STEEL CASTINGS HANDBOOK

SUPPLEMENT 3

TOLERANCES

STEEL FOUNDERS'
SOCIETY OF AMERICA

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Steel Castings Handbook
Supplement 3

Dimensional Tolerances

Contents

DIMENSIONAL TOLERANCES

To assign dimensions and tolerances to a part which is produced as a casting involves consideration of functional requirements of the finished part, allowances for any machining operations which may be involved in producing the finished part, and allowances for production requirements such as draft. Allowances for castings and the major tolerance considerations in the production of parts as steel castings are presented below. Along with this information a set of tolerance grades is introduced to facilitate communication on tolerances.

DRAFT ALLOWANCES

Draft is the angle which must be allowed for on all vertical faces of a pattern to permit its removal from the sand mold without tearing the mold walls (Figure 1). The amount of draft depends upon the size of the casting, the method of production, and whether molding is performed by hand or machine. Machine molding will require a minimum amount of draft. Interior surfaces in green sand molds usually require more draft than exterior surfaces. The amount of draft recommended under normal conditions is about 3/16 in. per ft (approximately 1.5°). Draft can be eliminated in some cases through special molding techniques. These situations and the specific amount of draft required should be discussed with personnel of the foundry that will produce the casting.

Draft should be designated on the casting drawing. The draft angle selected should be no less than can be tolerated in the design or the cost of the pattern equipment. Table 1 and Figure 2 are presented to aid the engineer in determining the added thickness of the part for various draft angles and draft depths.

MACHINING ALLOWANCES

Castings which are to be machined must have sufficient metal stock on all surfaces requiring machining. The necessary allowance, commonly called finish, depends upon the size and shape of the casting, the surface to be machined, the hardness of the steel, roughness of the casting surface, the tendency to warp, and the type of tooling used for machining.

Standard finish allowances for steel castings are difficult to formulate since each casting is unique. However, Table 2 is presented as a general guide. Allowances that would be acceptable for one casting may not be adequate for others. In general, allowances may vary from 3/16 in. to 3/4 in. (5 to 19 mm), depending upon the variables listed above. Machining allowances should be discussed with personnel of the foundry that will supply the casting.

The relatively simple shape of a cast "center plate", shown in Figure 3 by a combined casting and machine drawing, offers an illustration for the use of machining allowances which are presented in Table 2.

The outside diameter of the center plate is to be machined to 15 11/16 in. (398 mm). According to Table 2, an allowance of 1/4 in. (6 mm) should be provided for the outside radius. The dimension of the cast diameter is therefore chosen as 16 3/16 in. [15 11/16 + 2(1/4) = 16 3/16 in. = 411 mm].

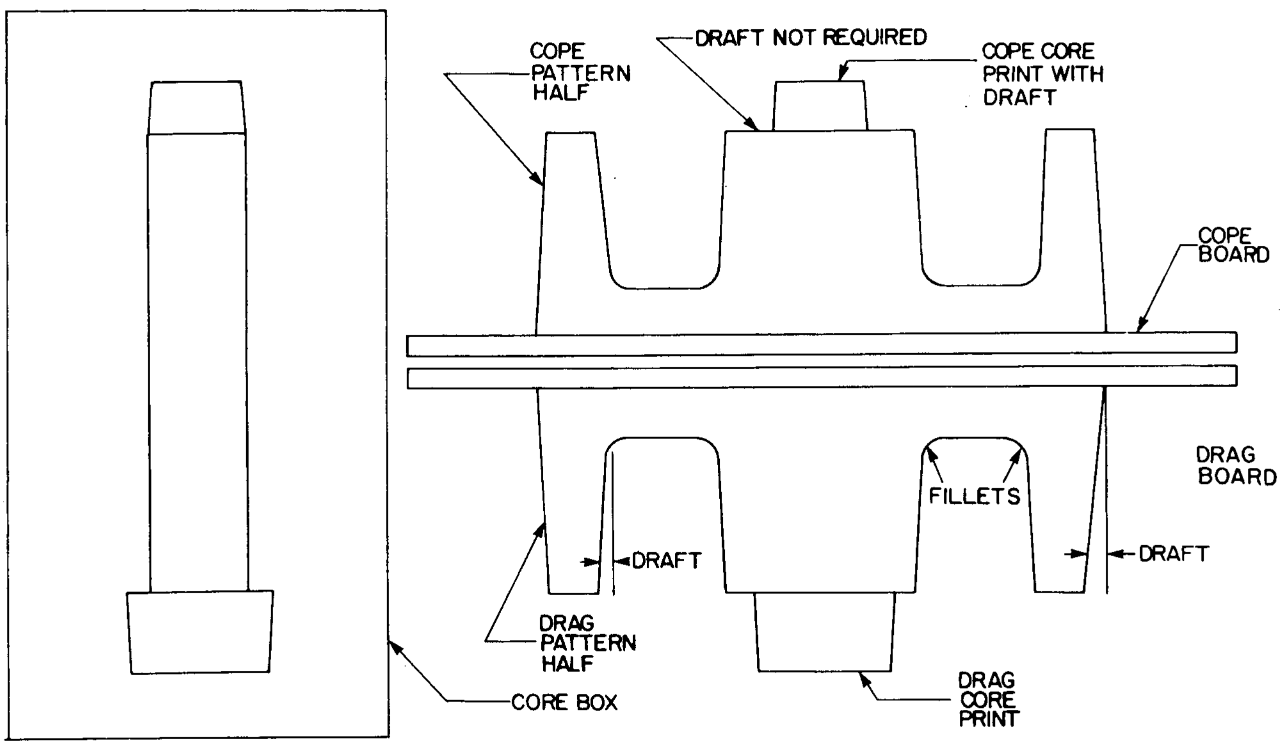

Fig. 1 Schematic illustration of a full split pattern and core box to produce a wheel-type casting. Note that draft is required on the vertical surfaces to allow the pattern to be drawn away from the mold. The core that will be made in the core box will form a cylindrical cavity to reduce machining.

TABLE 1 Draft, in inches,* for Various Draft Angles and Depths (see Figure 2 for definitions)

1/32 to 1/2 in.

Depth	1/32	1/16	3/32	1/8	5/32	3/16	7/32	1/4	9/32	5/16	11/32	3/8	13/32	7/16	15/32	1/2
1/2°	.0003	.0005	.0008	.0011	.0014	.0016	.0019	.0022	.0025	.0027	.003	.0033	.0035	.0038	.0041	.0044
1°	.0005	.0011	.0017	.0022	.0028	.0033	.0039	.0043	.005	.0055	.006	.0066	.007	.0077	.008	.0088
2°	.001	.002	.003	.004	.005	.006	.008	.009	.010	.011	.012	.013	.014	.015	.016	.018
3°	.0016	.0033	.0049	.0066	.008	.0098	.011	.013	.014	.016	.018	.020	.021	.023	.024	.026
4°	.002	.004	.006	.009	.011	.013	.015	.018	.020	.022	.024	.026	.028	.031	.033	.035
5°	.0027	.0055	.008	.0109	.014	.016	.019	.022	.024	.027	.030	.033	.035	.038	.041	.044
6°	.003	.007	.010	.013	.016	.019	.023	.026	.030	.033	.036	.039	.043	.046	.049	.053
7°	.0038	.0077	.0115	.015	.019	.023	.027	.031	.034	.038	.042	.046	.050	.054	.058	.061
8°	.004	.009	.013	.018	.022	.027	.031	.035	.040	.044	.049	.053	.057	.062	.066	.071
9°	.005	.010	.015	.020	.025	.030	.035	.040	.045	.050	.055	.060	.064	.069	.074	.079
10°	.0055	.011	.0165	.022	.027	.033	.039	.044	.049	.055	.061	.066	.071	.077	.083	.088

1/2 to 1 in.

Depth	17/32	9/16	19/32	5/8	21/32	11/16	23/32	3/4	25/32	13/16	27/32	7/8	29/32	15/16	31/32	1
1/2°	.0046	.0049	.0052	.0055	.0057	.006	.0063	.0065	.0068	.0071	.0074	.0076	.0079	.0082	.0085	.0087
1°	.009	.0099	.010	.011	.011	.012	.013	.013	.014	.014	.015	.015	.016	.017	.017	.0175
2°	.019	.020	.021	.022	.023	.024	.025	.027	.028	.029	.030	.031	.032	.033	.034	.035
3°	.028	.030	.031	.033	.035	.036	.038	.039	.040	.043	.045	.046	.048	.050	.051	.052
4°	.037	.039	.042	.044	.046	.048	.050	.053	.055	.057	.059	.061	.063	.066	.068	.070
5°	.046	.049	.052	.055	.057	.060	.063	.066	.068	.071	.074	.077	.079	.082	.084	.087
6°	.056	.059	.062	.066	.069	.072	.075	.079	.081	.085	.089	.092	.095	.098	.101	.105
7°	.065	.069	.073	.077	.082	.085	.088	.092	.096	.100	.104	.107	.111	.115	.119	.123
8°	.075	.079	.084	.088	.092	.096	.101	.106	.110	.115	.119	.123	.128	.132	.137	.141
9°	.034	.088	.094	.100	.104	.109	.114	.119	.124	.129	.134	.139	.144	.149	.153	.158
10°	.093	.099	.105	.110	.115	.121	.126	.132	.137	.143	.149	.154	.159	.165	.170	.176

* 1 in. = 25.4 mm

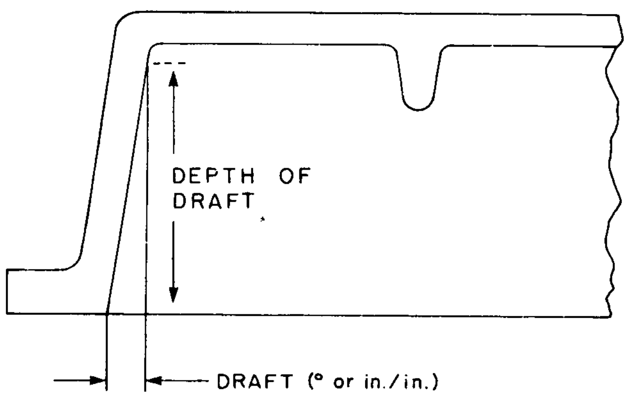

Fig. 2 Draft angle facilitates pattern removal from the mold.

TABLE 2 A Guide To Machine Finish Allowances*

Circular Shapes			
Casting Diameter		Machine Allowance on the Outside Radius of Rings, Spoked Wheels, Spoked Gears, Circular Shaped Castings	
in.	mm	in.	mm
Up to 18	Up to 457	1/4	6
18 to 36	457 to 914	5/16	8
36 to 48	914 to 1219	3/8	10
48 to 72	1219 to 1829	1/2	13
72 to 108	1829 to 2743	5/8	16
108 and up**	2743 and up	3/4	19
Bores			
Bore Diameter		Machine Allowance on Bore Radius	
in.	mm	in.	mm
Up to 1.5	Up to 38	Up to 3/16 or Cast Solid	Up to 5 or Cast Solid
1.5 to 7	38 to 178	3/16 to 1/4	5 to 6
7 to 12	178 to 305	1/4 to 3/8	6 to 10
12 to 20	305 to 508	3/8 to 1/2	10 to 13
Flat Shapes			
Greatest Dimension of the Casting		Machine Allowances	
in.	mm	in.	mm
Up to 12	Up to 305	3/16	5
12 to 24	305 to 610	1/4	6
24 to 48	610 to 1220	5/16	8
48 to 96	1220 to 2438	3/8	10
96 and up	2438 and up	1/2	13

*These allowances apply to short orders, and may be reduced to some degree on production runs which permit adequate pilot work to be done. They also indicate that a flat surface is more easily produced than a true circle.

**Machine allowances for castings of very large size, such as greater than 15 ft (5000 mm), should be determined through consultation with the foundry that is to produce them.

Machine Finish Allowances

The dimensional allowance to be added to the casting section for machining purposes will depend entirely on the design of the casting. Certain faces of a casting may require larger allowances than others as a result of their position in the mold, and the possible hindered contraction stresses that may be acting on the castings. For example, the cope side of a large casting may require 5/8 in. (16 mm) allowance whereas on the drag and side walls 3/8 in. (10 mm) may be ample.

Sufficient excess metal should be allowed to satisfactorily accomplish the necessary machining operations. One very good rule is to allow enough "finish" so that the first cut remains in its entirety below the cast surface of the metal by at least 1/16 in. (1.6 mm).

Definite values of machine finish allowances cannot be established for all casting designs, but certain guides can be suggested to designers. Such guides have been prepared and are given above for gears, wheels, and other circular-shaped castings.

