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LINEAR AND ANGULAR MEASUREMENTS

MODERNIZED UNIVERSAL BASE SET OF END MEASURES

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A technique for improving universal sets of plane-parallel end measures widely used in different branches of mechanical engineering is proposed. An original algorithm for the design of universal sets with improved characteristics that ensure ease of operation is developed on the basis of an analysis of existing sets of end measures.

Keywords: *plane-parallel end measure, set of measures.*

There exist sets of plane-parallel steel end measures produced by different manufacturers, for example, the KALIBR Southern Ural Instrument Factory and the Krasnyi Instrumentalshchik Kirov Factory (Russia), Mitutoyo (Japan), Hexagon Metrology TESA (Sweden), and others. Special and universal standard sets of end measures [1] are used to inspect certain articles and measuring instruments (protractors, micrometers, gauge instruments, optical gages). In these sets, the required dimension (component dimension) may be obtained over a broad range by addition (fitting in) of several end measures of a set in different combinations. The advantage of a set of end measures is seen in the ease with which the component dimensions are obtained thanks to groups of measures with fixed step of the dimensions: 0.005, 0.010, 0.100, 0.500, 1.000, and 10.000 mm. However, according to an analysis [2, 3], a redundant quantity of end measures is used in universal sets to obtain the component dimensions, which leads to an increase in the weight and cost of the sets. Sets of end measures (and proposals for creating sets) [2, 3] are known which, by comparison with universal sets, enable an expansion in the range of measurements (interval of the series of component dimensions with given step) while maintaining the number of measures in the set. There also exist effective sets (and proposals to create such sets) of end measures of reduced specific quantity of metal [4, 5]. The difficulties associated with the selection of measures in blocks due to the specific nature of the dimensions of the measures is a shortcoming of these sets.

The results of studies [2–13] have served as a basis for the development of an original algorithm for the design of universal sets of plane-parallel end measures. By means of the algorithm, it is possible to achieve both an expansion of the technological capabilities of the sets as well as ease of use of the sets in production applications (the component dimensions are obtained from at most five measures of the set).

In sets obtained using the algorithm of [4, 5], which are highly efficient from the point of view of the specific quantity of metal, the dimensions of all the measures (elements) in the groups are governed by the relationships

$$A_{1-m} = A_{n-(m-1)} + \delta_{(m-1)}; \quad A_{nm-m} = A_{1-m} + (n_m - 1)\delta_m, \tag{1}$$

where A_{1-m} is the dimension of the first element in the mth group; $A_{n-(m-1)}$ and $\delta_{(m-1)}$, dimension of last element and step of dimensions of measures of the group numbered $m - 1$; and A_{nm-m}, n_m, and δ_m, the dimension of the last element, number of elements, and step of dimensions of measures of mth group.

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Sets of five groups in which the number of elements in the groups is given by

$$n_1 = (K_1\delta_1 - A_{11})/\delta_1 + 1; \quad n_m = [K_m\delta_m - (K_{(m-1)} + 1)\delta_{(m-1)}]/\delta_m + 1, \tag{2}$$

possess the highest technical characteristics (limits of the series of component dimensions with specified step, number of component dimensions, etc.). Here n_1 and n_m are the number of elements in the first group and in the mth group, respectively; K_1, $K_{(m-1)}$, and K_m, ratios of dimension of last element of group to step of dimensions of measures of given group for groups numbered 1, $m - 1$, and m, respectively; A_{11}, dimension of first element of first group of set; δ_1, $\delta_{(m-1)}$, and δ_m, step of dimensions of measures in the corresponding groups.

Here the values of K_1, ..., K_m are defined as

$$K_m = A_{nm-m}/\delta_m \tag{3}$$

and, according to our analysis of the dimensions of the measures in groups of many sets, are found in the following intervals: $100 \le K_1 \le 201$; $51 \le K_2 \le 150$; $8 \le K_2 \le 20$; $5 \le K_4 \le 50$; $1 \le K_5 \le 10$, and the combination of their values must satisfy the condition

$$K_1[1 - \delta_1/\delta_2] + ... + K_{(m-1)}[1 - \delta_{(m-1)}/\delta_m] + K_m = (N - 5) + A_{11}/\delta_1 + [\delta_1/\delta_2 + ... + \delta_{(m-1)}/\delta_m], \tag{4}$$

where N is the total number of elements in the set, $N = n_1 + ... + n_5$.

