REFERENCE & TECHNICAL DATA

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GEAR REFERENCE GUIDE

WM Berg manufactures several styles of gears. Each gear has and serves its own particular application. Listed below are brief descriptions and application notes for the variety of available styles. Further information can be obtained from numerous gear and mechanical design handbooks, or by contacting our engineering department.

Gear Types

Spur Gears are the most recognized style of gear. Spur gears are used exclusively to transmit rotary motion between parallel shafts, while maintaining uniform speed and torque. The involute tooth form, being the simplest to generate, permits high manufacturing tolerances to be attained.

Internal Gears, unlike spur gears, have teeth cut on the inside diameter (I.D.) of the gear blank. They are generally stronger and more efficient than the mating pinion gear. The pitch diameter (P.D.) of the internal gear must be at least 1.5 times the P.D. of the mating pinion. If this condition is not met, interferences between the tips of the teeth will occur. Internal gears provide the designer with the ability to achieve higher contact and drive ratios than standard spur gears at shorter center distances. They also enable a velocity change without a directional change. This would require an idler gear with standard spurs.

Helical Gears are similar to spur gears with the exception that the teeth are cut at an angle to the axis of the shaft (helix angle). The helix cut creates a wider contact area enabling higher strengths and torques to be achieved. Though helical gearsets operate quieter and smoother than spur gears, they are slightly less efficient. Helical gears can run on parallel shafts or may be offset as much as the helix angle will permit. Axial thrust loads are developed during operation and must be considered when selecting bearings and mounting arrangements.

Gear Racks are best described as spur gears of infinite pitch radius. They will translate rotary motion to linear motion (rack driven by pinion) and vice versa. Gear racks will mate pinions of the same pitch.

Anti-Backlash Gears are the most widely used and most inexpensive method of eliminating the inaccuracies encountered in low torque gear trains, where precise positioning is essential to an application.

The split gear design incorporates springs, which force the floating gear in a direction opposite the rotation of the fixed gear, effectively enlarging the tooth width and overcoming the space, or backlash, between the teeth of the gear with which it is meshed.

Two types of design are available, one utilizing scissor springs (Figure 1), and the second for larger diameter gears, utilizing extension springs (Figure 2). Anti-backlash gears are stocked in aluminum or stainless steel but can be supplied in other materials or to other configurations on request.

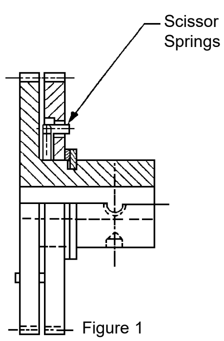

Figure 1

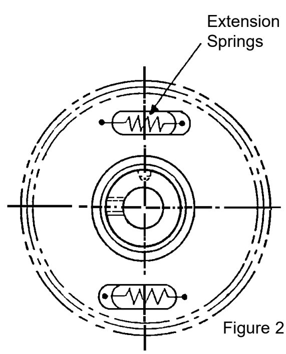

Figure 2

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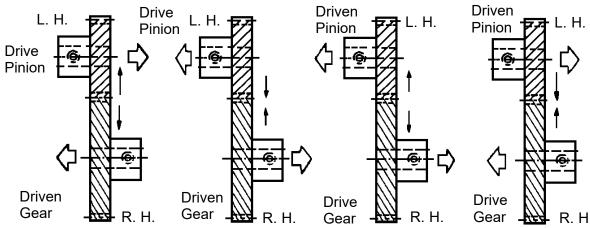
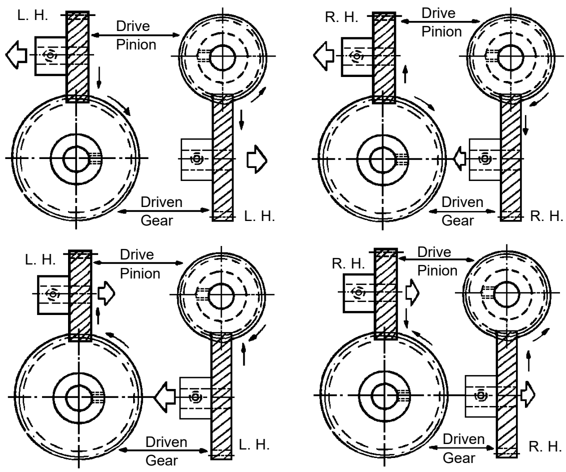
Helical Gears

