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By Irvin H. Fullmer

ABSTRACT

A quantitative comparison is made among the tentative American, the British, and the German national standards for metal fits. It is pointed out that the American standard is a simplification of practice, by the selection of the practice which meets the majority of requirements of interchangeable quantity production. It is therefore much simpler than the European systems designed to cover all types of machine construction. Each of the three national systems is briefly described, and the basis upon which the comparison is made is outlined.

The fits of the American system are compared with fits of the European systems having the basic hole and unilateral tolerances. Comparisons are made by means of two diagrams. The first is a graph showing the relative positions of the limiting dimensions of shafts and holes of the three systems for all diameters from 0.2 inch to 10 inches. The second shows the tightest and loosest conditions for each class of fit of the 1-inch and the 8-inch basic sizes. From these diagrams a selection was made of the British and German fits corresponding most closely to the American fits. A bibliography is appended covering recent literature relating to metal fits.

CONTENTS

I. INTRODUCTION

This paper has for its purposes (1) the quantitative comparison, so far as possible, of the tentative American with two outstanding European national standards of tolerances and allowances for metal fits—namely, the British and the German—selecting those types of fits of the British and German systems which correspond in fundamentals to those of the American system, and by means of charts showing the significance of the differences among them; and (2) to select the particular fits of the British and German systems which most nearly correspond to those of the American system. Other comparisons among various national standards for fits, made from somewhat different points of view, are cited in the appended bibliography.

In accord with present-day practices and tendencies in engineering standardization and the elimination of waste in industry, the American standard tolerances and allowances for metal fits not only involve the standardization of limits on dimensions of shafts and holes for various classes of fit, but also a simplification of practice by the selection of the one practice, out of several in use, which is based on the needs of modern quantity production, which careful investigation has shown to be the one most widely used, and the features of which are such as to make for the greatest economy in production.

The practice selected as standard consequently has as its basis the principles that (1) the tolerances on both shaft and hole shall be unilateral; (2) the allowances necessary to secure various classes of fit shall, whenever practicable, be applied to the shaft, and the minimum hole shall be the basic size; and (3) the number of classes of fit shall be the minimum number necessary to serve practical purposes.

In the British standard, however, both unilateral and bilateral tolerances and allowances on either or both shafts and holes are provided, and the German system consists of two complete standards, one on the hole basis and the other on the shaft basis, but in which unilateral tolerances only are applied. Moreover, in both the British and German standards a multiplicity of classes of fits is provided.

These differences among the national standards here considered arise from differences in prevailing practice. In England bilateral tolerances are extensively used; however, the British Engineering Standards Association recommends the use of unilateral tolerances when such use does not conflict with predominating present practice. Unilateral tolerances greatly predominate in the United States and are generally recognized as best suited for interchangeable quantity production. The greater simplicity of the American standard is due to the fact that it was drawn up specifically to meet most of the requirements in interchangeable quantity production; whereas it is recognized that there are cases, especially in other less preponderant types of machine construction, in which the standard is not applicable. On the other hand, the British and German systems are intended to cover practically the entire field of machinery building, less emphasis being placed on interchangeable quantity production, which accounts for their greater complexity.

II. DESCRIPTION OF SYSTEMS

In order more clearly to understand the quantitative comparisons among the three systems, the following brief descriptions are given:

1. AMERICAN

Presented in report No. B4a–1925 of the American Engineering Standards Committee, entitled "Tentative American Standard Tolerances, Allowances, and Gages for Metal Fits." Eight classes of fit are provided; namely, loose, free, medium, snug, wringing, tight, medium force, and heavy force or shrink. Allowances are applied on the shaft and for clearance fits are proportional to $\sqrt[3]{d^2}$, d being the basic diameter. For interference fits the allowances are such that the average interference of metal, by selective assembly, is proportional to d. Tolerances on both shaft and hole are proportional to $\sqrt[3]{d}$ and the minimum hole is the basic size.