The machined bore diameter is to be 2 1/8 in. (54 mm). The machining allowance on the bore radius should be taken as 3/16 to 1/4 in. (5 to 6 mm) according to Table 2. Taking the allowance as 3/16 in. (5 mm), the cast bore diameter should be 1 3/4 in. [2 1/8-2(3/16) = 1 3/4 in. = 44.5 mm].

The thickness of the center plate is to be machined to 2 5/8 in. (67 mm). According to Table 2, the machine allowance for flat shapes is 1/4 in. (6 mm) for castings whose greatest dimension is between 12 and 24 in. (305 and 610 mm). The cast thickness dimension is therefore 3 1/8 in. [2 5/8 + 2(1/4) = 3 1/8 in. = 79 mm].

VARIABLES AFFECTING DIMENSIONAL TOLERANCES

Dimensional tolerances are permissible deviations of the manufactured parts from the specified nominal dimensions. The magnitude of tolerances which can be met depends on several factors:

1) Whether only one or a few castings are produced from a pattern, or whether the part is produced in large quantities.
2) The design of the casting, and the dimension type.
3) The pattern and core box equipment employed to produce molds and cores.
4) The process employed for producing molds and cores.
5) Casting weight and dimension length.
6) Whether the castings are to be gaged and dimensionally upgraded as part of the finishing and inspection operation.

Number of Castings Produced

The production numbers, the casting design, and the dimension type play an important role in determining the tolerances which can be met because the contraction behavior of steel during solidification and cooling must be compensated for in the construction of the pattern.

This contraction is a three-stage process: liquid contraction, solidification contraction, and solid contraction. If this contraction were unhindered, it would be approximately 3/16 to 1/4 in. per foot (1.56—2.08%), for most steels. However, contraction is hindered by the mold and cores to varying degrees, even in different parts of a single casting. It will vary from almost nothing to the full 1/4 in. per foot (2.08%). Added to the complexity of predicting contraction are the normal variations in mold hardness and mold stability at elevated temperatures which may cause mold wall movement, an increase in mold volume. The effect of mold wall movement is particularly noticeable in the thickest dimensions of heavy castings, and may give rise to apparent expansion (1). The net change of a dimension due to the true contraction

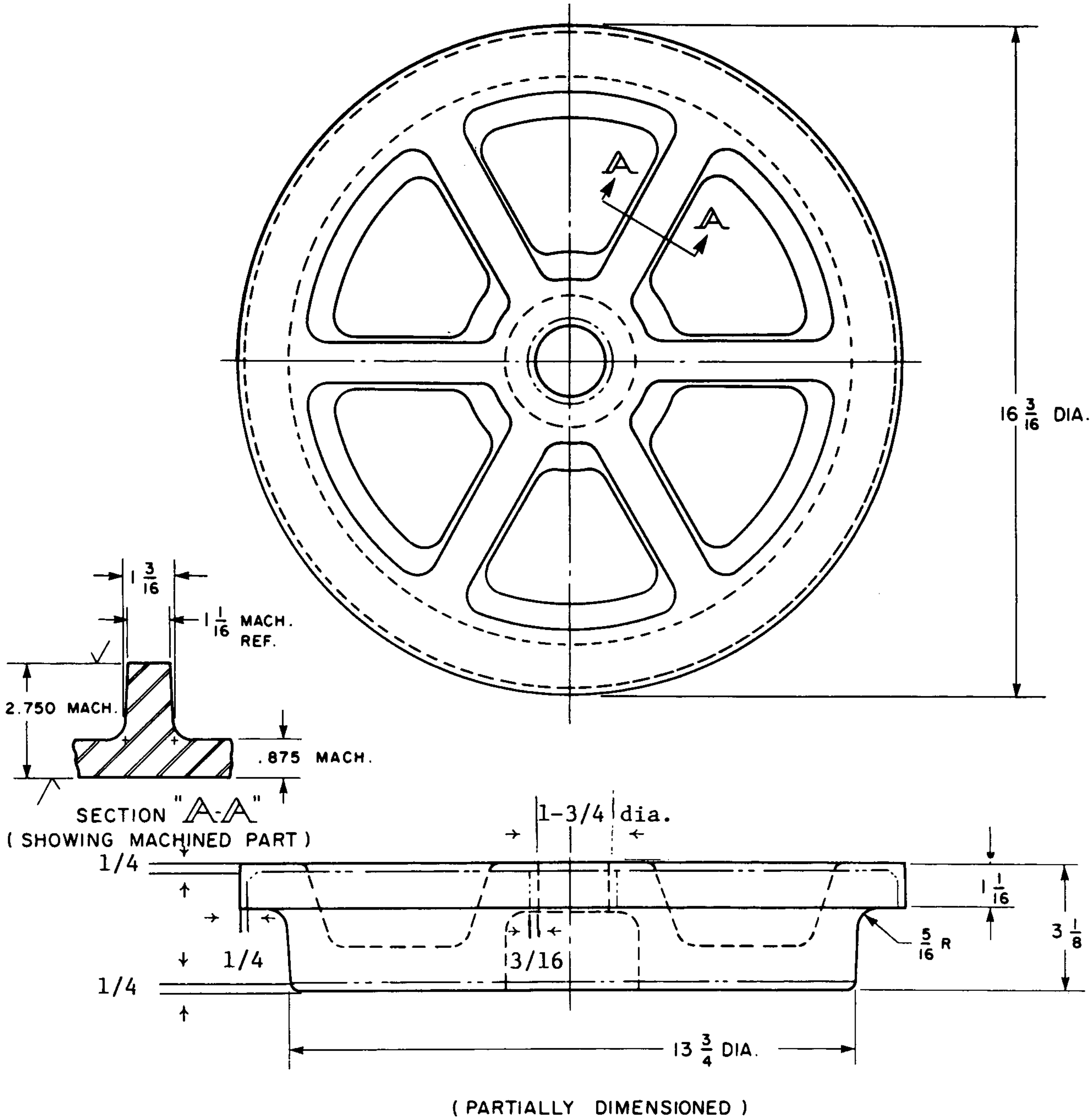

Fig. 3 Machine allowances of a cast "center plate" showing a combined casting and machine drawing. Solid lines indicate the cast part, and broken lines the machined dimensions (dimensions in inches, conversion: 1 in. = 25.4 mm).

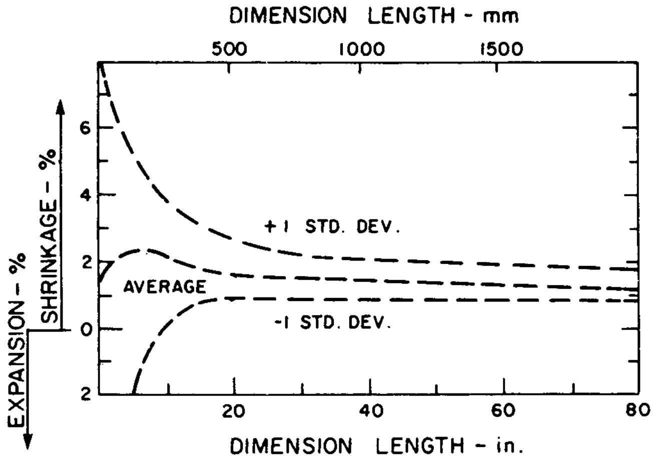

Fig. 4 Relation of apparent shrinkage to dimension length (4).

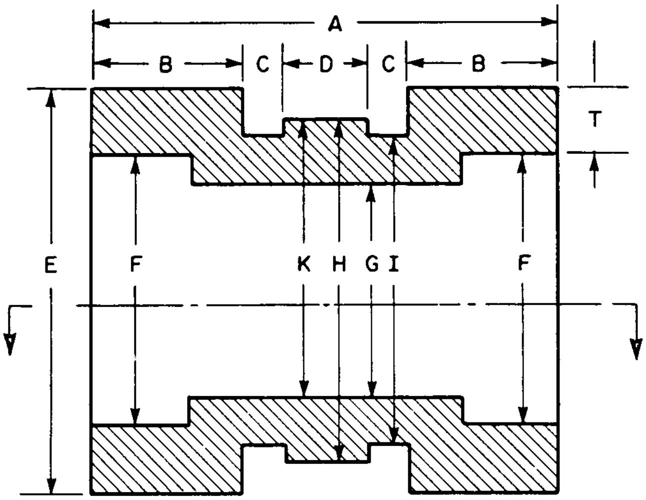

Fig. 5 Dimension types of a casting classified by the mold components which control them.

A,B,C,D	=	Mold to Mold	MM
T	=	Mold to Core	MC
E,H,I	=	Mold to Mold Across the Parting Line	MMPL
K	=	Mold to Core Across the Parting Line	MCPL
F,G	=	Wholly on One Core	WC

and mold wall movement is referred to as apparent contraction. Figure 4 summarizes extensive data from a 1977 SFSA study. It illustrates the difficulty of predicting the contraction or shrinkage behavior of cast steel, especially for dimensions less than 10 in. (254 mm).

The production of castings in large numbers usually provides the oportunities to make changes in pattern equipment and manufacturing processes to compensate for unexpected, or abnormal casting contraction behavior. Tighter tolerances can therefore be met by production castings than by castings produced as one of a kind, or where only few castings are produced from a given pattern.

Casting Design and Cores

The design of castings, especially the complexity introduced by cored passages is another consideration in determining tolerances which can be met. The accuracy and precision of cored passage dimensions may be limited by the ability to make cores which will resist bowing or sagging caused by their own size or shape and by the pressure of surrounding metal. The minimum diameter core which can be used successfully in steel castings is dependent upon three factors: 1) the thickness of the metal section surrounding the core, 2) the length of the core, and 3) the special precautions and procedures used by the foundry. The first two of these factors are functions of the design, and must be given consideration by the design engineer when the casting drawings are developed.

Dimension Type

Various dimension types are recognized (Figure 5) depending on whether they are controlled by the mold alone, by a core only, or by combinations of these, with and without the effect of the parting line.

Correction factors for dimensional tolerances, depending on their various dimension types, are given in Table 3. The correction factors in Table 3 are presented for comparison purposes only. They are not intended as guidelines for assigning tolerances on drawings. Dimensions controlled by a single core exhibit a variability of only 95% of the mold-to-mold dimension variability. This result is in line with the generally greater strength of the core material compared to the mold aggregate. Mold-to-mold dimensions across the parting line are 24% more variable, while mold-to-core dimensions are 39% more variable. The greater variability of these dimensions results from the "degrees of freedom" for movement introduced by the parting line in the first instance, and the exactness of fit of the core in the core print of the mold in the latter. Core-to-core dimensions crossing the parting line tend to exhibit the largest variation. Two degrees-of-freedom due to the fit of the core in the core print of the mold plus the parting line, on the one hand, and the fit of the two cores relative to each other in their respective core prints on the other hand, increase the variability. Thus, when a casting is in the design stages, consideration must be given to how each critical dimension will be formed by the various core/mold relationships. These aspects should be discussed with the producing foundry early in the planning to assure the best solutions.

TABLE 3 Effect* of Dimension Type on Dimensional Tolerance (2)

Dimension Type	Process Capability Correction Factor**
Wholly on one core—WC	.95
Mold-to-Mold—MM	1.00
MM across parting line—MM_{PL}	1.24
Mold-to-Core—MC	1.39
Core-to-Core—CC	1.57
MC across parting line—MC_{PL}	1.78

*These correction factors are presented for comparison purposes only. They are not intended as guide lines for assigning tolerances on drawings.
*Relative to MM type dimensions

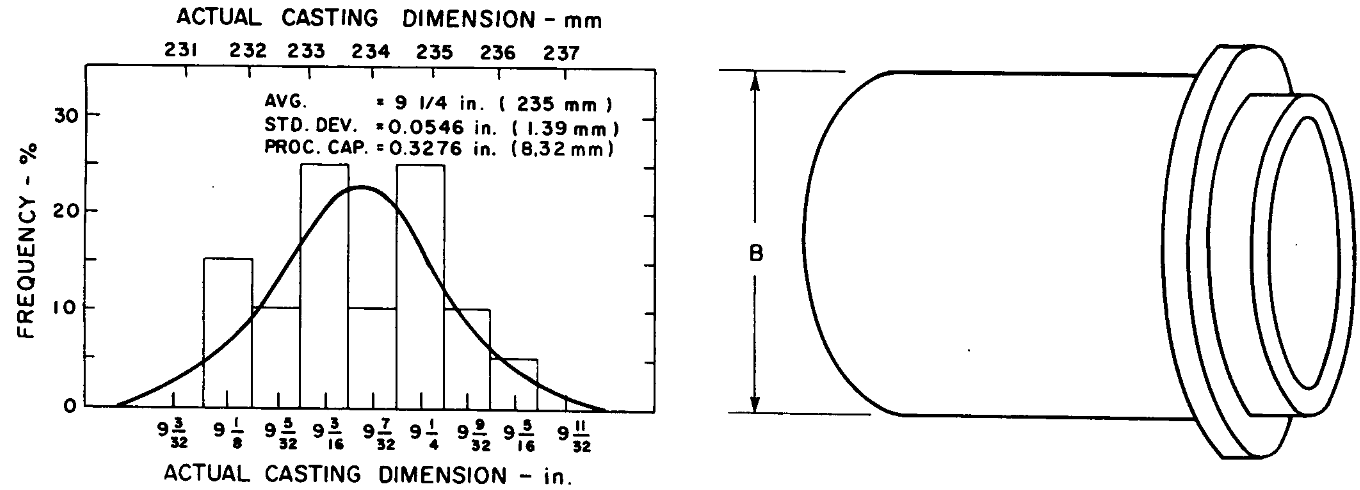

Fig. 6 Histogram and statistically determined distribution curve of actual casting dimensions held on dimension B of the bearing retainer pictured. The pattern was pine, mounted on cope and drag boards.