Parallel Shafts



Right Angle Shafts



L. H. = Left Hand
R.H. = Right Hand
->. = Direction of Thrust

Special helical gears cut to order.

Bevel Gears are used exclusively to transmit rotary motion between intersecting shafts. Though commonly seen in right angle drives, bevel gears can be cut to drive any angle. A cross section of the gear tooth reveals a profile similar to a spur gear. However, as the tooth is generated, the cross section decreases the closer it gets to the center of the gear. Bevel gear sets will produce axial thrust loads which must be compensated for when selecting bearings and designing mounting fixtures. Bevel gears of 1:1 ratio are referred to as miter gears.

Worms & Worm Gears are the best choice of gearing when high drive reduction is required. Worm wheels resemble helical gears with the addition of a throat cut into the out diameter (O.D.) of the wheel. The throat permits the worm wheel to fully envelope the threads of the worm. Threads, not teeth, are cut on the worm. Adjusting the number of threads can achieve different ratios without altering mounting arrangements. A unique feature of worm and wheel assemblies is their ability to prohibit back driving. Certain pitches and leads of the worm will not permit the worm wheel to drive the worm. This is useful when an application requires the output to lock-up should the application operate in the opposite direction. The worm is self locking when the helix angle is less than 5°. The worm is back drivable when the helix angle is greater than 10°. Worm and worm wheel assemblies must be mounted on perpendicular, non-intersecting shafts.

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While many gearing assemblies can be developed from our extensive inventory, our engineers have designed multiple styles of gearboxes that are "ready to install". Refer to the catalog for styles and selection, then contact our sales department for availability and pricing.

TABLE 1: Gear Assembly Efficiencies

TYPE	EFFICIENCY RANGE %	RATIO RANGE	PITCH LINE VELOCITY (FEET/MIN)
SPUR	97 TO 99	1:1 TO 10:1	10,000
BEVEL	97 TO 99	1:1 TO 8:1	10,000
WORM	50 TO 90	5:1 TO 400:1	25,000
HELICAL	96 TO 98	1:1 TO 8:1	10,000

Special Bore
+ .0005
Tol. - .0000

Designator	Designator	Designator
.0781 = B	.1873 = H	.3748 = M
.0900 = V	.1875 = HH	.3750 = MM
.0937 = D	.2405 = J	.4998 = R
.1200 = E	.2498 = K	.5000 = RR
.1248 = F	.2500 = KK	.6248 = T
.1250 = FF	.3123 = L	.6250 = TT
.1562 = G	.3125 = LL	.6871 = W

Example:
Stock Number P48S28-120 (1/4" bore to be rebored to .3748)
Specify as follows: P48S28-120-M

Table 2 lists the standard metric motor shaft and bearing bore diameters that are most commonly used.

To modify US standard bore components to metric bores, select nearest standard to designed metric bore and modify bore. Modification charge will apply. **NOTE**: True metric components are also available; see metric catalog.