2. BRITISH

Presented in report No. 164–1924 of the British Engineering Standards Association, entitled "Limits and Fits for Engineering." No definite series of fits are specified, but series of hole and shaft tolerances and allowances are given, leaving with the user the choice of particular combinations of shafts and holes, of which there are 154 possible combinations, to produce desired qualities of fit. Tolerances and allowances are proportional to $d^{0.4375}$ (as nearly as could be determined from the tabulated data on page 20 of the report) and are determined by multiplying a range factor "r" and a size multiplier "m," "r" being a constant for all diameters and "m" a variable depending on the basic diameter. Range factors are designated by capital letters; for example, unilateral holes designated as "B," "U," "V," and "W," have range factors of 0.0001, 0.0002, 0.0004, and 0.0008 inch, respectively. Bilateral holes are designated as "K," "X," "Y," and "Z," and oversize holes, or holes to which allowances are applied, as "A," "G," and "H." Shafts to which various allowances and tolerances are applied are designated as "TT," "T," "S," "R," "Q," "P," "M," and "L," which lie below the basic diameter; "B," "C," "D," "E," and "F," which lie above the basic diameter; and "K," which is bilateral in relation to the basic diameter. Thus, a particular class of fit obtained by combining some particular shaft and hole is designated by combining the corresponding letters; for example, "UT." It is recommended in the British report that such terms as "push fit," "close running fit," etc., should not be used, but that fits be specified by the general names—"interference fit," "transition fit," or "clearance fit." Also, although bilateral limits are given, the use of the unilateral system as applied to cylindrical mating surfaces is recommended in cases where it does not conflict with predominating present practice.

3. GERMAN

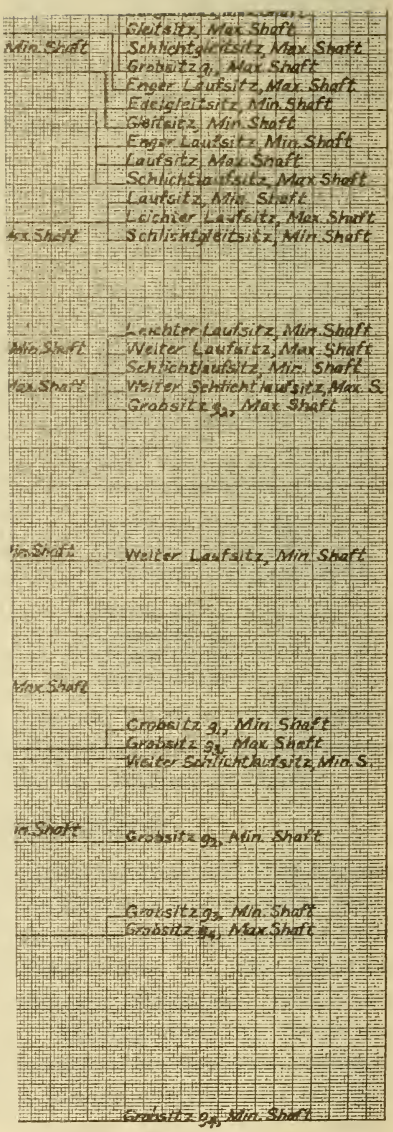
Summarized graphically in Dinormen 777 and 778, March, 1924, of the Normenausschuss der Deutschen Industrie and for which maximum and minimum clearances and interferences are given in Dinormen 152 and 153, July, 1925. There are two complete series of fits, one on the hole basis and the other on the shaft basis. Also, there are four general grades of fits, designated as Edelpassung, Feinpassung, Schlichtpassung, and Grobpassung, corresponding, in the hole-basis series, to hole tolerances of 1, 1½, 3, and 10 fit units and in the shaft-basis series to shaft tolerances of 1, 1, 3, and 10 fit units, respectively; one fit unit (Passeinheit) being equal to $0.005\sqrt[3]{d}$ mm. By applying various allowances and tolerances to the mating members the following 22 classes of fit are obtained:

Edelpassung	Edelfestsitz	Excellent tight fit.
	Edeltreibsitz	Excellent drive fit.
	Edelhaftsitz	Excellent binding fit.
	Edelschiebesitz	Excellent push fit.
	Edelgleitsitz	Excellent sliding fit.
Feinpassung	Preszsitz	Press fit.
	Festsitz	Tight fit.
	Treibsitz	Drive fit.
	Haftsitz	Binding fit.
	Schiebesitz	Push fit.
	Gleitsitz	Sliding fit.
	Enger Laufsitz	Close running fit.
	Laufsitz	Running fit.
	Leichter Laufsitz	Light running fit.
	Weiter Laufsitz	Loose running fit.
Schlichtpassung	Schlichtgleitsitz	Ordinary sliding fit.
	Schlichtlaufsitz	Ordinary running fit.
	Weiter Schlichtlaufsitz	Ordinary loose running fit.
Grobpassung	Grobsitz g_1	Coarse fit, g_1.
	Grobsitz g_2	Coarse fit, g_2.
	Grobsitz g_3	Coarse fit, g_3.
	Grobsitz g_4	Coarse fit, g_4.

Eleven additional classes of fit are obtained by cross combinations of shafts and holes—as, for example, "Bohrungen der Feinpassungen auf Schlichtwelle"—that is, fine fit holes on ordinary fit shafts.

III. BASIS OF COMPARISON

As the first step in making a quantitative comparison of the three systems under consideration, bilateral tolerances and oversize holes in the British system and the shaft basis in the German system have been disregarded. This places all comparisons on the common foundation of the hole basis and unilateral tolerances, which are fundamental in the American system. Having done so, there are still two factors which complicate the making of comparisons, namely, the large number of classes of fit in the foreign systems and the fact that the allowances and tolerances in the three systems bear different relations to the basic diameter. To attempt to superimpose on a


Gleitsitz, Max. Shaft
Min. Shaft
Schlichtgleitsitz, Max. Shaft
Grobsitz g_1, Max. Shaft
Enger Laufsitz, Max. Shaft
Edelgleitsitz, Min. Shaft
Gleitsitz, Min. Shaft
Enger Laufsitz, Min. Shaft
Laufsitz, Max. Shaft
Schlichtlaufsitz, Max. Shaft
Laufsitz, Min. Shaft
Leichter Laufsitz, Max. Shaft
Schlichtgleitsitz, Min. Shaft
Leichter Laufsitz, Min. Shaft
Weiter Laufsitz, Max. Shaft
Schlichtlaufsitz, Min. Shaft
Weiter Schlichtlaufsitz, Max. S.
Grobsitz g_2, Max. Shaft
Weiter Laufsitz, Min. Shaft
Grobsitz g_1, Min. Shaft
Grobsitz g_3, Max. Shaft
Weiter Schlichtlaufsitz, Min. S.
Grobsitz g_2, Min. Shaft
Grobsitz g_3, Min. Shaft
Grobsitz g_4, Max. Shaft
Grobsitz g_4, Min. Shaft