Pattern and Core Box Equipment

Conformance of casting dimensions to design dimensions is determined, to a marked degree, by the pattern employed in producing the casting. The pattern is of paramount importance because it must be constructed with dimensions that compensate for the contraction of the steel in the mold, i.e. the proper patternmakers' shrink rule must be applied. Also, the tolerances of castings produced from the same pattern by different foundries will usually not be identical. Each foundry differs somewhat in process capability and therefore has its own charateristic shrink rule which it employs when constructing new patterns. Conditions which may exist in one foundry are very likely to be different in another foundry. For example, the compactability of molding sands will differ from foundry to foundry, hence, mold walls will exhibit varying abilities to resist deformation by molten metal pressure.

Since the degree of hindered contraction tends to be characteristic of a foundry's set of operating conditions, it is wise to consult the foundry engineer for guidance prior to pattern construction. It is recommended that the foundry selected to make a particular casting also have control of pattern construction so that the experience of the foundry with regard to hindered contraction will help to minimize pattern alterations and their costs.

The expected length of the production run from a pattern is another consideration in choosing pattern materials. Dimensional variations from casting to casting within a lot will be greater for soft wood patterns than for metal patterns. This is illustrated in the histograms of Figures 6 and 7. These data show that for a similar dimension the process capability, or tolerances, which can be achieved on castings made with a pine pattern are much broader [standard deviation = 0.0546 in. (1.39 mm)] than for those made with aluminum pat-

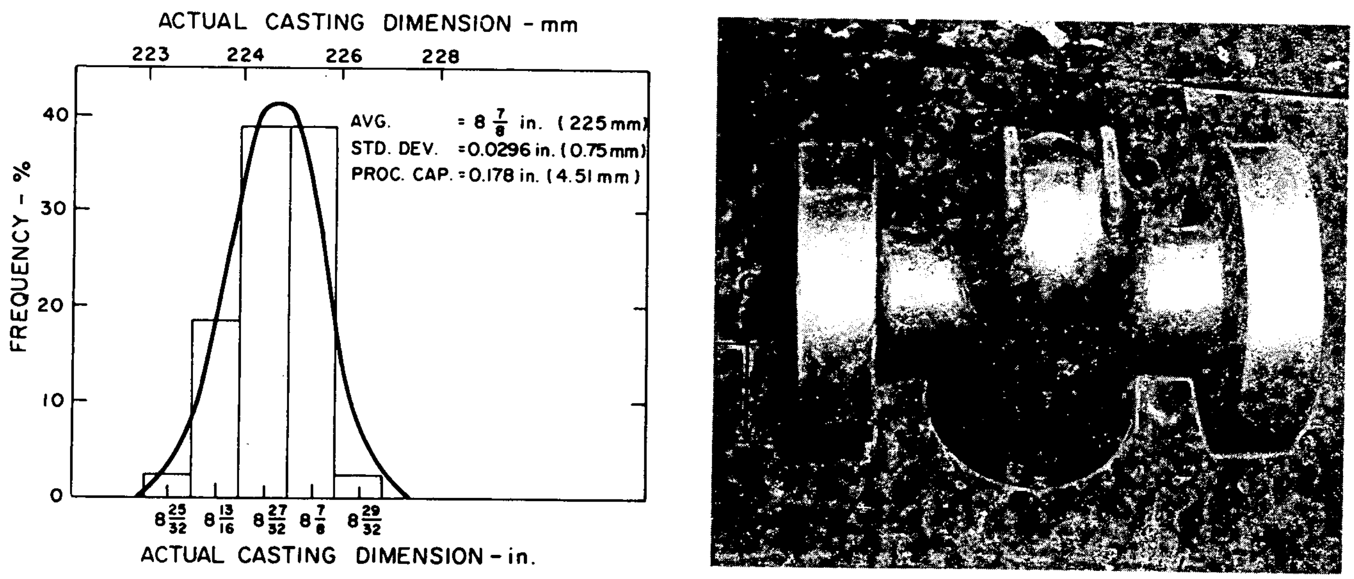

Fig. 7 Histogram and distribution curve of actual casting dimensions obtained on dimension G of the valve body shown. The casting was made from an aluminum pattern and mounted on cope and drag boards.

tern equipment [standard deviation = 0.0296 in. (0.75 mm)]. The greater variation associated with use of wood patterns is due to the sensitivity of wood to changes in moisture and its lower resistance to the effects of molding pressures.

The ability of the pattern material to resist wear should be considered when planning longer production runs. During extended production runs, as pattern surfaces wear, a gradual shift occurs in the average dimensions of a casting. Therefore, it is common to face wear surfaces of wooden patterns with metal to reduce variations associated with wear.

The following is a list of pattern equipment types, in order of decreasing dimensional variations which may be expected from casting to casting:

Loose Wood Pattern	Greatest Variation
Pine Pattern, mounted on cope and drag boards	
Hard Wood Pattern, mounted on cope and drag boards	
Plastic Pattern, mounted on cope and drag boards	
Metal Pattern, mounted on cope and drag boards	
Metal Matchplate	Least Variation

Wooden patterns may wear extensively during repeated use and expand or shrink significantly due to changes in humidity and temperature. Pine patterns are the least expensive, but can be used only for limited production due to wear. Plywood is useful for its reduced tendency to shrinkage and associated warping. Hardwood, certain plastic materials, and metal patterns are preferred for better wear resistance, dimensional stability, and rigidity. Metal patterns on rigid metal matchplates reduce dmensional variations significantly. Higher cost pattern equipment of this type is selected for long production runs and tighter dimensional tolerances. Loose soft wood patterns are preferred where few castings are to be produced and where tolerances can be sacrificed for economy and prompt delivery.

A summary of pattern equipment effects in Table 4 indicates that the dimensional tolerances of steel castings made with metal patterns, mounted on cope and drag boards, are 30% larger than those produced with metal matchplates. Similarly, mounted hardwood patterns require 60% larger tolerances, while loose wood patterns require 110% larger tolerances. The values in Table 4 are presented for comparison purposes only. They are not intended as guidelines for assigning tolerances on drawings.

TABLE 4 Relative Dimensional Tolerances* for Steel Castings Produced with Different Pattern Equipment in Green Sand Molds (2)

Pattern Equipment	Relative Dimensional Tolerances—%
Metal Matchplate	100
Metal Pattern Mounted on Wood	130
Wood Pattern Mounted on Wood	160
Loose Wood Patterns	210

*These relative dimensional tolerance values are presented for comparison purposes only.

When designing pattern equipment provisions should be made for 1) pattern alterations to meet the customer's tolerances, 2) convex or concave alterations to minimize the effect of warpage on areas that carry flatness tolerances, 3) adequate core prints for consistent core locations in tightly toleranced areas, 4) pattern and core box adjustments which may be needed so that the design dimensions agree with the averages obtained during production runs, and 5) alteration of areas carrying squareness tolerances.

Molding Processes

Significant factors in determining the tolerance range which can be held in a lot of castings are the molding process and production techniques. Table 5 is a general comparison of steel casting molding methods. The values presented in the table should be used for comparative purposes only and not as design tolerances to be placed on drawings.

Molding equipment also affects dimensional tolerance capabilities. For instance, high pressure green sand molding produces harder molds which resist mold wall movement more effectively. Tighter tolerances are thus possible for this type equipment. Among the conventional green sand molds produced on jolt squeeze machines, plain jolt machines, and sand slingers, smaller basic differences exist. The apparent effect of equipment used is usually due to the casting weight because each of the equipment types tends to be selected for certain casting size and weight ranges.

Casting Weight and Dimension Length

The casting weight has a very significant effect on dimensional variations, i.e. the ability to produce a given dimension consistently (Figure 8). Both the casting weight and the dimension length influence the process capability relative to dimensional tolerances in a nonlinear fashion as shown in the Equation 1. This equation reflects average results in the industry for heat-treated and shot-blasted castings up to 2000 lb (907 kg) which have not been upgraded by grinding to gage, pressing, coining, etc. (2). The equation also reflects some molding process and dimension type effects discussed above.

Equation 1

$$T = 0.01296\, W^{1/3} + 0.0221\, L^{1/3} - 0.00138$$

—0.04128 if no-bake molded
—0.04224 if shell molded
—0.03165 if the dimension is controlled by one core
+0.03336 if the dimension is controlled by two cores, or crosses a parting line.

The basic equation applies to green sand molding and to dimensions controlled by the mold only. The last four terms are used only when applicable.

The correlation coefficient of this equation, R^2, was 0.50. This coefficient represents the fraction of the data

TABLE 5 A General Comparison* of Steel Casting Methods

Casting Requirements	Green Sand	Chemically Bonded	Shell	Ceramic	Investment
Surface Smoothness	Fair	Fair	Good	Very Good	Excellent
Minimum Metal Section-in. (mm)	1/4 (6.4)	3/16 (4.8)	5/32 (3.9)	3/32 (4.8)	1/16 (1.6)
Base Tolerances for a 1-in. (25.4 mm) cube-in. (mm)	±0.030 (.76)	±0.020 (.51)	±0.008 (.20)	±0.006 (.15)	±0.005 (.13)
Added Tolerance-in. (mm) Across a Parting Face	±0.030 (.76)	±0.030 (.76)	±0.010 (.25)	±0.010 (.25)	No Parting
Intricacy	Fair	Good	Very Good	Extra Good	Excellent
Finish Allowances	Most	Most	Average	Least	Least
Adaptability	No Limit,	No Limit	Limited	Limited	Limited
Pattern Costs	Low	Low	High	Average	High
Lead Time	Shortest	Shortest	Long	Short	Longest

*Values are presented for comparison only and should not be used directly as design tolerances on drawings.

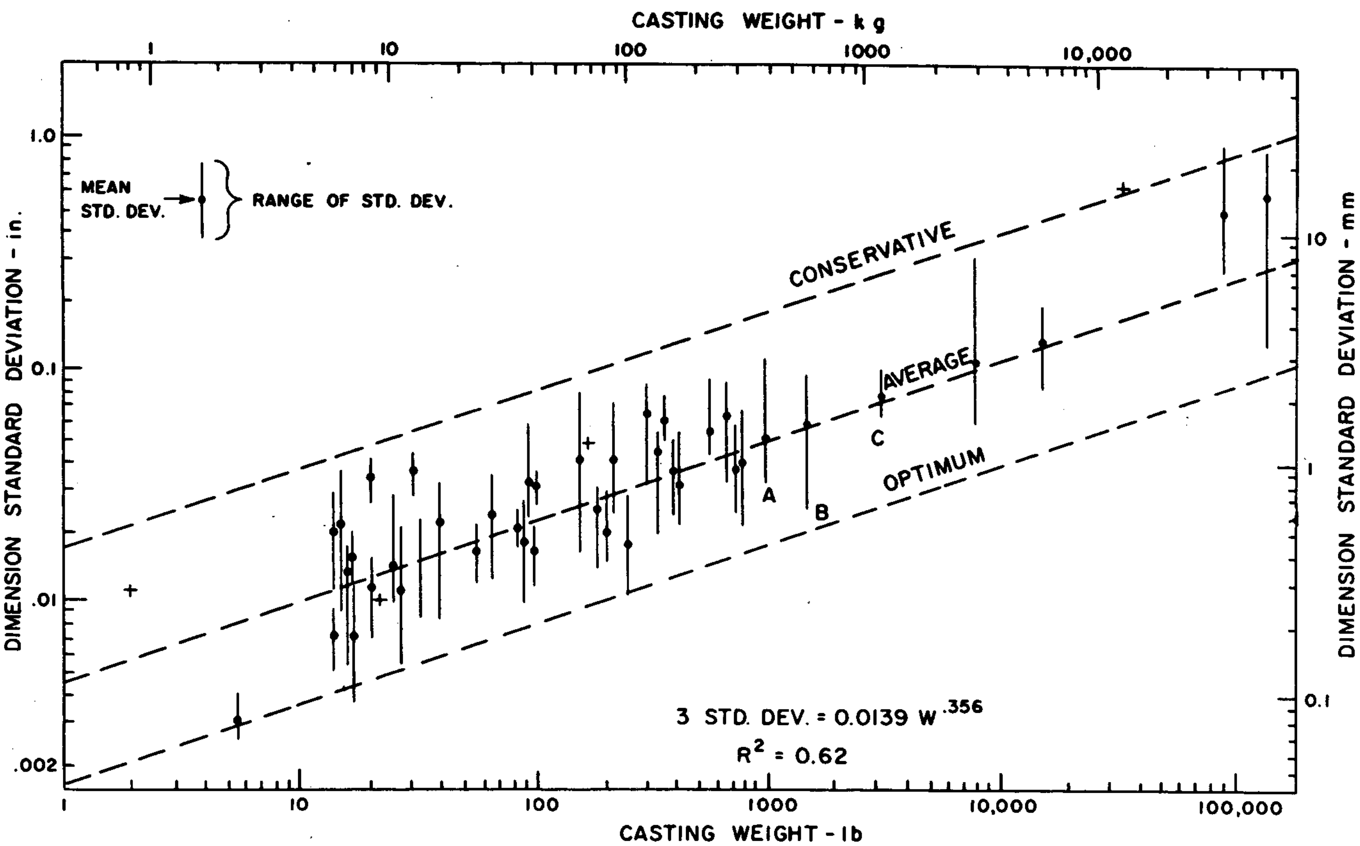

Fig. 8 The relation of casting weight to dimensional variability in terms of the standard deviation (2).

