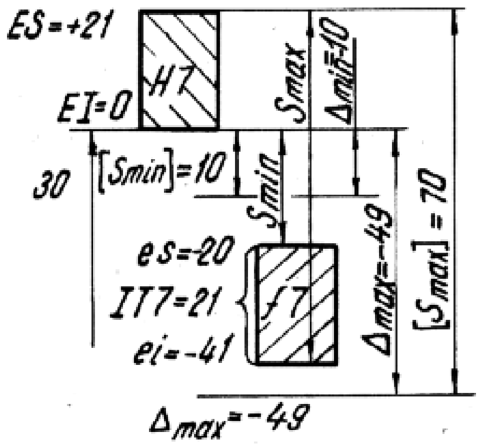


Fig. 7-12. A scheme of the fit 30H7/f7.

7. Looking at the fundamental deviation table we define the letter of the shaft tolerance zone. This is the letter f (the fundamental deviation fd=-20 μm).

8. We define shaft tolerance: IT7=21 μm.

9. We define lower deviation: ei=-20-21=-41 μm.

10. We define clearances:

$S_{min}=20 \mu m > [S_{min}]=10 \mu m$; $S_{max}=ES-ei= =+21-(-41)=62 \mu m<[S_{max}]=70 \mu m$.

All conditions are executed.

11. We have defined the fit: H7/f7 or 30H7/f7.

6.5. Control of Surface Finish

The smoothness of a machined surface is determined by a combination of factors involved in the machining process. Some of the most significant of them include: type and condition of cutting tool used, rigidness of the machine and setup, type of material being cut, depth of cut, rate of feed, cutting speed, and kind of cutting fluid used. Figure 6-13 shows surface characteristics involved in measurements of surface finish quality.

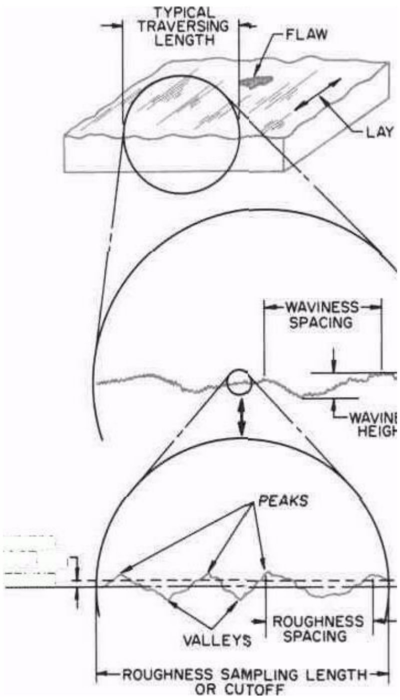


Fig. 6-13. Surface characteristics.

The type of surface required for a given product is determined by the designer. Such items as bearings, gear teeth, and pistons must have controlled surface quality. For example, the surface on a bearing can be excessively rough or smooth. If it is too rough, it will wear rapidly, resulting in limited life. If it is too smooth, it will not have adequate provision for oil pockets and it will be difficult to keep lubricated, thus again resulting in limited life.

To require a high surface quality where it is not necessary is expensive and unprofitable. Where detailed specifications concerning surface quality are not indicated, it means that the surface normally produced by that particular kind of machine operation is adequate.

The machinist must produce machined surfaces which meet specified standards of quality, and must be able to interpret the surface quality specifications indicated on drawings and blueprints. The machinist also must know how to determine whether machined surfaces meet surface quality specifications.

All machined surfaces, including those which appear to be very flat and smooth, have surface irregularities. Under high magnification, scratches or grooves in the form of peaks and valleys are revealed. These irregularities may or may not be superimposed on larger waves. Such complex factors as height, width, and direction of surface irregularities determine surface texture. They are specified with standard symbols on drawings.

The following terms related to surface texture have been defined by the American National Standards Institute (ANSI) and have been extracted from ANSI B46.1-1978 with the permission of the publisher:

Surface texture. Repetitive or random deviations from the nominal surface which form the three-dimensional topography of the surface. Surface texture includes roughness, waviness, lay, and flaws.

Profile. The profile is the contour of a surface in a plane perpendicular to the surface, unless some other angle is specified.

Centerline. The centerline is the line about which roughness is measured and is a line parallel to the general direction of the profile within the limits of the sampling length, such that the sum of the areas contained between it and those parts of the profile which lie on either side are equal.