TABLE 2: Metric Motor Shaft & Bearing Bore Diameters

U.S. Standard Bore Diameters		Standard Metric System Bores		Recommended Rebore
Fractional	**Decimal**	**mm**	**Metric Tolerances**	**Dimensions & Tolerances**
1/8	.1248 + .0005	4	H7	.1573 + .0005
3/16	.1873 + .0005	5	H7	.1966 + .0005
3/16	.1873 + .0005	6	H7	.2360 + .0005
1/4	.2498 + .0005	7	H7	.2757 + .0006
1/4	.2498 + .0005	8	H7	.3148 + .0006
5/16	.3123 + .0005	9	H7	.3541 + .0006
3/8	.3748 + .0005	10	H7	.3935 + .0006
3/8	.3748 + .0005	12	H7	.4725 + .0007
1/2	.4998 + .0005	14	H7	.5510+ .0007
1/2	.4998 + .0005	15	H7	.5907+ .0007

Other basic Berg code designators

W = Worm Wheel
H = Helical Gears
M = Miter & Bevel Gears
R = Racks Spur
S = Shafting

AP = Anti-backlash Pin Hub
AC = Anti-backlash Clamp Hub
PH = Pin Hub
CH = Clamp Hub
CG = Clamps - Gears

NOTE: Most gears as specified by the Berg numbering system are stock. Any others, not listed in our catalogs, are considered specials and are gears cut to order using basic stock blanks.

All prices and quantity discounts are available on request. No exchanges or returns are expected on special non-stock parts as all such parts are made to your particular specification and have no resale value.

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Gear Tooth Strength

Many factors must be considered when designing a gear train. The information listed on this page should be used as a general guideline for your application. We recommend consulting our engineering department if more critical strength calculation is required.

When a gear train is transmitting motion, it is safe to assume that all of the load is being carried by one tooth. This is because as the load approaches the end of the tooth, where the bending force would be the greatest, a second tooth comes into mesh to share the load. Simple results can be obtained from the Lewis bending strength equation.

$$W_t = \frac{SFY}{D.P.}$$

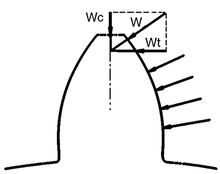
W_t = Maximum transmitted load (lbs)

S = Maximum bending tooth stress (taken as 1/3 of the tensile strength), see Mechanical Properties table

F = Face width of gear (in.)

D.P. = Diametral Pitch = 1/module (for equation only)

Y = Lewis Factor



NOTE: The maximum bending tooth stress (S) is valid for well lubricated, low shock applications. For high shock, poorly lubricated applications, the safe stress could be as low as .025S. If your design calls for an unfriendly environment for gears, you might want to lower S to assure a reasonable amount of gear life.

LEWIS FACTOR - Y

NO. OF TEETH	14 1/2° INVOLUTE	20° INVOLUTE
10	0.176	0.201
11	0.192	0.226
12	0.210	0.245
13	0.223	0.264
14	0.236	0.276
15	0.245	0.289
16	0.255	0.295
17	0.264	0.302
18	0.270	0.308
19	0.277	0.314
20	0.283	0.320
22	0.292	0.330
24	0.302	0.337
26	0.308	0.344
28	0.314	0.352
30	0.318	0.358
32	0.322	0.364
34	0.325	0.370
36	0.329	0.377
38	0.332	0.383
40	0.336	0.389
45	0.340	0.399
50	0.346	0.408
55	0.352	0.415
60	0.355	0.421
65	0.358	0.425
70	0.360	0.429
75	0.361	0.433
80	0.363	0.436
90	0.366	0.442
100	0.368	0.446
150	0.375	0.458
200	0.378	0.463
300	0.382	0.471
RACK	0.390	0.484

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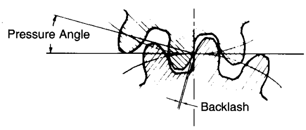
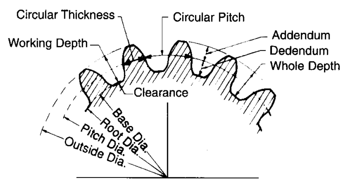
TABLE 3: Gear Tooth Proportions