variation which the equation can account for. The error of estimation was 0.016 in. (0.41 mm) and the level of confidence was in excess of 99%. The term W for casting weight is expressed in pounds, those of the tolerance, T (where T is defined as the Process Capability, ±3σ, and is expressed in ± in.), and dimension length, L, are expressed in inches. Note that this equation is intended only to reflect relative effects of parameters that influence dimensional control capabilities and tolerances. Tolerances and tolerance grades are discussed in greater detail in the following paragraphs.

Gaging and Dimensional Upgrading

The tolerances for dimensions of as-cast surfaces are a matter for agreement between the producer and consumer of the castings. However, to minimize the rejection of castings for dimensional reasons the tolerances selected should be comparable to the process capability for the particular set of operating conditions under consideration. Tolerances tigher than the process capability will necessitate that the casting be subject to special processing to upgrade the dimensional characteristics. Table 6 lists some of the additional operations or special manufacturing processes which may be performed to provide castings within tolerance limits more concise than the natural process capability.

TABLE 6 Additional Operations Employed to Control to Concise Tolerances

1. Patterns
   - 1.1 Changes in construction, mounting and material (e.g., wood to metal matchplate).
   - 1.2 Alteration of patterns after production of pilot castings.
2. Molding and core making
   - 2.1 Changes in molds (e.g., green sand to shell or to CO_2 sand).
   - 2.2 Changes in cores (e.g., oil sand to shell).
   - 2.3 Mold and core setting gages
3. Finishing
   - 3.1 Gage grinding (e.g., belt sanding grinding or surface grinding to gage).
   - 3.2 Hand straighten to gage.
   - 3.3 Hydraulic press to gage.
   - *3.4 Coining to gage.
   - *3.5 Machine locating points.
   - *3.6 Rough machine to gage.
   - *3.7 Target machine casting.
   - *3.8 Finish machine part.

*Not all steel foundries offer these finishing operations.

Tight tolerances significantly affect the cost and delivery time of the castings. Most castings have only one or a few critical dimensions which require tight tolerances. Placing close limitations on dimensions which are not critical merely increases the final casting cost without benefit to the purchase. The operations listed in Table 6 lend themselves to a job shop or a short order; and their cost can be determined readily. These operations are also used on production of satisfying customer needs. The dimensional tolerances for cast surfaces need not be concise, if the casting is to be finished machined.

VALUE ANALYSIS OF DIMENSIONAL TOLERANCES

Value analysis is the best method of determining whether concise casting tolerances should be specified. If value analysis indicates that the narrow tolerance is not worth its cost, the obvious answer is not to spend the extra money necessary to control dimensions that tightly. On the other hand, a close tolerance may well save the customer much more than it costs the foundry to maintain the tolerance. In either case, both the customer and the foundry must be satisfied with the outcome of such an investigation. The best way to obtain mutual satisfaction is through a joint effort in the value analysis program.

Fig. 9 Unmachined link casting on right compared with the original machined forging.

An example of a value analysis program for concise dimensional tolerances is presented to illustrate accomplishments that can be obtained in a cooperative effort. Figure 9 shows a forged and machined link on the left while the link of the right is an unmachined, semi-precision steel casting. The tolerances on the machined forging are very close. The casting has three critical dimensions with concise tolerances. One of these dimensions, the bore diameter will suffice for the example. The forged part was bored and the hole diameter was specified as 1.250 ± 0.003 in. (31.75 ± 0.08 mm). The casting drawing dimension based on value analysis required a tolerance of ± 0.010 in. (0.254 mm).

The foundry considered the casting production method economical even though extra costs were incurred over the standard costs of producing a casting to more economical tolerances. The extra costs included the following: 1) alteration of pattern and core boxes twice and production of the necessary pilot castings (25 castings for each alteration), 2) 100% gage inspection, 3) belt sanding to gage on riser contacts, and 4) ream bores to gage on 25% of production.

The quality control department of the foundry required dimensional checks on the following: 1) shell core box prior to placing it in operation, and at the beginning and end of the production run, 2) core dimensions prior to placing them in the mold, 3) pouring rates and temperature, 4) bore dimensions after casting shakeout, and 5) dimensions after heat treating.

The pattern equipment was altered based on the tolerance information obtained from pilot castings and the second sample lot was produced under the same controlled procedures.

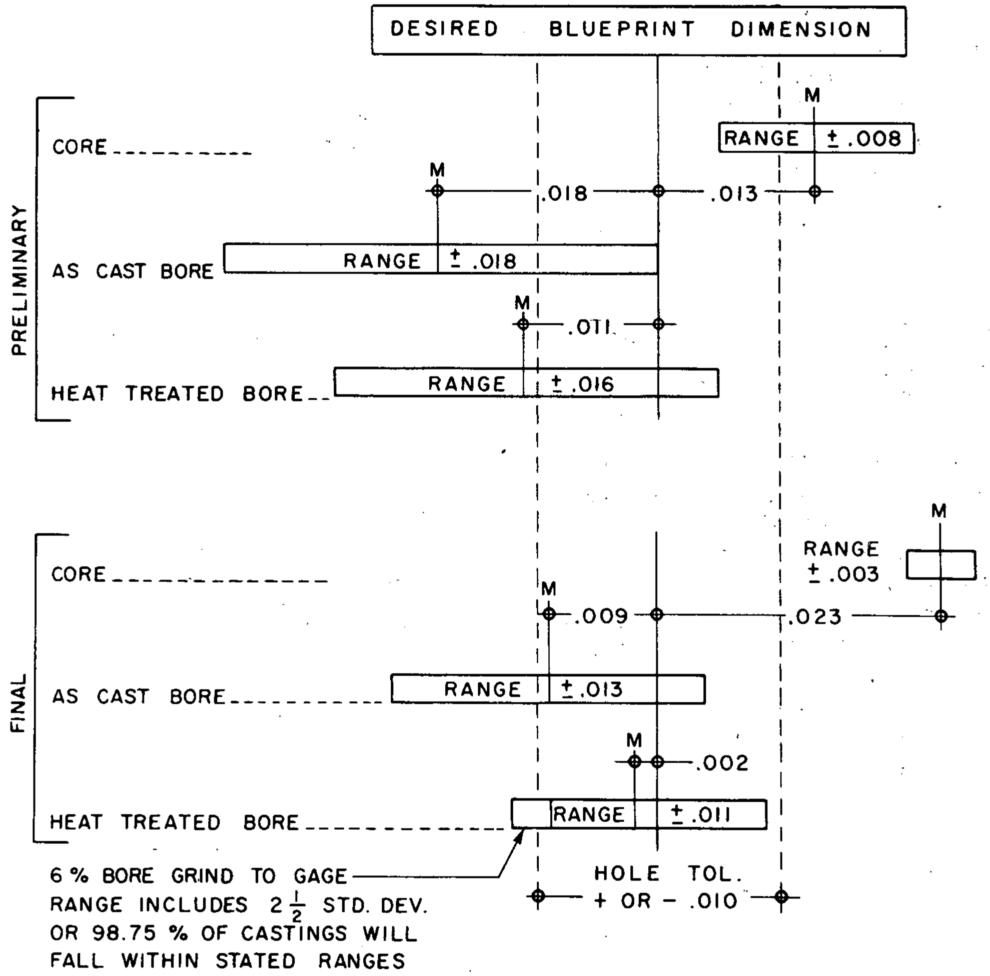

Fig. 10 Median dimensions and ranges of bore diameter of a link casting during various stages of processing (1 in. = 25.4 mm).

Figure 10 is a bar chart depicting graphically the results of the investigation. The preliminary tests showed the core dimension median was + 0.013 in. (0.33 mm) and the cast bore median was -0.018 in. (0.46 mm) from the drawing dimension. The difference between the medians is 0.031 in. (0.79 mm). The final core median was +0.023 in. (0.58 mm) and the final cast bore was -0.009 in. (0.23 mm). This is a 0.032 in. (0.81 mm) difference. The median measurement of the as-cast bore was -0.018 in. (0.46 mm) and the median of its preliminary heat treated bore was -0.011 in. (0.28 mm). This is a growth of 0.007 in. (0.18 mm). After all corrections, the difference between the final heat treated bore and the as-cast bore is again 0.007 in. (0.18 mm). The greatest correction was gained through altering the core box, because the casting required a multiple cavity core box to meet production requirements. Each box produced two cores with open ends, so the probability of error was multiplied rapidly. A gage grind operation for 6% of the production was put into the cost. The 125 ksi (862 MPa) yield strength link castings are used without machining and are 25% less expensive than the machined forgings.

TOLERANCES FOR PRODUCTION CASTINGS

The tolerances discussed in this section were developed from heat treated castings, which had not been gaged, and dimensionally upgraded. The tolerances discussed reflect the capabilities of the casting process. As mentioned earlier, tighter tolerances can be met with the aid of additional operations in the foundry, as listed in Table 6.

Tolerances are generally expressed in decimals or in thirty-seconds of an inch (±1/32 in., ±0.79 mm). Sometimes they are unsymmetrical such as +3/32 to -0 in. (+2.38 to -0 mm) when unique conditions, such as fits between male and female parts, are involved. The total variation would be ±3/64 in. (1.19 mm) and distributed about the average dimension which is not the design dimension. When unsymmetrical tolerances are specified, the foundry engineer will aim to meet the midpoint of the tolerance range rather than the design dimension in order to take best advantage of his process capability limits.

Tolerance Grades

Castings made for different applications will have different requirements with regard to the exactness of their dimensions. A series of tolerance grades is a practical means of communicating the needed tolerances to the foundry, and of explaining to the customers the ability of the foundry's process or processes, without subsequent dimensional upgrading. The generation of tolerance grades is therefore desirable, and five tolerance classes, T3—T7, have been established (2). These classes were established on the basis of a detailed SFSA study of 57 different production casting designs from 30 different foundries. The study included 1370 castings ranging from 2 to 131,000 lb (1 to 59,400 kg). A variety of molding processes and techniques were represented, including shell molding, no-bake molding, green sand molding, etc. Five tolerance grades, T3—T7, were developed, based on the relationship to casting weight and dimension length. The following equations define the tolerances (± in) for each of the grades:

$T3 = 0.005\ W^{1/3} + 0.022\ L^{1/3}$ Equation 2
$T4 = 0.010\ W^{1/3} + 0.022\ L^{1/3}$ Equation 3
$T5 = 0.016\ W^{1/3} + 0.022\ L^{1/3}$ Equation 4
$T6 = 0.027\ W^{1/3} + 0.022\ L^{1/3}$ Equation 5
$T7 = 0.044\ W^{1/3} + 0.022\ L^{1/3}$ Equation 6

The units in the above equations are pounds for weight and inches for length and tolerances. A visual comparison of the five grades is presented in Figure 11 without the effect of dimension length. The actual tolerances are depicted in Figures 12 through 16. Listings are provided for these tolerance classes in pounds and inches (Tables 7a through 11a), and in kilograms and millimeters (Tables 7b through 11b). The tightest tolerance class, T3, represents the least dimensional variation encountered in the study. The designation T3 was chosen to provide room for additional tolerance grades in the future and for specialized processes such as investment and ceramic molding. Tolerance grades T5 and T7 represent the average and greatest variation encountered, respectively. The intermediate grades, T4 and T6, were selected to provide for a geometric progression from T3 to T7.