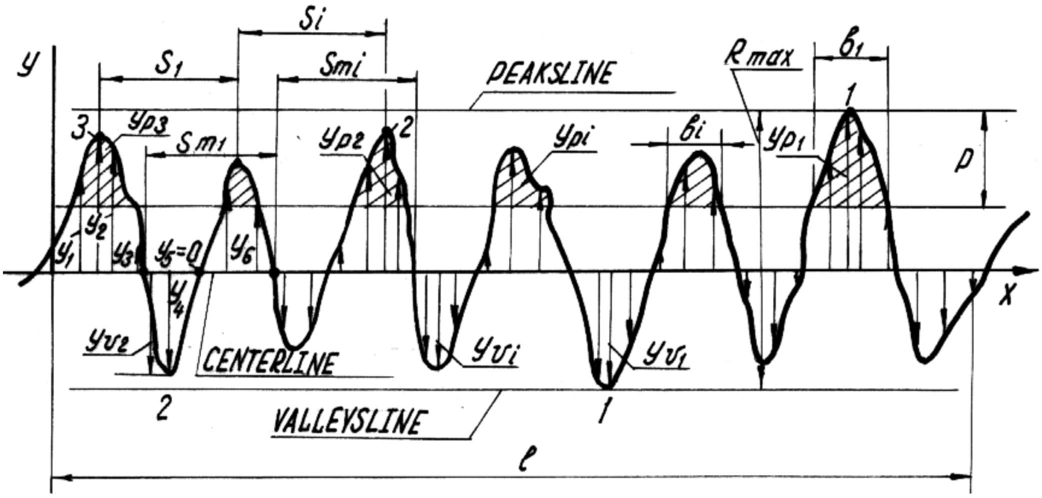


Fig. 6-14. Short section of hypothetical profile divided into increments.

Roughness. Roughness consists of the finer irregularities in the surface texture, usually including those irregularities which result from the inherent action of the production process. These are considered to include the traverse feed marks and other irregularities within the limits of the roughness sampling length.

Roughness average. Roughness average is the arithmetic average of the absolute values of the measured profile height deviations taken within the sampling length and measured from the graphical centerline, Fig. 6-1. Roughness average is expressed in micrometers.

$$Ra = \frac{1}{n}\sum_{i=1}^{n}|yi| = \frac{1}{l}\int_{0}^{l}|y(x)|dx, \qquad (6.1)$$

Roughness sampling length. The roughness sampling length **l** is the sampling length within which the roughness average is determined. This length is chosen, or specified, to separate the profile irregularities which are designated as roughness from those irregularities designated as waviness. Roughness sampling length is measured in millimeters. Standard values are (mm): 0.08 ($Ra<0.025\mu m$), 0.25 ($0.025<Ra<0.4$), 0.8 ($0.4<Ra<3.2$), 2.5 ($3.2<Ra<12.5$), 8 ($12.5<Ra<100$).

Height of the profile roughness on ten points. Height of the profile roughness on ten points is a sum average absolute values of the 5 highest peaks and of the 5 depthest valleys taken within the sampling length and measured from the graphical centerline. Roughness is expressed in micrometers.

$$Rz = \frac{1}{5}\left[\sum_{i=1}^{5}|yi| + \sum_{j=1}^{5}|yj|\right], \qquad (6.2)$$

Roughness spacing. Roughness spacing is the average spacing between adjacent peaks of the measured profile within the roughness sampling length. Roughness spacing average is expressed in millimeters.

$$S = \frac{1}{n}\sum_{i=1}^{n}Si, \qquad (6.3)$$

Roughness spacing on the centerline. Roughness spacing on the centerline is the average spacing measured on the graphical centerline of the measured profile within the roughness sampling length. Roughness spacing average is expressed in millimeters.

$$Sm = \frac{1}{n}\sum_{i=1}^{n} Smi, \qquad (6.4)$$

Relative profile length. This parameter is measured on the specified level **p** relatively the centerline, and **p** is calculated in percents (5%, 10%, 15%, 20%, 25%, 30%, 40%, etc.) relatively R_{max}. Relative profile length is expressed in %.

$$tp = \frac{1}{l}\sum_{i=1}^{n} bi, \qquad (6.5)$$

Cutoff. The cutoff is the electrical response characteristic of the roughness average measuring instrument which is selected to limit the spacing of the surface irregularities to be included in the assessment of roughness average. The cutoff is rated in millimeters.

Waviness is the more widely spaced component of the surface texture. Unless otherwise noted, waviness is to include all irregularities whose spacing is greater than the roughness sampling length and less than the waviness sampling length. Waviness may result from such factors as machine or work deflections, vibration, chatter, heat treatment, or warping strains. Roughness may be considered superimposed on a «wavy» surface.