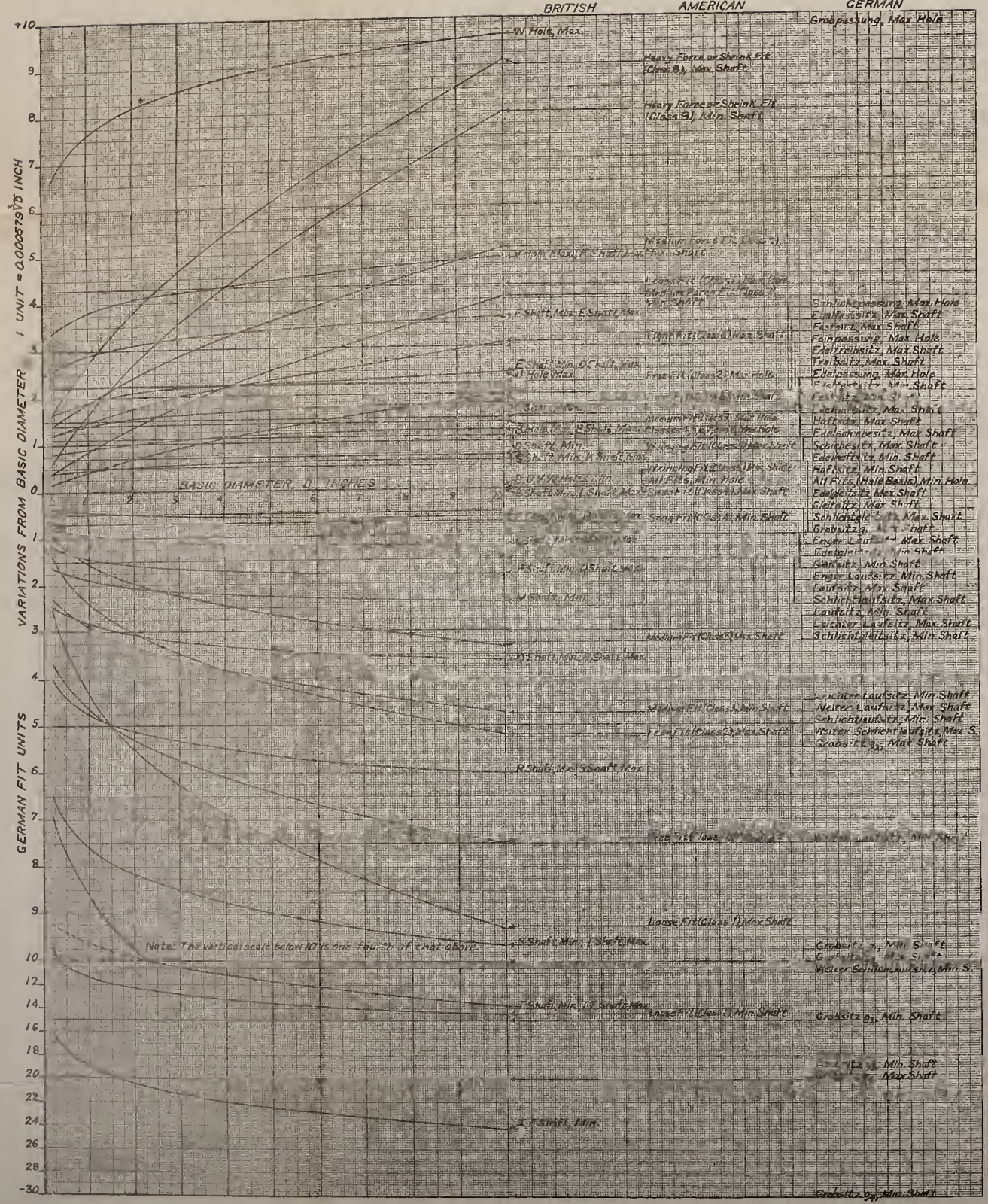
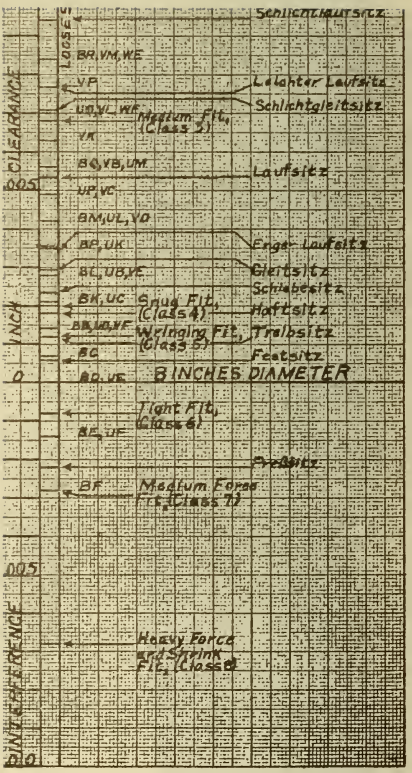


FIG. 1.—*Intercomparison of maximum and minimum shaft and hole dimensions*


Schlichtlaufsitz
Leichter Laufsitz
Schlichtgleitsitz
Laufsitz
Enger Laufsitz
Gleitsitz
Schiebesitz
Haftsitz
Treibsitz
Festsitz
8 INCHES DIAMETER
Loose
CLEARANCE
.005
INCH
0
INTERFERENCE
.005
0
BA,VM,WE
VP
UA,VL,WF
Medium Fit, (Class 3)
VK
BQ,VB,UM
UP,VC
BM,UL,YD
BF,UK
BL,UB,YE
BK,UC
Snug Fit, (Class 4)
BR,UQ,YF
Wringing Fit, (Class 5)
BC
BD,UE
Tight Fit, (Class 6)
BE,UF
BF
Medium Force Fit, (Class 7)
Heavy Force and Shrink Fits, (Class 8)

INCH SIZE

single chart, with diameters as abscissas and deviations from basic diameter as ordinates, the stepped lines representing variations in fractions of an inch from the basic diameters, corresponding to the allowances and tolerances, of all sizes of shafts and holes of the three systems would result in a hopelessly confused diagram, although such a chart would present most completely the comparison desired. Two distinct methods of plotting, therefore, were chosen, which together appear to be adequate for making a satisfactory comparison of the three systems, and the resulting diagrams are given herewith as Figures 1 and 2.