DIAMETRAL PITCH	CIRCULAR PITCH	CIRCULAR THICKNESS	ADDENDUM	DEDENDUM	WORKING DEPTH	WHOLE DEPTH
12	.26180	.13090	.0833	.1020	.1667	.1853
16	.19635	.09818	.0625	.0770	.1250	.1395
20	.15708	.07854	.0500	.0620	.1000	.1120
24	.13090	.06545	.0417	.0520	.0833	.0937
1/10	.10000	.05000	.0318	.0402	.0637	.0720
32	.09817	.04909	.0313	.0395	.0625	.0708
48	.06545	.03272	.0208	.0270	.0417	.0487
1/20	.05000	.02500	.0159	.0211	.0318	.0370
64	.04909	.02454	.0156	.0208	.0313	.0364
72	.04363	.02182	.0139	.0187	.0278	.0362
80	.03927	.01963	.0125	.0170	.0250	.0295
96	.03272	.01636	.0104	.0145	.0208	.0249
100	.03142	.01571	.0100	.0140	.0200	.0240
120	.02618	.01309	.0083	.0120	.0167	.0203
200	.01571	.00785	.0050	.0080	.0100	.0130

Gear Terms & Abbreviations





Base Diameter - (B.D.) The diameter of the circle from which the involute is generated.

Backlash - Is the amount by which the width of a tooth space exceeds the thickness of the engaging tooth of a mating gear, when both gears are at nominal center distances.

Center Distance - (C.D.) Distance between the centers of mating gears.

Circular Pitch - (C.P.) The distance, along the Pitch Circle, between corresponding points of adjacent teeth.

Circular Thickness - Thickness of tooth on pitch circle.

Diametral Pitch - (D.P.) Number of teeth in a gear having one inch pitch diameter. Ex.: A gear having 48 teeth and a 1” pitch diameter is a 48 diametral pitch.

Number of Teeth - (N)

Outside Diameter - (O.D.) Diameter measuring on tops of teeth.

Pressure Angle - (P.A.) The angle between a line tangent to the pitch circle and a line perpendicular to the tooth profile at the point of contact.

Pitch Diameter - (P.D.) Diameter of the pitch circle.

Pitch Circle - An imaginary circle, whose diameter is equal to the number of teeth divided by diameter pitch.

Testing Diameter - (T.D.) A diameter, established by inspection with a master gear of known size. It is equal to twice the difference between the tight mesh center distance, and the sum of the master gear testing diameter, divided by 2.

$$T.D. = 2 \times \left(\frac{\text{Tight Mesh}}{\text{Center Distance}} - \frac{\text{T.D. Master Gear}}{2} \right)$$

Module - (M) A measurement of gear tooth size obtained by dividing the pitch diameter, in mm, by the number of teeth.

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TABLE 4: Rules & Formulas for Standard Full Depth Spur Gears