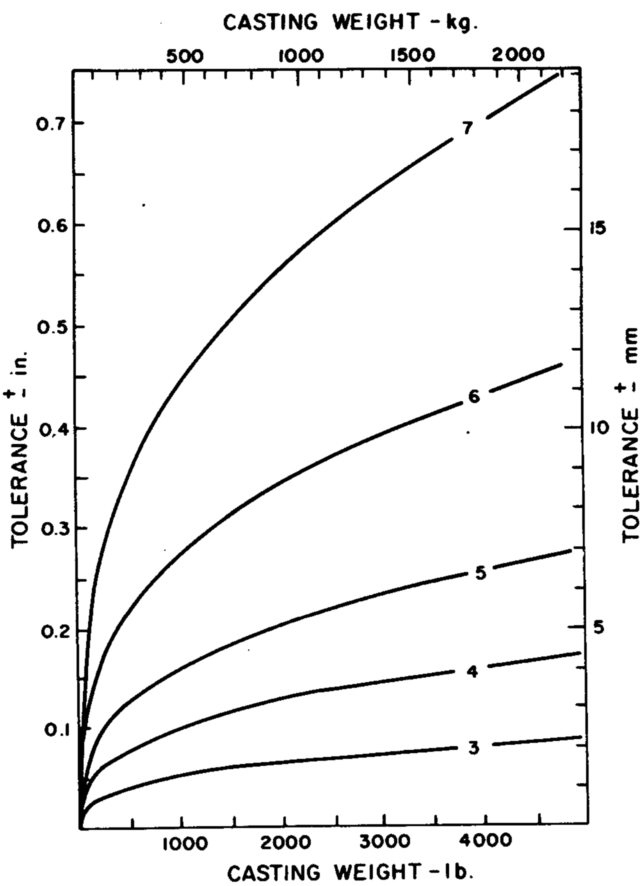

Fig. 11 Comparison of tolerance grades, without the effect of dimension length (2).

Tolerance Grade 3
Tolerances expected or exceeded by specialized processes, e.g. shell or no-bake processes

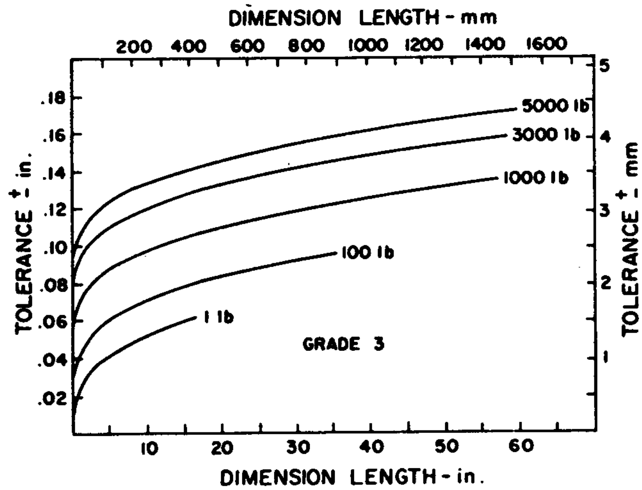

Fig. 12 Tolerance values for tolerance grade T3, effect of casting weight and dimension lengths (2).

Tolerance Grade 4

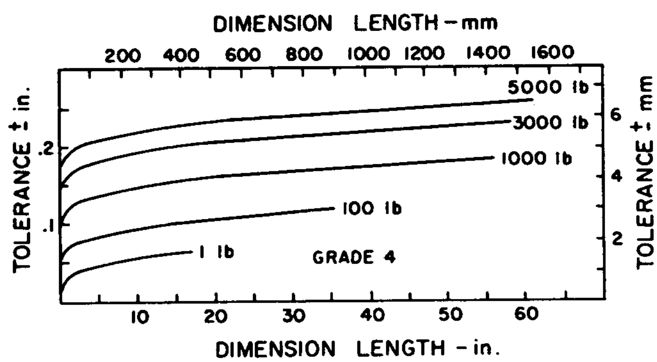

Fig. 13 Tolerance values for tolerance grade T4, effect of casting weight and dimension length (2).

Tolerance Grade 5
Tolerances representative of standard production techniques

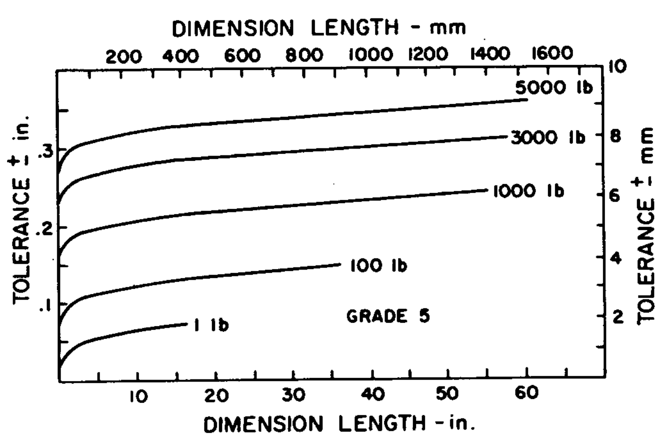

Fig. 14 Tolerance values for tolerance grade T5, effect of casting weight and dimension length (2).

Tolerance Grade 6

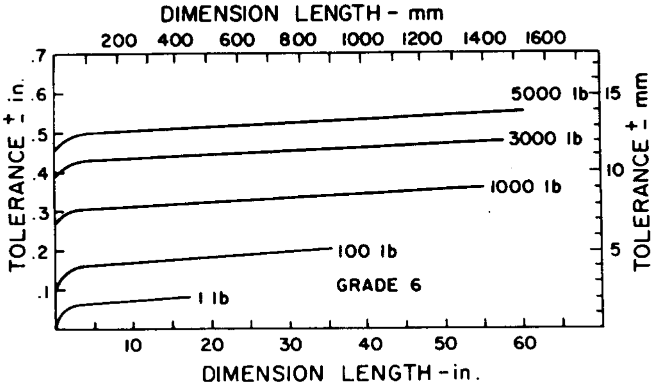

Fig. 15 Tolerance values for tolerance grade T6, effect of casting weight and dimension length (2).

Tolerance Grade 7

Tolerances that may be expected for complex casting configurations

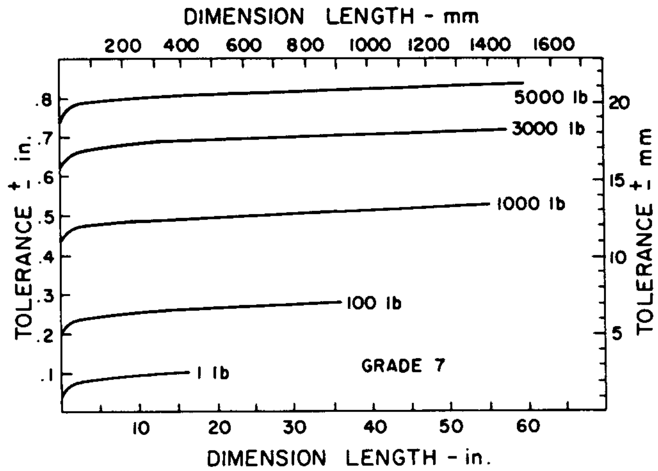

Fig. 16 Tolerance values for tolerance grade T7, effect of casting weight and dimension length (2).

To illustrate the use of the tolerance grades with an example, a 10 in. (254 mm) long dimension, according to the average industry Grade 5 (Table 9a), may be expected to be produced to ±0.12 in. (3 mm) for a 100 lb (45 kg) casting and to ±0.21 in. (5.3 mm) for a 1000 lb (454 kg) casting. A more reproducible process might be able to hold tolerances according to Grade T4 (Table 8a), i.e., ±0.09 in. (2.3 mm) and ±0.15 in. (3.8 mm), respectively.

The tolerance values in Tables 7a through 11a are listed for casting weights up to 5000 lb (2268 kg). Those in Tables 7b through 11b are listed for casting weights up to 2500 kg (5512 lb). Additional values can be computed using Equations 2 through 6. Computed values are within the limits of the SFSA studies up to casting weights of 131,000 lb (59,400 kg), even though such heavy castings are not made as "production castings."

TABLE 7a Tolerances (±inches) for Tolerance Grade T3 (2)

	Casting Weight, lb																		
L*	2	5	10	20		75	100	150	200	250	500	750	1000	1250	1500	2000	3000	4000	5000
.5	.024	.026	.028	.031	.036	.039	.041	.044	.047	.049	.057	.063	.068	.071	.075	.081	.090	.097	.103
1.0	.028	.031	.033	.036	.041	.043	.045	.049	.051	.054	.062	.068	.072	.076	.079	.085	.094	.101	.108
2.0	.034	.036	.039	.041	.046	.049	.051	.054	.057	.059	.068	.073	.078	.082	.085	.091	.100	.107	.113
4.0	.041	.044	.046	.049	.054	.056	.058	.062	.064	.067	.075	.081	.085	.089	.092	.098	.107	.114	.121
6.0	.046	.049	.051	.054	.059	.061	.063	.067	.069	.072	.080	.086	.090	.094	.097	.103	.112	.120	.126
8.0	.050	.053	.055	.058	.063	.065	.067	.071	.073	.076	.084	.090	.094	.098	.101	.107	.116	.124	.130
10.0	.054	.056	.058	.061	.066	.069	.071	.074	.077	.079	.087	.093	.098	.101	.105	.111	.120	.127	.133
15.0	.061	.063	.065	.068	.073	.076	.078	.081	.084	.086	.094	.100	.105	.108	.112	.117	.127	.134	.140
20.0	.066	.069	.071	.074	.078	.081	.083	.087	.089	.091	.100	.105	.110	.114	.117	.123	.132	.139	.145
30.0	.075	.077	.079	.082	.087	.090	.092	.095	.098	.100	.108	.114	.119	.123	.126	.132	.141	.148	.154
40.0	.082	.084	.086	.089	.094	.097	.099	.102	.105	.107	.115	.121	.126	.129	.133	.139	.148	.155	.161
50.0	.088	.090	.092	.095	.100	.103	.105	.108	.111	.113	.121	.127	.131	.135	.139	.144	.154	.161	.167
60.0	.093	.095	.097	.100	.105	.108	.110	.113	.116	.118	.126	.132	.137	.140	.144	.150	.159	.166	.172

*Dimension length in inches

TABLE 7b Tolerances (±mm) for Tolerance Grade T3

	Casting Weight, kg.																
L*	1	2	5	10	25	50	75	100	150	200	400	600	800	1000	1500	2000	2500
20	.68	.72	.80	.87	1.00	1.12	1.21	1.28	1.39	1.48	1.73	1.91	2.05	2.17	2.41	2.60	2.76
40	.82	.86	.93	1.01	1.13	1.26	1.35	1.42	1.53	1.62	1.87	2.04	2.18	2.30	2.54	2.73	2.89
80	.98	1.03	1.10	1.18	1.30	1.43	1.52	1.59	1.70	1.79	2.04	2.21	2.35	2.47	2.71	2.90	3.06
100	1.05	1.09	1.17	1.24	1.37	1.49	1.58	1.65	1.76	1.85	2.10	2.28	2.42	2.54	2.77	2.97	3.13
150	1.18	1.22	1.29	1.37	1.49	1.62	1.71	1.78	1.89	1.98	2.23	2.40	2.54	2.66	2.90	3.09	3.25
200	1.28	1.32	1.39	1.47	1.60	1.72	1.81	1.88	1.99	2.08	2.33	2.51	2.65	2.76	3.00	3.19	3.36
300	1.44	1.48	1.56	1.63	1.76	1.88	1.97	2.04	2.15	2.24	2.49	2.67	2.81	2.93	3.16	3.36	3.52
400	1.57	1.61	1.68	1.76	1.88	2.01	2.10	2.17	2.28	2.37	2.62	2.79	2.94	3.05	3.29	3.48	3.64
500	1.67	1.72	1.79	1.86	1.99	2.12	2.21	2.28	2.39	2.48	2.73	2.90	3.04	3.16	3.40	3.59	3.75
750	1.89	1.94	2.01	2.08	2.21	2.34	2.42	2.49	2.61	2.69	2.95	3.12	3.26	3.38	3.62	3.81	3.97
1000	2.07	2.11	2.18	2.26	2.38	2.51	2.60	2.67	2.78	2.87	3.12	3.30	3.44	3.55	3.79	3.98	4.14
1250	2.21	2.26	2.33	2.40	2.53	2.66	2.74	2.82	2.93	3.01	3.27	3.44	3.58	3.70	3.94	4.13	4.29
1500	2.34	2.38	2.46	2.53	2.66	2.79	2.87	2.94	3.05	3.14	3.39	3.57	3.71	3.83	4.07	4.26	4.42