The implementation of the algorithm (design of the set) is realized in the following sequence: assignment of initial data; determination of the number of measures in the groups; determination of the dimensions of the measures in the set; and determination of the characteristics of the set.

Example

We select the dimension of the first measure of the first group $A_{11} = 0.5$ mm.

We specify the values of the steps of the dimensions of the measures in the groups of the set: δ_1, δ_2, δ_3, δ_4, and δ_5, correspondingly equal to 0.005, 0.010, 0.100, 0.500, and 10.000 mm.

For each group of values, we determine $K_1 = 137$; $K_2 = 79$; $K_3 = 14$; $K_4 = 19$; $K_5 = 10$. (We make the selection from the recommended intervals so that the computed values n_1, ..., n_5 are positive integers.)

We calculate the number of measures in the groups by means of (2): $n_1 = 38$; $n_2 = 11$; $n_3 = 7$; $n_4 = 17$; $n_5 = 10$.

We find the total number N of measures in the set as the sum of the number of measures in the groups: $N = 83$.

We check condition (4) from the values of the left- and right-hand sides of the equality and obtain 178.85 = 178.85.

We determine the dimensions of the least and greatest measures in the set (in groups 1–5) from (1): $A_{11} = 0.5$ mm; $A_{12} = 0.69$ mm; $A_{13} = 0.8$ mm; $A_{14} = 1.5$ mm; $A_{15} = 10$ mm; $A_{n1-1} = 0.685$ mm; $A_{n2-2} = 0.79$ mm; $A_{n3-3} = 1.4$ mm; $A_{n4-4} = 9.5$ mm; $A_{n5-5} = 100$ mm.

We find the dimensions of all the remaining measures in the set in light of the dimensions of the first measures and the steps of the dimensions of the measures in the corresponding group (Table 1).

If a constraint on N is introduced in the initial design data, then K_1, ..., K_m from (3) are established from condition (4), which reduces to a Diophantine equation and is solved in integers on a computer by means of a special program. The program yields several alternative combinations of K_1, ..., K_m for each of which sets are generated and their technical characteristics determined. The selection of the optimal set is arrived at as a result of a comparison of the characteristics.

Table 2 presents a set of measures according to the algorithm proposed in [4, 5], while Table 3 presents a set of measures obtained from the algorithm of [1]. As in the preceding set (cf. Table 1), the known sets consist of 83 measures and the dimension of the greatest measures and of the block are correspondingly 100 and 400 mm, and make it possible to obtain a series of component dimensions with step 0.005 mm.

The following characteristics are used to arrive at a comparative estimate of the sets: total length of measures (TLM); minimal component dimension (MCD) of series of dimensions with specified step (lower limit of series) as well as greatest component dimension (GCD) (upper limit of series); number of component dimensions (NCD) of continuous series; percentage

TABLE 1. Parameters of Proposed Set (83 measures, 5 groups)

Group No.	Number of measures in group	Step of dimensions of measures, mm	Minimal and maximal dimensions of measures, mm
1	38	0.005	0.500; 0.685
2	11	0.010	0.690; 0.790
3	7	0.100	0.800; 1.400
4	17	0.500	1.500; 9.500
5	10	10.000	10.000; 100.000

TABLE 2. Set of Measures Based on [4, 5] (83 measures, 5 groups)

Group No.	Number of measures in group	Step of dimensions of measures, mm	Minimal and maximal dimensions of measures, mm
1	21	0.005	0.500; 0.600
2	57	0.105	0.700; 6.580
3	3	6.180	12.655; 25.015
4	1	–	49.520
5	1	–	98.525

TABLE 3. Set of Measures Based on [1] (83 measures, 5 groups)

Group No.	Number of measures in group	Step of dimensions of measures, mm	Minimal and maximal dimensions of measures, mm
1	2	0.005	1.005; 1.010
2	48	0.010	1.020; 1.490
3	4	0.100	1.600; 1.900
4	19	0.500	0.500; 9.500
5	10	10.000	10.000; 100.000

of component dimensions (PCD5) of five measures; ease of use (EU) of set (ease of compiling a required dimension from the measures in the set).

The ease of use of a set is characterized by whether it is possible to use the least number of measures to obtain the component dimensions and by the minimal time spent on a search for these measures in the set, determined by the productivity of the user. As a rule, most existing sets in a block comprise at most five measures, moreover, their selection is performed according to a principle of elimination of the greatest number of decimal places (beginning with the least significant digit) from a desired component dimension. We will show how this is done using as an example the process of obtaining a component dimension of 123.985 mm.