As indicated in the above description of the systems, the tolerances and allowances of each of the three systems are based on mathematical formulas in which they are some function of the basic diameter. This permits making a comparison on the basis of these formulas rather than on the actual limiting dimensions for the various sizes. Referring to Figure 1: Inasmuch as all of the allowances and tolerances in the German system and the tolerances in the American system are some function of the cube root of the basic diameter, it was decided that the German fit unit, $0.005\sqrt[3]{d}$ mm or $0.00057874\sqrt[3]{d}$ inch, would be the most convenient unit for plotting. Accordingly, the ordinates in Figure 1 are German fit units and the abscissas are basic diameters in inches. Thus, all limiting dimensions which are functions of $\sqrt[3]{d}$ are represented by straight horizontal lines. These include all of the German limiting dimensions, the limiting dimensions of all holes in the American system, and the limiting dimensions of shafts of classes 4 and 5 fits in the American system. Those in the British system, being functions of $d^{0.4375}$, are represented by curves which throughout most of the range are nearly horizontal. Limiting dimensions for classes 1, 2, and 3 shafts in the American system, which are functions of $d^{0.6667}$, are represented by flatter curves sloped at a somewhat steeper angle, and limiting dimensions for classes 6, 7, and 8 shafts in the American system, which are functions of d, are still flatter curves sloped at a still steeper angle. In other respects Figure 1 is self-explanatory, but it should be mentioned that the "Preszsitz" (press fit) in the German system has been omitted, for the reason that no mathematical basis for the limiting dimensions of the shaft is given in the German standard sheets available.

Figure 2 permits a more direct comparison of the actual quality of fit as represented by the tightest and loosest conditions obtaining for a given size for each class of fit. It is necessary merely to note the various features of the chart without any preliminary analysis. Comparison diagrams are given for two representative basic sizes; namely, the 1-inch and the 8-inch. Plotted on a vertical scale for each British combination of shaft and hole, for each American fit,