*Dimension length in mm

TABLE 8a Tolerances (±inches) for Tolerance Grade T4 (2)

L*	Casting Weight, lb 2	5	10	20	50	75	100	150	200	250	500	750	1000	1250	1500	2000	3000	4000	5000
.5	.030	.035	.039	.045	.054	.060	.064	.071	.076	.081	.097	.108	.118	.125	.132	.144	.162	.176	.189
1.0	.035	.039	.044	.049	.059	.064	.069	.075	.081	.085	.101	.113	.122	.130	.137	.148	.166	.181	.193
2.0	.040	.045	.049	.055	.065	.070	.074	.081	.086	.091	.107	.119	.128	.136	.142	.154	.172	.187	.199
4.0	.048	.052	.057	.062	.072	.077	.081	.088	.094	.098	.114	.126	.135	.143	.150	.161	.179	.194	.206
6.0	.053	.057	.062	.067	.077	.082	.087	.093	.099	.103	.120	.131	.140	.148	.155	.166	.184	.199	.211
8.0	.057	.061	.066	.071	.081	.086	.091	.097	.103	.107	.124	.135	.144	.152	.159	.170	.188	.203	.215
10.0	.060	.065	.069	.075	.084	.090	.094	.101	.106	.111	.127	.138	.148	.155	.162	.174	.192	.206	.219
15.0	.067	.072	.076	.082	.091	.097	.101	.108	.113	.117	.134	.145	.155	.162	.169	.180	.199	.213	.226
20.0	.073	.077	.082	.087	.097	.102	.106	.113	.118	.123	.139	.151	.160	.168	.174	.186	.204	.219	.231
30.0	.081	.086	.090	.096	.106	.111	.115	.122	.127	.132	.148	.160	.169	.176	.183	.195	.213	.227	.240
40.0	.088	.093	.097	.103	.112	.118	.122	.129	.134	.139	.155	.166	.176	.183	.190	.202	.220	.234	.247
50.0	.094	.099	.103	.109	.118	.124	.128	.135	.140	.144	.161	.172	.181	.189	.196	.207	.226	.240	.252
60.0	.099	.104	.108	.114	.123	.129	.133	.140	.145	.150	.166	.177	.187	.194	.201	.213	.231	.245	.258

*Dimension length in inches

TABLE 8b Tolerances (±mm) for Tolerance Grade T4

L*	Casting Weight, kg. 1	2	5	10	25	50	75	100	150	200	400	600	800	1000	1500	2000	2500
20	.85	.93	1.08	1.23	1.48	1.73	1.91	2.05	2.27	2.45	2.95	3.30	3.59	3.82	4.30	4.68	5.00
40	.98	1.07	1.22	1.36	1.62	1.87	2.04	2.18	2.41	2.58	3.09	3.44	3.72	3.96	4.43	4.82	5.14
80	1.15	1.24	1.38	1.53	1.79	2.04	2.21	2.35	2.58	2.75	3.25	3.61	3.89	4.13	4.60	4.98	5.31
100	1.21	1.30	1.45	1.59	1.85	2.10	2.28	2.42	2.64	2.82	3.32	3.67	3.95	4.19	4.67	5.05	5.37
150	1.34	1.43	1.58	1.72	1.98	2.23	2.40	2.54	2.77	2.94	3.45	3.80	4.08	4.32	4.79	5.18	5.50
200	1.44	1.53	1.68	1.82	2.08	2.33	2.51	2.65	2.87	3.05	3.55	3.90	4.18	4.42	4.90	5.28	5.60
300	1.60	1.69	1.84	1.98	2.24	2.49	2.67	2.81	3.03	3.21	3.71	4.06	4.34	4.58	5.06	5.44	5.76
400	1.73	1.82	1.97	2.11	2.37	2.62	2.79	2.94	3.16	3.33	3.84	4.19	4.47	4.71	5.19	5.57	5.89
500	1.84	1.93	2.07	2.22	2.48	2.73	2.90	3.04	3.27	3.44	3.94	4.30	4.58	4.81	5.29	5.67	6.00
750	2.06	2.14	2.29	2.44	2.69	2.95	3.12	3.26	3.48	3.66	4.16	4.52	4.80	5.03	5.51	5.89	6.21
1000	2.23	2.32	2.47	2.61	2.87	3.12	3.30	3.44	3.66	3.83	4.34	4.69	4.97	5.21	5.69	6.07	6.39
1250	2.38	2.46	2.61	2.76	3.01	3.27	3.44	3.58	3.80	3.98	4.48	4.84	5.12	5.35	5.83	6.21	6.53
1500	2.51	2.59	2.74	2.89	3.14	3.39	3.57	3.71	3.93	4.11	4.61	4.96	5.25	5.48	5.96	6.34	6.66

*Dimension length in mm

TABLE 9a Tolerances (±inches) for Tolerance Grade T5 (2)

L*	Casting Weight, lb 2	5	10	20	50	75	100	150	200	250	500	750	1000	1250	1500	2000	3000	4000	5000
.5	.038	.045	.052	.061	.076	.085	.092	.103	.111	.118	.145	.163	.178	.190	.201	.219	.248		
1.0	.042	.049	.057	.066	.081	.090	.096	.107	.116	.123	.149	.167	.182	.194	.205	.224	.253	.276	.296
2.0	.048	.055	.062	.071	.087	.095	.102	.113	.121	.129	.155	.173	.188	.200	.211	.229	.259	.282	.301
4.0	.055	.062	.070	.079	.094	.103	.109	.120	.129	.136	.162	.180	.195	.207	.218	.237	.266	.289	.309
6.0	.060	.068	.075	.084	.099	.108	.114	.125	.134	.141	.167	.186	.200	.213	.223	.242	.271	.294	.314
8.0	.064	.072	.079	.088	.103	.112	.118	.129	.138	.145	.171	.190	.204	.217	.227	.246	.275	.298	.318
10.0	.068	.075	.082	.091	.107	.115	.122	.133	.141	.148	.175	.193	.208	.220	.231	.249	.278	.302	.321
15.0	.075	.082	.089	.098	.113	.122	.129	.140	.148	.155	.181	.200	.215	.227	.238	.256	.285	.308	.328
20.0	.080	.087	.094	.103	.119	.127	.134	.145	.154	.161	.187	.205	.220	.232	.243	.262	.291	.314	.334
30.0	.089	.096	.103	.112	.128	.136	.143	.154	.162	.169	.196	.214	.229	.241	.252	.270	.299	.323	.342
40.0	.096	.103	.110	.119	.135	.143	.150	.161	.169	.176	.203	.221	.236	.248	.259	.277	.306	.330	.349
50.0	.102	.109	.116	.125	.140	.149	.156	.166	.175	.182	.208	.227	.241	.254	.265	.283	.312	.335	.355
60.0	.107	.114	.121	.130	.145	.154	.161	.172	.180	.187	.214	.232	.247	.259	.270	.288	.317	.341	.360

*Dimension length in inches

TABLE 9b Tolerances (±mm) for Tolerance Grade T5

L*	Casting Weight, kg. 1	2	5	10	25	50	75	100	150	200	400	600	800	1000	1500	2000	2500
20	1.05	1.18	1.42	1.66	2.06	2.47	2.75	2.97	3.33	3.61	4.41	4.98	5.43	5.81	6.57	7.18	7.70
40	1.18	1.32	1.56	1.79	2.20	2.60	2.88	3.11	3.46	3.74	4.55	5.11	5.56	5.94	6.71	7.32	7.83
80	1.35	1.49	1.72	1.96	2.37	2.77	3.05	3.27	3.63	3.91	4.72	5.28	5.73	6.11	6.87	7.48	8.00
100	1.41	1.55	1.79	2.02	2.43	2.83	3.11	3.34	3.69	3.98	4.78	5.34	5.79	6.17	6.94	7.55	8.06
150	1.54	1.68	1.92	2.15	2.56	2.96	3.24	3.47	3.82	4.10	4.91	5.47	5.92	6.30	7.07	7.68	8.19
200	1.64	1.78	2.02	2.25	2.66	3.06	3.34	3.57	3.92	4.21	5.01	5.57	6.02	6.40	7.17	7.78	8.29
300	1.80	1.94	2.18	2.41	2.82	3.22	3.50	3.73	4.08	4.37	5.17	5.73	6.18	6.56	7.33	7.94	8.45
400	1.93	2.07	2.31	2.54	2.95	3.35	3.63	3.86	4.21	4.49	5.30	5.86	6.31	6.69	7.46	8.07	8.58
500	2.04	2.18	2.41	2.65	3.06	3.46	3.74	3.96	4.32	4.60	5.41	5.97	6.42	6.80	7.56	8.17	8.69
750	2.26	2.39	2.63	2.87	3.27	3.68	3.96	4.18	4.54	4.82	5.63	6.19	6.64	7.02	7.78	8.39	8.91
1000	2.43	2.57	2.81	3.04	3.45	3.85	4.13	4.36	4.71	4.99	5.80	6.36	6.81	7.19	7.96	8.57	9.08
1250	2.58	2.71	2.95	3.19	3.59	4.00	4.28	4.50	4.86	5.14	5.95	6.51	6.96	7.34	8.10	8.71	9.23
1500	2.71	2.84	3.08	3.32	3.72	4.13	4.41	4.63	4.99	5.27	6.07	6.64	7.09	7.47	8.23	8.84	9.36

*Dimension length in mm

TABLE 10a Tolerances (±inches) for Tolerance Grade T6 (2)

	Casting Weight, lb																	
L*	2	5	10	20	50	75	100	150	200	250	500	750	1000	1250	1500	2000	3000	4000	5000
.5	.052	.064	.076	.091	.117	.131	.143	.161	.175	.188	.232								
1.0	.056	.068	.080	.095	.122	.136	.147	.166	.180	.192	.236	.267	.292	.313	.331	.362	.412	.451	.484
2.0	.062	.074	.086	.101	.127	.142	.153	.171	.186	.198	.242	.273	.298	.319	.337	.368	.417	.456	.490
4.0	.069	.081	.093	.108	.135	.149	.160	.179	.193	.205	.249	.280	.305	.326	.344	.375	.424	.464	.497
6.0	.074	.086	.098	.113	.140	.154	.165	.184	.198	.210	.254	.285	.310	.331	.349	.380	.430	.469	.502
8.0	.078	.090	.102	.117	.144	.158	.170	.188	.202	.214	.258	.290	.314	.335	.353	.384	.434	.473	.506
10.0	.082	.094	.106	.121	.147	.161	.173	.191	.206	.218	.262	.293	.318	.338	.357	.388	.437	.476	.509
15.0	.089	.101	.113	.128	.154	.168	.180	.198	.212	.225	.269	.300	.325	.345	.364	.395	.444	.483	.516
20.0	.094	.106	.118	.133	.159	.174	.185	.203	.218	.230	.274	.305	.330	.351	.369	.400	.449	.489	.522
30.0	.103	.115	.127	.142	.168	.183	.194	.212	.227	.239	.283	.314	.339	.360	.378	.409	.458	.497	.530
40.0	.110	.122	.134	.149	.175	.189	.201	.219	.233	.246	.290	.321	.346	.366	.385	.416	.465	.504	.537
50.0	.115	.128	.140	.155	.181	.195	.207	.225	.239	.252	.296	.327	.351	.372	.390	.422	.471	.510	.543
60.0	.121	.133	.145	.160	.186	.200	.212	.230	.244	.257	.301	.332	.357	.377	.396	.427	.476	.515	.548