TO GET	HAVING	RULE	FORMULA
The diametral pitch	THE CIRCULAR PITCH	DIVIDE 3.1416 BY THE CIRCULAR PITCH	$DP=\frac{3.1416}{CP}$
The diametral pitch	THE PITCH DIAMETER AND THE NUMBER OF TEETH	DIVIDE NUMBER OF TEETH BY PITCH DIAMETER	$DP=\frac{N}{PD}$
The diametral pitch	THE OUTSIDE DIAMETER AND THE NUMBER OF TEETH	DIVIDE NUMBER OF TEETH PLUS 2 BY THE OUTSIDE DIAMETER	$DP=\frac{N+2}{OD}$
Pitch Diameter	THE NUMBER OF TEETH AND THE DIAMETRAL PITCH	DIVIDE THE NUMBER OF TEETH BY THE DIAMETRAL PITCH	$PD=\frac{N}{DP}$
Pitch Diameter	THE OUTSIDE DIAMETER AND THE DIAMETRAL PITCH	SUBTRACT FROM THE OUTSIDE DIAMETER THE QUOTIENT OF 2 DIVIDED BY THE DIAMETRAL PITCH	$PD=OD-\frac{2}{DP}$
Outside Diameter	THE NUMBER OF TEETH AND THE DIAMETRAL PITCH	DIVIDE NUMBER OF TEETH PLUS 2 BY THE DIAMETRAL PITCH	$OD=\frac{N+2}{DP}$
Outside Diameter	THE PITCH DIAMETER AND THE NUMBER OF TEETH	DIVIDE THE NUMBER OF TEETH PLUS 2 BY THE QUOTIENT OF NUMBER OF TEETH DIVIDED BY THE PITCH DIAMETER	$OD=\frac{N+2}{\frac{N}{PD}}$
Number of teeth	THE PITCH DIAMETER AND THE DIAMETRAL PITCH	MULTIPLY PITCH DIAMETER BY THE DIAMETRAL PITCH	$N=PD \times DP$
Thickness of tooth	THE DIAMETRAL PITCH	DIVIDE 1.5708 BY THE DIAMETRAL PITCH	$T=\frac{1.5708}{DP}$
Addendum	THE DIAMETRAL PITCH	DIVIDE 1 BY THE DIAMETRAL PITCH	$ADD.=\frac{1}{DP}$
Addendum	THE PITCH DIAMETER AND THE NUMBER OF TEETH	DIVIDE THE PITCH DIAMETER BY THE NUMBER OF TEETH	$ADD.=\frac{PD}{N}$
Working depth	THE DIAMETRAL PITCH	DIVIDE 2 BY THE DIAMETRAL PITCH	$WDE=\frac{2}{DP}$
Whole depth	THE DIAMETRAL PITCH	DIVIDE 2.2 BYTHE DIAMETRAL PITCH AND ADD .002	$WD=\frac{2.2}{DP}+.002$
Clearance	THE DIAMETRAL PITCH	DIVIDE .2 BYTHE DIAMETRAL PITCH AND ADD .002	$C=\frac{.2}{DP}+.002$
Standard center distance	NUMBERS OF TEETH IN MATING GEARS & DIAMETRAL PITCH	ADD THE NUMBERS OF TEETH IN THE MATING GEARS & DIVIDE BY 2 TIMES THE DIAMETRAL PITCH	$\frac{N1+N2}{2 \times DP}$
Backlash	PRESSURE ANGLE, STANDARD CENTER DISTANCE, & MEASURED CENTER DISTANCE	MULTIPLY 2 TIMES THE TANGENT OF THE PRESSURE ANGLE TIMES THE DIFFERENCE BETWEEN THE STANDARD & THE MEASURED CENTER DISTANCES.	B = 2 (TAN P.A)X DIFF.

Explanation of Class "C" Backlash

The American Gear Manufacturers Association (AGMA) publishes gear standards which are recognized and accepted throughout the country. However, many designers tend to use tolerances much tighter than necessary to "play safe" in obtaining final backlash tolerance.

This practice can be costly and is not very realistic. There is not always a benefit in paying for AGMA quality 12 or 14 gears if quality 10 will do the job just as well. Of course, there are applications where the output backlash tolerances will require the use of more precise gears but their use and added cost will be justified.

You will notice that none of the gears in our catalog show a pitch diameter tolerance. The pitch diameter is theoretical, and therefore, should not be toleranced. Tolerancing of pitch diameter will usually cause binding between mating gears at one or more points which results in excessive gear tooth wear, improper lubrication, shaft distortion and bearing overload, shortening the unit's life and drastically reducing accuracy.

Typically, a letter — A, B, C or D — is used to define the amount of tooth thinning to assure minimum backlash at standard center distance. This letter designation, along with the AGMA quality number and diametral pitch, are used in the "center distance inspection" of a gear. There is no possibility of interference between mating gears at standard distance with this evaluation method. However, the center distance tolerance will increase or decrease backlash values depending on whether they are plus or minus. Our gears are all cut to class "C" backlash in AGMA 10 quality and 20° pressure angles.

Standard AGMA Center Distance Inspection Procedure

The following shows the excursion of an indicating device when checking the total composite error and size of a gear on a variable center distance fixture, with a master of known accuracy.