Waviness height. The waviness height is the peak-to-valley height of the modified profile from which the roughness and flaws have been removed by filtering, smoothing, or other means. The measurement is to be taken normal to the normal profile within the limits of the waviness sampling length and expressed in millimeters.

Waviness spacing. The waviness spacing is the average spacing between adjacent peaks of the measured profile within the waviness sampling length.

Lay. Lay is the direction of the predominant surface pattern, ordinarily determined by the production method used.

Flaws. Flaws are unintentional irregularities which occur at one place or at relatively infrequent or widely varying intervals on the surface. Flaws include such defects as cracks, blow holes, checks, ridges, scratches, etc. Unless otherwise is specified, the effect of flaws shall not be included in the roughness average measurements. Where flaws are to be restricted or controlled, a special note as to the method of inspection should be included on the drawing or in the specifications.

Application of Surface Finish Symbols

Surface quality is designated with a surface finish symbol and ratings. The symbol is similar to a check mark, but with a horizontal extension line added, Fig.6-15. The long leg of the check-like symbol is to the right as the drawing is read. If only the roughness height is designated, the horizontal extension line may be omitted.

The point of the surface symbol is located on the line indicating the surface specified. It also may be located on an extension line or leader pointing to the surface specified, as in Fig. 6-15. Symbols used with the surface symbol to indicate lay are shown in Table 6-1.

Surface quality ratings for various characteristics such as roughness, waviness, and lay are positioned specifically in relation to the surface symbol. The relative location of these specifications and ratings is indicated in Table 6-2.

Designations for Roughness Height

The roughness average, according to the ISO standard, is expressed in micrometers as the simple **arithmetical average** (AA) deviation, measured normal to the centerline. In previous standards the roughness height was expressed in micrometers as the **root mean square average** (RMS) deviation, measured normal to the centerline. Certain instruments are equipped with a selector switch for selecting either the RMS or the AA reading.

Table 6-1. Lay symbols.

Lay symbol	Meaning
=	Lay approximately parallel to the line representing the surface to which the symbol is applied.
⊥	Lay approximately perpendicular to the line representing the surface to which the symbol is applied.
×	Lay angular in both directions to the line representing the surface to which the symbol is applied.
M	Lay multidirectional.
C	Lay approximately circular relative to the center of the surface to which the symbol is applied.
R	Lay approximately radial relative to the center of the surface to which the symbol is applied.
P	Lay particulate, nondirectional, or protuberant.

Roughness measuring instruments calibrated for AA values will indicate approximately 11 percent lower for a given surface than those calibrated for RMS average values. However, because the absolute limit of roughness for satisfactory functioning of a surface is indefinite, many manufacturers adopt AA ratings without changing the RMS values indicated on older drawings. For most surface measurement applications, the difference between the two values is of no consequence.

In order to eliminate error or confusion in the use of various stylus instruments, standards are included in ANSI B46.1-1978. For instruments indicating a numerical value only, a spherical-tip stylus with a 10 micrometer (400 microinch) radius tip is standard. The accuracy of instruments for surface roughness measurement should be checked periodically by measuring a precision reference specimen.

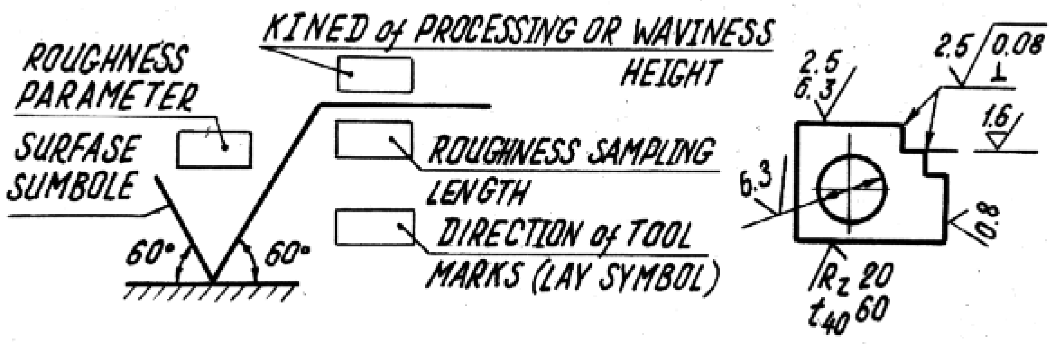


Fig. 6-15. Application of surface finish symbols.