*Dimension length in inches

TABLE 10b Tolerances (±mm) for Tolerance Grade T6

	Casting Weight, kg.															
L*	1	2	5	10	25	50	75	100	150	200	400	600	800	1000	1500	2000	2500
20	1.41	1.64	2.04	2.44	3.13	3.80	4.28	4.66	5.26	5.74	7.09	8.04	8.80	9.44	10.73	11.76	12.63
40	1.54	1.77	2.18	2.57	3.26	3.94	4.41	4.79	5.39	5.87	7.23	8.18	8.94	9.58	10.87	11.90	12.76
80	1.71	1.94	2.35	2.74	3.43	4.11	4.58	4.96	5.56	6.04	7.40	8.35	9.11	9.75	11.04	12.07	12.93
100	1.77	2.01	2.41	2.81	3.49	4.17	4.65	5.03	5.63	6.10	7.46	8.41	9.17	9.81	11.10	12.13	13.00
150	1.90	2.13	2.54	2.93	3.62	4.30	4.77	5.15	5.75	6.23	7.59	8.54	9.30	9.94	11.23	12.26	13.12
200	2.00	2.24	2.64	3.03	3.72	4.40	4.88	5.25	5.85	6.33	7.69	8.64	9.40	10.04	11.33	12.36	13.23
300	2.17	2.40	2.80	3.20	3.88	4.56	5.04	5.42	6.02	6.49	7.85	8.80	9.56	10.20	11.49	12.52	13.39
400	2.29	2.53	2.93	3.32	4.01	4.69	5.16	5.54	6.14	6.62	7.98	8.93	9.69	10.33	11.62	12.65	13.52
500	2.40	2.63	3.04	3.43	4.12	4.80	5.27	5.65	6.25	6.73	8.09	9.04	9.80	10.44	11.73	12.76	13.62
750	2.62	2.85	3.25	3.65	4.34	5.02	5.49	5.87	6.47	6.95	8.30	9.26	10.01	10.65	11.95	12.97	13.84
1000	2.79	3.03	3.43	3.82	4.51	5.19	5.67	6.04	6.64	7.12	8.48	9.43	10.19	10.83	12.12	13.15	14.02
1250	2.94	3.17	3.57	3.97	4.66	5.34	5.81	6.19	6.79	7.27	8.62	9.58	10.33	10.97	12.27	13.29	14.16
1500	3.07	3.30	3.70	4.10	4.79	5.46	5.94	6.32	6.92	7.40	8.75	9.70	10.46	11.10	12.39	13.42	14.29

*Dimension length in mm

TABLE 11a Tolerances (±inches) for Tolerance Grade T7 (2)

	Casting Weight, lb																	
L*	2	5	10	20	50	75	100	150	200	250	500	750	1000	1250	1500	2000	3000	4000	5000
.5	.073	.093	.112	.137	.180	.203	.222												
1.0	.078	.097	.117	.142	.184	.208	.226	.256	.279	.299	.371	.422	.462						
2.0	.083	.103	.123	.147	.190	.213	.232	.262	.285	.305	.377	.428	.468	.502	.532	.582	.662		
4.0	.091	.110	.130	.155	.197	.221	.239	.269	.292	.312	.384	.435	.475	.509	.539	.589	.670	.734	.787
6.0	.096	.115	.135	.160	.202	.226	.244	.274	.297	.317	.389	.440	.480	.514	.544	.595	.675	.739	.793
8.0	.100	.119	.139	.164	.206	.230	.248	.278	.302	.321	.393	.444	.484	.518	.548	.599	.679	.743	.797
10.0	.103	.123	.142	.167	.210	.233	.252	.281	.305	.325	.397	.447	.488	.522	.551	.602	.682	.746	.800
15.0	.110	.130	.149	.174	.217	.240	.259	.288	.312	.332	.404	.454	.495	.528	.558	.609	.689	.753	.807
20.0	.115	.135	.155	.179	.222	.246	.264	.294	.317	.337	.409	.460	.500	.534	.564	.614	.695	.758	.812
30.0	.124	.144	.163	.188	.231	.254	.273	.302	.326	.346	.418	.468	.509	.543	.572	.623	.703	.767	.821
40.0	.131	.151	.170	.195	.238	.261	.280	.309	.333	.353	.425	.475	.516	.550	.579	.630	.710	.774	.828
50.0	.137	.157	.176	.201	.244	.267	.286	.315	.339	.359	.431	.481	.521	.555	.585	.636	.716	.780	.834
60.0	.142	.162	.181	.206	.249	.272	.291	.320	.344	.364	.436	.486	.527	.560	.590	.641	.721	.785	.839

*Dimension length in inches

TABLE 11b Tolerances (±mm) for Tolerance Grade T7

	Casting Weight, kg.															
L*	1	2	5	10	25	50	75	100	150	200	400	600	800	1000	1500	2000	2500
20	1.97	2.35	3.00	3.65	4.77	5.87	6.65	7.27	8.24	9.02	11.23	12.78	14.02	15.06	17.17	18.84	20.26
40	2.10	2.48	3.14	3.78	4.90	6.01	6.78	7.40	8.38	9.16	11.37	12.92	14.15	15.20	17.30	18.98	20.39
80	2.27	2.65	3.31	3.95	5.07	6.18	6.95	7.57	8.55	9.33	11.54	13.09	14.32	15.37	17.47	19.15	20.56
100	2.34	2.72	3.37	4.02	5.14	6.24	7.02	7.63	8.61	9.39	11.60	13.15	14.39	15.43	17.53	19.21	20.62
150	2.46	2.84	3.50	4.14	5.26	6.37	7.14	7.76	8.74	9.52	11.73	13.28	14.51	15.56	17.66	19.34	20.75
200	2.57	2.94	3.60	4.25	5.37	6.47	7.25	7.86	8.84	9.62	11.83	13.38	14.62	15.66	17.76	19.44	20.85
300	2.73	3.11	3.76	4.41	5.53	6.63	7.41	8.02	9.00	9.78	11.99	13.54	14.78	15.82	17.92	19.60	21.02
400	2.86	3.23	3.89	4.53	5.65	6.76	7.54	8.15	9.13	9.91	12.12	13.67	14.90	15.95	18.05	19.73	21.14
500	2.96	3.34	4.00	4.64	5.76	6.87	7.64	8.26	9.24	10.02	12.23	13.78	15.01	16.06	18.16	19.84	21.25
750	3.18	3.56	4.21	4.86	5.98	7.09	7.86	8.48	9.46	10.23	12.45	14.00	15.23	16.27	18.38	20.05	21.47
1000	3.36	3.73	4.39	5.03	6.15	7.26	8.04	8.65	9.63	10.41	12.62	14.17	15.40	16.45	18.55	20.23	21.64
1250	3.50	3.88	4.54	5.18	6.30	7.41	8.18	8.80	9.78	10.55	12.77	14.32	15.55	16.59	18.70	20.38	21.79
1500	3.63	4.01	4.66	5.31	6.43	7.54	8.31	8.93	9.91	10.68	12.89	14.45	15.68	16.72	18.83	20.50	21.92

*Dimension length in mm

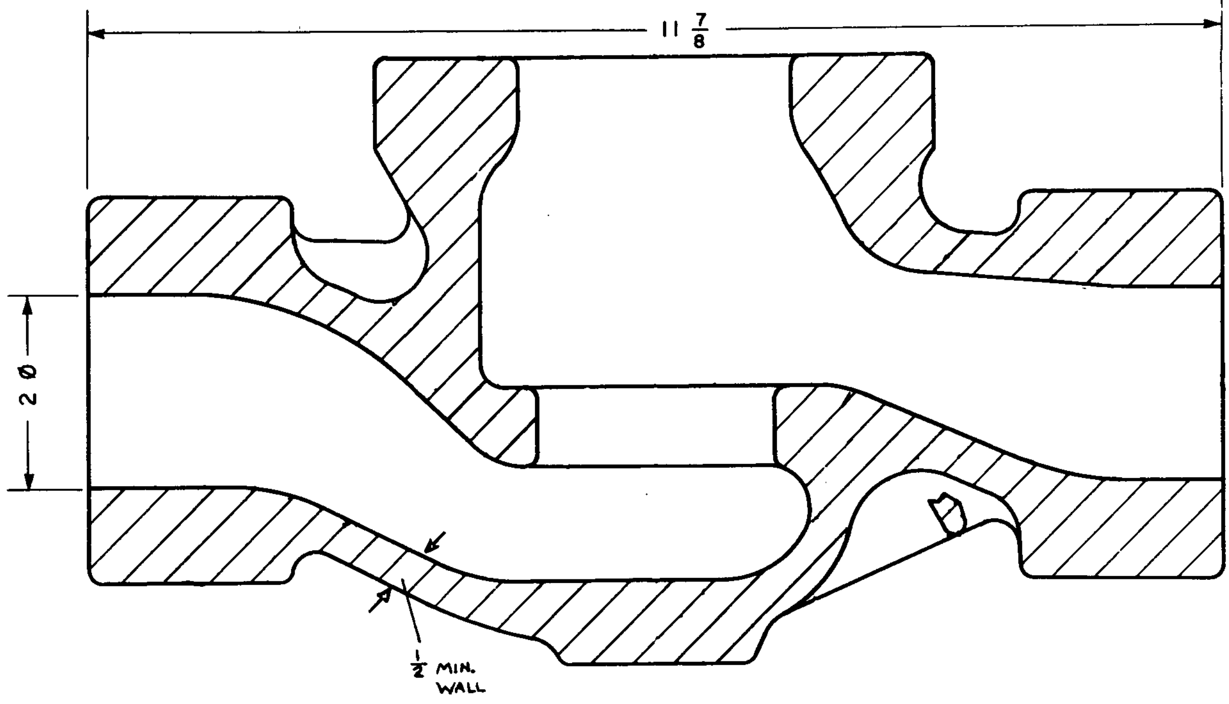

Fig. 17 Casting drawing of section through valve (dimensions in inches, conversion: 1 in. = 25.4 mm)

Suggested Use of Tolerance Grades

The tolerance grades T3 through T7 are applicable to heat treated and shotblasted production steel castings which have not been upgraded by gaging, grinding, coining, pressing, or other dimensional upgrading procedures.

Tolerances for dimensions which cross a parting line or which are controlled by two or more cores should be increased by 0.03 in. (0.8 mm) or selected according to the next higher tolerance grade.

The five grades, and additional grades which can be computed by multiplying the one third power of casting weight by an appropriate factor, represent different degrees of process capability as determined by the number of pattern adjustments which can be performed and the processes available for casting production.

The lower number tolerance grades are more applicable to investment, shell, and no-bake molding methods. Higher number tolerance grades are applicable to many green sand molding processes where few pattern changes and/or process adjustments can be made.

The tolerance series is intended as mutual information between foundries and customers on dimensional deviations. A customer can express what dimensional accuracy is desired. A foundry can, with reference to the tolerance grade, give information on which tolerance grade or grades it normally attains with different molding methods.

It is recommended that the customer ask the foundry about the dimensional accuracy obtained with different molding methods and resources at its disposal. With this knowledge, the designer can decide if closer tolerances are needed for selected dimensions.

For critical dimensions, a foundry may be able to achieve closer tolerances than normally possible by, for instance, applying special measures which control the position of a core in the mold. Even tighter tolerances than those represented by Grades T3 through T7 can be achieved by suitable upgrading operations or special processes which, in turn, add to the cost of the casting but may reduce the cost of the finished part.

Examples. The preceding parts of this presentation have emphasized the very important effect of pattern equipment and foundry techniques relative to the tolerances which can be achieved. Tolerances should therefore be discussed with the foundry engineer of the prospective casting manufacturer because he alone can evaluate the capabilities of the foundry's equipment and processes relative to the part to be produced, and the pattern which may be available from the customer. As a first estimate of the tolerances that can be met by production castings, tolerance grade T5 (Tables 9a, 9b) should be selected if a green sand molding process is to be used, tolerance grade T4 (Tables 8a, 8b) when no-bake molding is to be employed, and tolerance grade T3 (Tables 7a, 7b) for shell molding. Values for production casting tolerances obtained in this manner will in most instances be conservative, and tighter tolerances will be possible in some cases depending on the type of pattern, core boxes and their condition.

The 30 lb valve casting in Figure 17 could be produced by either green sand molding, no-bake, or shell molding using cores made from oil, no-bake, or shell sand. The tolerances for several dimensions are discussed below for illustration purposes.

Flange-to-flange Distance of 11-7/8 in.. Since the Tables do not list the tolerances for the exact dimension of 11 7/8 in., and the weight of 30 lb, equations 2 through 4 can be employed, and yield the following values for the tolerance grades T3 through T5:

T3	±0.066 in.
T4	±0.081 in.
T5	±0.100 in.

By comparison the tolerance values for a 20 lb casting with a 10 in. dimension can be determined from Tables 7a through 9a to be 0.061, 0.075, and 0.091 in., respectively. For the purposes of illustrating the use of the tolerance grade system, and the effect of manufacturing considerations, these differences are not significant as shown below:

Tolerance Grade	Computed for W=30 lb and L=11-7/8 in.	From Tables for W=20 lb and L=10 in.
T3	± 0.066 in.	± 0.061 in.
T4	± 0.081	± 0.075
T5	± 0.100	± 0.091

For the three common molding methods considered above, shell molding is readily seen to achieve the tighest tolerance, followed by no-bake molding, and finally the conventional green sand molding process. Again, it should be kept in mind that these values are merely first guidelines. The foundry engineer of the prospective supplier will be able to assess the tolerances more closely based on his experience, the equipment available in the foundry, the core boxes, and the pattern. He will also be able to suggest where tighter tolerances can be achieved and the impact of these on the casting cost.

Flange I.D. of 2 in.. If the core employed to produce the internal configuration of the component is produced as a one-piece core, tighter tolerances are possible, compared to the use of split cores which must be glued together and which may therefore be slightly out of round. Tolerance grade T4 should be selected as a first approach for cores produced from no-bake, and oil bonded and baked cores. Tolerance grade T3 is applicable for cores made from shell molded sand.