For a set of measures based on [1] (Table 3), we first select the measure 1.005 mm in order to eliminate thousandths from the required dimension. The new value is 122.980 mm. We then eliminate the next digit and select the measure 1.480 mm. With the new dimension 121.500 mm we are able to use the measure 1.500 mm (we are eliminating tenths), then 20 mm (eliminating tens), and 100 mm. Ultimately, a total of only five measures needs to be selected in order to obtain the dimension: 100 + 20 + 1.500 + 1.480 + 1.005 = 123.985.

TABLE 4. Comparative Evaluation of Different Sets of End Measures

Characteristic of set	Set					
	based on [4, 5]		based on [1]		proposed set	
	value of characteristic	rank	value of characteristic	rank	value of characteristic	rank
TLM, mm	423.580	3	714.255	1	681.855	2
MCD, mm	1.005	2	**2.000**	1	**1.000**	3
GCD, mm	180.240	1	202.510	3	202.190	2
NCD, units	35848	1	40103	2	40239	3
PCD5, %	31.9924	1	21.1705	2	19.7271	3
EU	Difficult to use	1	Easy to use	2	Easy to use	2
Total rank	–	9	–	11	–	15

Note. The lower limits of the greatest series of component dimensions with specified step of 0.005 mm are indicated by means of bold-facing; for the proposed set, it is determined by a single measure of dimension 1 mm.

The principle of elimination of decimal positions in a component dimension is preserved for a set found with the use of the proposed algorithm (cf. Table 1): 123.985 – 0.685 = 123.300 (thousandths and hundredths positions eliminated); 123.300 – 1.300 = 122.000 (tenths position eliminated); 122.000 – 2.000 = 120,000 (units position eliminated); 120 – 20 = 100 (tens position eliminated); 100 – 100 = 0. Thus, five end measures are also necessary.

In a highly efficient (in terms of reduced specific quantity of metal) set (cf. Table 2), the principle of elimination of positions is not applicable, since in all the groups of this set the dimensions of the measures may contain digits in all positions (thousands, hundredths, tenths, etc.). In the standard and proposed sets, the dimensions of the measures in each group have a limited number of positions (for example, there are only units and tenths in groups 3 and 4 of the proposed set). The combination of measures in the set (cf. Table 2) is in some sense unique – the dimension 123.985 may be obtained from four measures: 123.985 = 98.525 + 18.835 + 6.055 + 0.570. The time it takes to select the measures in order to obtain a component measure is greater, despite the fact that there are fewer measures (the required measure is obtained by trial and error in the process of checking many alternative combinations of measures). Thus, the standard and proposed sets may be considered easy and the set obtained on the basis of [4, 5], hard.

An expansion of the technological capabilities as a result of the use of the modernized sets is confirmed by the data of Table 4. The table presents a comparison of the characteristics of sets of measures based on the algorithm of [4, 5], the standard algorithm of [1], and the proposed algorithm in light of a rank estimate (a rank is established for each value of the parameter, with a rank of 1 corresponding to the minimal value). From Table 4 it follows that a set of measures constructed on the basis of [4, 5] is more efficient than a standard set and the proposed set in terms of specific quantity of metal (parameter TLM). However, the proposed set has a higher rank than the set constructed on the basis of [4, 5] and the set constructed on the basis of [1]. Like the standard set, the modernized set is easy to use, but despite a lesser specific content of metal, has expanded technological capabilities (increased series of component dimensions, greater NCD; and lesser NCD obtained from five measures).

Thus, a quantitative evaluation of the advantages of the proposed set as compared to the standard set leads us to note the following. The specific quantity of metal of the set decreases by 4.75% and the percentage of blocks formed from five measures by 1.44%; the interval of the greatest series of dimensions with step 0.005 mm decreases by 0.34%; the number of possible blocks of measures without repetition of the dimensions of the blocks decreases by 0.73%, and the number of dimensions of blocks with step 0.005 mm decreases by 14.78%.

Conclusions. Besides the two parameters of specific quantity of metal and series of component dimensions, an important characteristic of universal sets of plane-parallel end measures is the ease of use, which defines the productivity of the user of the sets. Existing universal sets of measures may be improved with the use of a design algorithm constructed on the basis of relationships between the number of groups in a set and number of measures in the groups and between the dimensions and step of the dimensions of the measures in the groups.

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