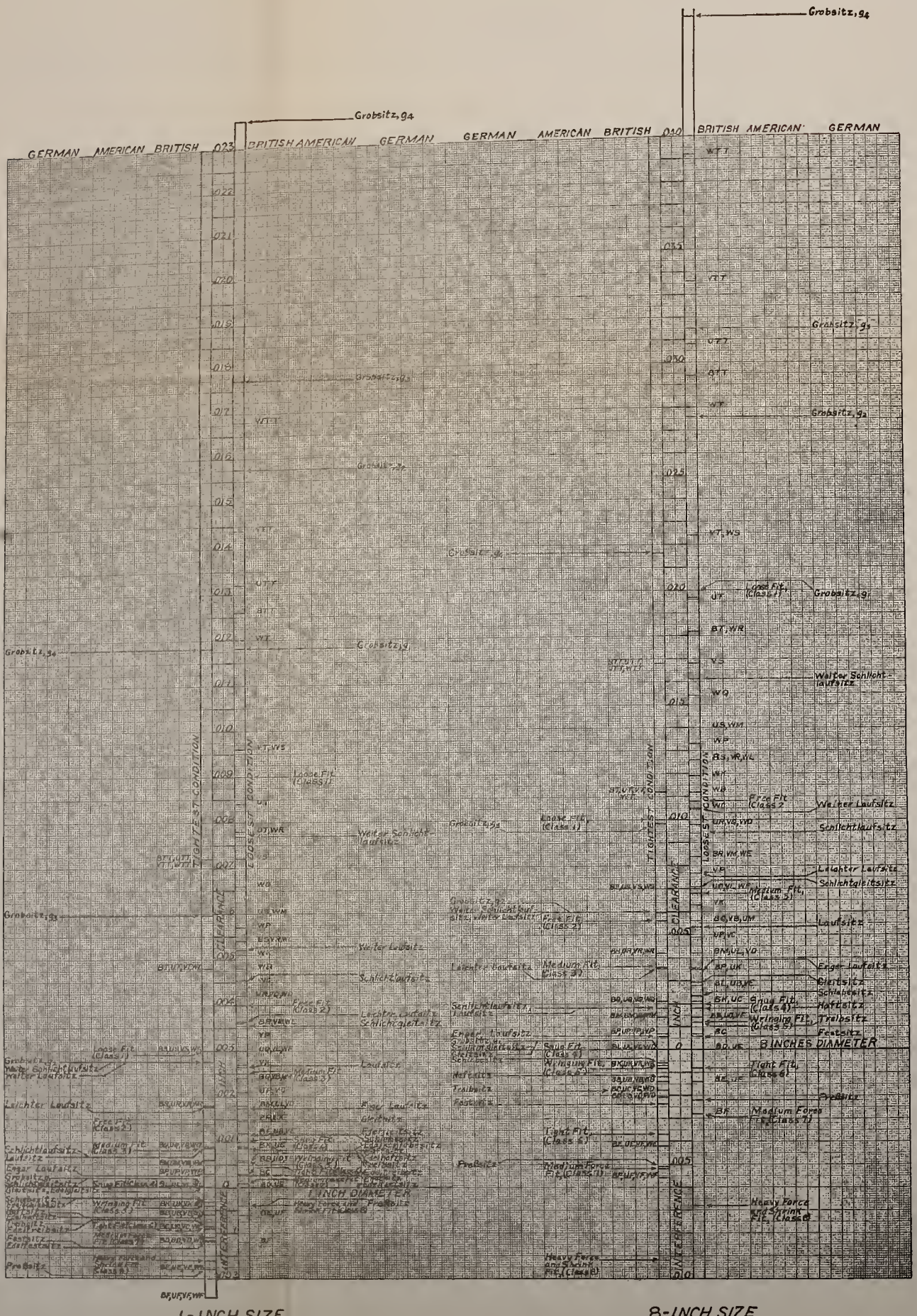


FIG. 2.—*Intercomparison of tightest and loosest conditions of fit*

and for each German fit there is given at the right of each diagram the loosest condition in decimal fractions of an inch, whether a clearance or interference, and at the left the tightest condition. Reading upward from the base line are clearances and reading downward are interferences. The two diagrams are plotted on different scales, the scale for the 1-inch diameter being extended sufficiently to prevent undue crowding and that for the 8-inch diameter being compressed sufficiently to represent the data within a convenient compass. Similar considerations necessitated placing the base lines at different levels. Other incidental features of the chart are that the German "Preszsitz" is included, inasmuch as maximum and minimum interferences are given for this fit in Dinorm 152; and the "Edel" fits do not occur for the 8-inch size, as they discontinue at 120 mm.

IV. CORRESPONDING FITS IN THE AMERICAN, BRITISH, AND GERMAN SYSTEMS

With regard to the relative values of Figures 1 and 2 for making comparisons among the three systems: As has been pointed out, by means of Figure 2, it is possible, for example, to determine which combination of shaft and hole in the British system corresponds most closely in quality of fit to the American loose fit (class 1). Figure 1 is valuable in that it shows the relative positions of the limiting dimensions of shafts and holes of the three systems. It is also especially valuable in showing how the limiting dimensions change with variation in basic size, and thus the extent to which any conclusion drawn from Figure 2 is applicable throughout the range of sizes from 0.2 inch to 10.0 inches.

The British and German fits corresponding most closely to the American fits, as determined by such a study of these charts, are as follows:

American	British	German
Loose fit (class 1)	U T	Weiter Schlichtlaufsitz.
Free fit (class 2)	U R	Weiter Laufsitz.
Medium fit (class 3)	B Q	Laufsitz.
Snug fit (class 4)	B L	Edelgleitsitz.
Wringing fit (class 5)	B B	Edelhaftsitz.
Tight fit (class 6)	U E	Festsitz.
Medium force fit (class 7)	B E	Preszsitz.
Heavy force or shrink fit (class 8)		

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