Tolerance Grade	Split Core From Tables, W=20 lb	One-Piece Core From Tables, W=20 lb
T3	—	± 0.041 in.
T4	± 0.055 + 0.03 = 0.085 in.	± 0.055

For split cores an extra allowance of 0.03 in. was made to allow for the parting line between the glued core halves. This parting line allowance has been discussed previously under the heading "Suggested Use of Tolerances." Shell cores are always made as one-piece construction where small diameters are involved, such as the 2 in. (51 mm) core for this valve. No entry was therefore made above for the tolerance of a split core according to tolerance grade T3. An alternate approach to accounting for the parting line, consisting of choosing the next higher tolerance grade, was suggested in the preceding section on "Suggested Use of Tolerance Grades." This approach gives very small allowances for short dimensions, and should only be employed when the casting weight, and dimension involved are considerably larger, i.e. when the tolerance of two adjacent tolerance grades is 0.03 in. (.7614 mm) or more. Tighter allowances are to be taken only on the advice of the foundry engineer of the foundry producing the part.

Wall Thickness of 1/2 inch. Since a minimum value is usually required for wall thicknesses (for valves) and since weld repair for wall thickness reasons is often impossible or impracticable, tolerances are typically chosen as one-sided, i.e. -0, + two times the table value for the tolerance grade. The tolerances determined in this manner are therefore:

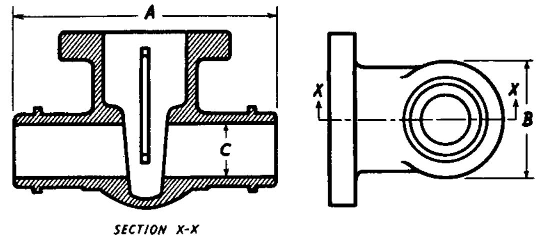

Fig. 18 Casting drawing of a 67 lb. valve.

Tolerance Grade	From tables, W=20 lb T=0.5 in.
T3	0.031 x 2 = ±0.062 in.
T4	0.045 x 2 = ±0.090
T5	0.061 x 2 = ±0.122

The above example represents a situation where the tolerances have to be estimated, on the basis of the casting process capability without upgrading. Two additional examples are presented below showing actual tolerances obtained without upgrading, and the tolerances that one would estimate from the tolerance grade tables.

The 67 lb valve body shown in Figure 18 was produced with green sand molds, using a hardwood pattern that was mounted on cope and drag boards. Shown below are the tolerances computed for three dimensions, as well as the deviations from the nominal dimensions.

Dimension Identi-fication	Length	Tolerance from Tables Grade	in.	Actual Data Most Freq. Dev. +	-	Max. Deviation +	-
A	14.7 in.	T5	±0.122	0	0.093 in.	0	0.156 in.
B	6.5	T5 0.108+0.03	=±0.138	0.063 in.	0	0.094 in.	0.031
C	3.0	T3	±0.056	0.031	0.031	0.031	0.031

The data show good agreement with the tolerance values taken from the tables. Tolerance grade T5 was chosen for the A Dimension and the B Dimension because they are controlled by the green sand mold. A parting line factor was also used for the A dimension because it is controlled by the two mold halves. The tolerance grade T3 was selected for the C Dimension because it is controlled by a one-piece shell mold core.

The cast transmission housing in Figure 19 weighs 408 lb, and was made by green sand molding, utilizing a hardwood pattern mounted on cope and drag boards.

Dimension Identi-fication	Length	Tolerance from Tables Grade	in.	Actual Data Most Freq. Dev. +	-	Max. Deviation +	-
A	15.1 in.	T50.181+0.03=	±0.211	0.015 in.	0	0.031 in.	0.062 in.
B	7.5	T4	±0.124	0.062	0.015 in.	0.125	0.031
C	42.2	T5	±0.203	0	0.093	0	0.187
D	16	T5	±0.181	0	0.031	0.062	0.062
E	1.25	T5	±0.149	0.062	0	0.125	0.125
F	0.56	T50.145x2=	+0.290,-0	0.062	0	0.125	0

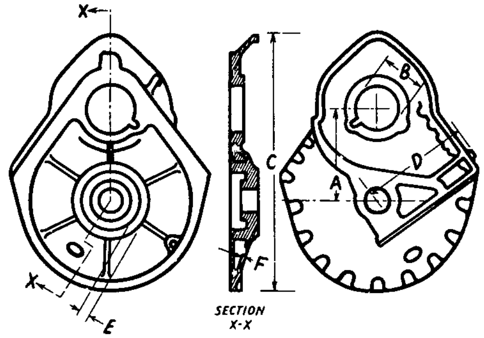

Fig. 19 Casting drawing of a 408 lb. transmission housing.

TABLE 13 Suggested Shape Tolerances for Steel Castings (Green Sand Molded)

Straightness	.010 in. per in. (1%)
Parallelism	1/64 in. per in. (1.56%)
Perpendicularity	1/64 in. per in. (1.56%)
Out of Round	
1/2 in. (13 mm) diameter	3/64 in. (1.19 mm) TIR*
1 in. (25 mm) diameter	2/32 in. (1.58 mm) TIR
2 in. (51 mm) diameter	4/32 in. (3.18 mm) TIR
Concentricity	
Largest diameter up to 5 in. (127 mm)	3/64 in. (2.38 mm) TIR
Each additional 3 in. (76 mm) add	1/64 in. (.40 mm)

*TIR—Total Indicator Reading

The selection of tolerance grades followed the same principles outlined for the preceding examples. The table value of the tolerance was increased 0.03 in. (.7614 mm) as discussed earlier, under the heading "Suggested Use of Tolerances". For the dimension F, which represents a wall thickness, a one-sided tolerance was selected because the actual wall must not be less than a certain value specified by the designer. The comparison of the actually observed dimensional variations with the tolerances selected from the tables indicates good agreement, and in many instances less variation than might be expected from the values obtained from tolerance grades T5 and T4.

TOLERANCES FOR SINGLE CASTINGS

Tolerances for single castings or a few castings produced from a given pattern should be established in close cooperation with the foundry that produces the casting(s). As a first estimate, these tolerances may be selected according to tolerance grade T7 from Tables 11a and 11b. Compared to production castings larger tolerances are required because the design characteristics of the casting are a major factor in tolerances which can be held without upgrading. An experienced foundry engineer can, in many instances, estimate the amount of hindered contraction that will occur on any given dimension, but only trial by actual production will show precisely how the casting will behave. Tolerances for the production of single castings or short orders should be liberal in order to accommodate the undetermined contraction behavior.

TOLERANCES FOR SPECIAL CASTING PROCESSES

A number of special casting processes are being used, some of which yield castings with closer tolerances than possible with the conventional processes discussed in the previous sections. Among these processes are the vacuum molding, or V process, ceramic molding, semi-permanent and permanent molding processes, and the investment casting process. Ceramic molding, semi-permanent, and the permanent mold casting processes are often specialized to certain products and in some cases alloys. Information on tolerances for these processes, and the V process that has been adopted in recent years by several U.S. steel foundries should be obtained directly from the foundries that employ these processes. A brief summary on tolerances for investment castings is presented below.

Investment Casting

Very close dimensional tolerances can be held on small steel castings which are produced by precision investment molding (Table 12). These average tolerances are normally expected values for steel castings in quantity and are for general guidance only. Premium tolerances are those which require added operations at extra cost, and provide for close tolerances on selected dimensions. If a casting has a number of particularly critical dimensions then these should be identified clearly on the drawing. The need for close consultation between the investment caster and customer cannot be overemphasized.

SHAPE TOLERANCES

To completely describe the shape of a component and to set tolerances on its shape, in addition to those on dimensions, tolerances are needed for such factors as parallelism, concentricity, angles, etc.

For conventional molding techniques for steel castings these shape tolerances are summarized in Table 13. For shell molded castings the shape tolerances are contained in the earlier Table 14. For investment molded castings, Table 15 is presented.

TABLE 12 Linear Tolerances of Investment Castings (3)

Dimension-in. (mm)	Tolerances-in. (mm) Normal*	Premium**
1/2 (13)	± .007 (.18)	± .003 (.08)
1 (25)	± .010 (.25)	± .005 (.13)
2 (51)	± .013 (.33)	± .008 (.20)
4 (102)	± .019 (.48)	± .012 (.30)
6 (152)	± .025 (.64)	± .015 (.38)
10 (254)	± .040 (1.02)	± .020 (.51)

*Normal is defined as those tolerances that can be expected for production repeatability on most casting dimensions.

**Premium tolerances are those tolerances which require additional operations at extra cost.

TABLE 14 Suggested Shape Tolerances for Shell Molded Castings

Mold parting + .010 in. (.25 mm)
Draft .002 in. per in. (.11°) minimum
Hole Diameter ± .005 in. per in. (.5%)
Concentricity .02 in. per in. (2%)
Angular Tolerance ± 45 minutes

TABLE 15 Suggested Shape Tolerances for Investment Castings (3)

Flatness and Straightness

The casting geometry is often the critical factor in control of overall flatness, straightness and dishing; customers should fully discuss dimensional requirements with the investment caster so as to take full advantage of his experience.

Flatness

Casting Length in. (mm)	As Cast in. (mm)	Mechanically Straightened in. (mm)
1 (25)	±.008 (.20)	±.004 (.10)
2 (51)	±.015 (.38)	±.006 (.15)
4 (102)	±.025 (.64)	±.010 (.25)
6 (152)	±.030 (.76)	±.015 (.38)

Straightness

Casting Length in. (mm)	As Cast in. (mm)	Mechanically Straightened in. (mm)
2 (51)	±.020 (.51)	±.010 (.25)
4 (102)	±.030 (.76)	±.020 (.51)
6 (152)	±.050 (1.27)	±.025 (.64)

Parallel Sections

Parallelism can be maintained to a tolerance of ±.005 in. (.13 mm) by the use of 'ties' to help control casting distortion. Typical figures are as follows:

Gap Size in. (mm)	Tolerance As Cast in. (mm)	Tolerance Straightened in. (mm)
1/4 (6.4)	±.003 (.08)	±.003 (.08)
1/2 (13)	±.005 (.13)	±.004 (.10)
1 (25)	±.007 (.18)	±.005 (.13)
1-1/2 (38)	±.010 (.25)	±.007 (.18)

PROFILE TOLERANCES

Profile tolerances were developed as a locating and tolerancing system to control the orientation of rough parts in a fixture and to provide a predictable amount of stock to be machined. In essence, an ideal or "perfect" profile is established for all casting surfaces and features. This perfect profile is surrounded by a "tolerance envelope"—the actual cast surface may exist anywhere within this envelope and still be considered acceptable. This is schematically depicted in Figure 20.

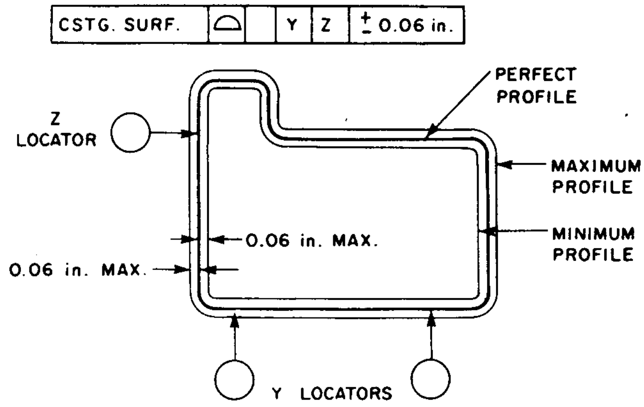

Fig. 20 Perfect profile of a casting surrounded by tolerance envelope. Conversion: 1 in. = 25.4 mm (4).

Three datum planes are established at right angles to each other. This is done through the use of locating points, or targets on the casting surface. These targets will usually correspond to the fixture contact points when the casting is set up for machining. Three points, not on a line, establish Datum Plane X; Datum Plane Y is established by two points and is perpendicular to Plane X; Datum Plane Z is established by one point and is perpendicular to planes X and Y. All dimensioning of the casting is relative to the estabished datum planes. These relations are discussed in Chapter 6 of the Steel Castings Handbook in greater detail.

The use of the profile tolerancing system requires particular care in deciding on locating points, i.e. datum points and planes, to insure that these references are compatible with manufacturing requirements of the foundry.

REFERENCES

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3. Personal Communication, H.T. Bidwell, Investment Casting Institute, Dallas, TX, January, 1979.
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Note: These tolerance grades are a suggested starting place for agreements between manufacturers and customers. They are not specifications and should not be used as such.

In the case of small attachments to large castings, the attachment should be located using the tolerance for the large casting; but attachment features should have tolerances based on treating the attachment as a separate casting.

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