It is recommended that the tolerances for tooth thickness shown in Table 5 be used in conjunction with pin measurements in order to obtain closer correlation with a size determination made by means of a master gear.

Column 1 gives the quality class. Column 2 gives the diametral pitch range for backlash values shown in column 8. Column 3 gives the backlash values for two gears of equal tooth thickness derived from column 8. Column 4 shows the total composite error for each of the classes shown in column 1.

Column 5 shows the minimum reduction in standard tooth thickness. This value is obtained by adding one half of the minimum value of column 2 (which gives the tooth thickness reduction per gear) to one half of the total composite error converted from a radial displacement to an equivalent tooth thickness. This is accomplished by multiplying the radial displacement to an equivalent tooth thickness. This is accomplished by multiplying the radial displacement by 2 tan x of operating pressure angle.

Column 6 gives the maximum deduction in standard tooth thickness obtained in a similar manner.

Column 7 gives the maximum indicator reading which is obtained by converting the values in column 5 to radial displacements and subtracting from them one half of the total composite error shown in column 4.

Column 8 gives the minimum indicator reading. This is obtained by converting the values in column 6 to radial displacements and adding one half of the total composite error.

The values in columns 5 and 6 are taken through the middle of the total composite error and are therefore in closer agreement with a determination of tooth thickness made by means of pins which ignore tooth to tooth error and runout.

This procedure, along with the accompanying tables, is the method used to check all Berg precision gears. We have found this method, which takes into consideration most problems commonly encountered in gear train design (such as bind, backlash, center distance tolerance, runout, composite error, etc.) to be the one which gives the most realistic results. Of course, it does not take into account the fit of gears, shafts and bearings; these problems are dealt with later on in this section under "recommended practices". All setups on gear checking fixtures are set up with "certified" master gears, and class "xx" accuracy carbide measuring wires are used.

TABLE 5: Tooth Thickness Tolerances for Class "C" Backlash Gears with 20º Pressure Angles

AGMA QUALITY CLASS	DIAMETRAL PITCH	BACKLASH IN MATING GEARS	TOTAL COMPOSITE ERROR	MINUMUM REDUCTION IN STD. TOOTH THICKNESS (Δt Min.)	MAXIMUM REDUCTION IN STD. TOOTH THICKNESS (Δt Max.)	INDICATOR LIMITS (GAGE ZEROED AT STANDARD PITCH RADIUS ALL VALUES MINUS)	
						MINUMUM	MAXIMUM
QUALITY 10 QUALITY 12 QUALITY 14	16 TO 48	.001-.002	PER AGMA STANDARD 2000-A88	.0009 .0007 .0006	.0014 .0012 .0011	.0007	.0024 .0019 .0017
QUALITY 10 QUALITY 12 QUALITY 14	1/20 TO 120	.0008-.0015		.0007 .0005 .0004	.0011 .0009 .0008	.0005	.0020 .0015 .0013

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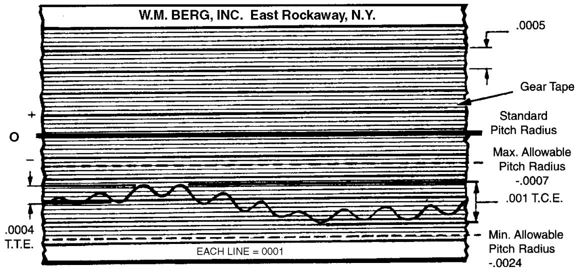
Typical Inspection Tape for a 48 D.P., 20° P.A. Quality 10C Gear



Recommended Practices

When specifying materials, it's recommended to have stainless steel pinions and aluminum mating gears. This is because pinions typically rotate through more cycles, thus experiencing greater tooth wear. Meshing stainless steel pinion with an aluminum gear tends to minimize this wear. The face widths of pinions are usually wider than face widths of mating gears to ensure full face contact without critical adjustment.

Where minimum backlash is a factor, it is important that fits between the bore of gears, inside diameter of bearings and the outside diameter of shafting be held as close as possible. The accuracy of precision gears is lost unless these fits are held closely. This means that a form of selective fitting must be used because it is too costly, if not impossible, to hold tolerances that will allow perfect fit assembly. The extent of this selective fitting is determined by the accuracy requirements of the finished assembly.

Factors That Control Backlash

- Precision class of gears
- Center distance tolerance
- Type of fit between gears, shafts & bearings
- Precision accuracy of bearings
- Straightness & adequate support of shafts

It is important when drilling gears to shafts that the shafts be properly supported. Failure to do so can result in bending shafts with the resultant runout conditions.

NOTE: Gears with 14 1/2° pressure angle will not mesh properly with gears of 20° pressure angle.

It is imperative that the gears are not damaged in handling. Our gears are packaged to avoid handling damage. If they can be left in this package until used the danger should be minimized. If they are removed they should be put on tote boards and covered to prevent gears from contacting each other, and to keep them clean.

Gear Train Design

Determining appropriate backlash is a key challenge of designing fine pitch gear trains. Backlash in mating gears or in a gear train can be broken down into three basic factors:

- The AGMA quality of gears, i.e. quality 10, 12, or 14 (former precision standards 1, 2, or 3)
- The letter which designates backlash, i.e. "C"
- The center distance & tolerance on which these gears operate

NOTE: Berg precision stock gears are manufactured to AGMA quality 10C, unless otherwise specified.

The accepted definition of backlash is "the amount by which the width of a tooth space exceeds the tooth thickness of the engaging tooth on the pitch circles." At first glance this meaning might lead us to think that backlash is a function of the gear cutting operation only. However, the teeth of a gear contribute very little to its overall backlash value.

A complete understanding of all the elements that induce backlash is mandatory in order to properly and economically design a gear train. The following factors must be individually considered for their own parameter:

- Standard center distance
- Center distance tolerance
- Size & tolerance of mating gears
- Total composite error of gears
- Fits between bores, shafts & bearings
- Bearing accuracy
- Radial play of bearing
- Shaft straightness & alignment
- Fits between electrical &/or mechanical component pilot diameters & housing bores
- Eccentricity & radial play of electrical &/or mechanical component shafts

Each factor, except standard center distance, tends to induce a "change in the center distance" which will push together or pull apart mating gears. Consequently, this push pull action produces two backlash values, minimum at the point of tightest mesh and maximum at the point of loosest mesh.

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Standard Center Distance

Standard center distance can be considered the starting point in the calculation of overall backlash values. Standard (theoretical) center distance is calculated by taking one-half (1/2) the sum of the (theoretical) pitch diameters of mating gears.

$$\text{Example: C.D.} = \frac{\text{P.D.}^1 + \text{P.D.}^2}{2}$$

Two gears having theoretical P.D.s of one inch (1") and two inches (2") respectively have a standard center distance of:

$$\text{C.D.} = \frac{1" + 2"}{2} = 1{,}500 \text{ C.D.}$$

Center Distance Tolerance

The problem of center distance and its tolerance is usually an extremely important area for consideration. It is important to remember that the minimum and maximum backlash values between mating gears, as outlined in the previous tables, are based on "standard" center distance mountings. Thus, if the center distance is in excess of the standard value, backlash will be increased. By the same token, if the C.D. is less than standard, backlash will be decreased. However, caution must be exercised to avoid interference between mating gears as a result of this decrease.

TABLE 6: Relationship of Change in C.D. to Backlash

ΔC (DIFFERENCE BETWEEN STANDARD AND ACTUAL CENTER DISTANCE)	B (BACKLASH IN INCHES)
.0001	.00007
.0002	.00014
.0003	.00022
.0004	.00029
.0005	.00036
.0006	.00044
.0007	.00051
.0008	.00058
.0009	.00066
.0010	.00073
.0011	.00080
.0012	.00087
.0013	.00095
.0014	.00102
.0015	.00109
.0016	.00116
.0017	.00124
.0018	.00131
.0019	.00138
.0020	.00146

The relationship of "change in center distance," which can be positive or negative depending upon C.D. tolerance, to backlash is expressed by the formula:

$B = 2 \tan ø \times \Delta C$ (1)

In which:

B = backlash in inches

ø = pressure angle

ΔC = difference between standard (theoretical) and actual center distance (ex. tan20° = .36397)

1. Standard centers + .001 tolerance
   $B = 2 \tan 20° \times \Delta C$
   $B = .72794 \times .001 = + .00073$ backlash
2. Standard centers - .0005 tolerance
   $B = 2 \tan 20° \times \Delta C$
   $B = .72794 \times .0005 = - .00036$ backlash

Backlash calculations can be divided into two categories:

- Systems where backlash is not critical
- Systems where backlash is critical & exact totals must be known

Section 1: Backlash Calculations for Non-Critical Gear Trains

Let us set up two test problems falling into the non-critical category. These two problems will deal with center distance tolerance, size and tolerance of mating gears, and total composite error of gears as they collectively contribute the greatest amount of change in center distance.

1. Two mating gears, 96 D.P. -20° P.A. having standard centers with A + .001 -.000 tolerance.
   Step A: Referring to Berg quality 10 gears yield a maximum of .0015 backlash at standard centers.
   Step B: With an actual center distance .001 greater than standard, an additional .0073 backlash is introduced (see Table 6).
   Step C: The total probable maximum backlash would be .0015 + .00073 = .00223
2. Again two mating gears, 96 D.P. -20° P.A. must have no more than .0015 backlash measured at the loosest point of mesh (see Table 5).
   Step A: Referring to Berg quality 10C gears yield a maximum of .0015 backlash at standard centers.
   Step B: Actual center distance .0005 greater than standard yields an additional .00036 backlash.
   Step C: The total probable backlash would be .0015 + .00036 = .008186 or .00036 above limit.

One solution would be to use quality 12C gears with the same center distance and tolerance. Again we find that the maximum backlash for quality 12C gears is .00109 and the center distance tolerance results in an additional .00036 for a total of .00145 or .00005 below limit.

Another means of overcoming this problem would be to incorporate anti-backlash or spring loaded gears. When this type of gear is used, center distance tolerance can be increased thereby reducing the cost of machining the housing. The increase in center distance when using anti-backlash gears should not exceed oz./D.P.

Before deciding on either of these two possibilities, let us see what can be done using quality 10C gears.

Referring to the minimum backlash value we have .0008. This indicates that there is a minimum of .0011 clearance (see Table 6). Now, because the center distance was dimensioned +.0000/-.0005 minimum backlash would be reduced to .00036/.00044 and the maximum could still be .00109 or .0045 below the limit, using Berg gears.

Section 2: Backlash Critical Gear Trains

If the previous section does not pinpoint the amount for backlash that your system will possess accurately enough for you then there are many steps that can be employed during the manufacturing process that can limit the amount of backlash in a gear train. These include cutting gears to class “D” or “E” backlash, and/or AGMA quality 12 or 14.

If backlash is critical and Berg anti-backlash gears will not suffice, consult our engineering department for how these changes will influence backlash.

Fine Pitch Gear Inspection Procedure

There has been much discussion and confusion regarding the center distance method of testing fine pitch gears. The Berg center distance method of testing uses the limits and tolerances as outlined in AGMA standards.

Figures 3 and 4 are schematic diagrams showing the basic requirements for making a center distance check. The diagrams are not to be interpreted as a recommended or suggested means of construction.

In order to make this check, the following items are required:

- Rolling Fixture
    - This fixture must incorporate provisions for accurately mounting both the master and the gear to be tested.
    - A means of accurately adjusting the weights to the correct testing pressure.
- Master Gear
    - With a maximum total composite error of .0001 and a standard pitch diameter of ± .0001 tolerance over wires.
- Hardened or ground pins or carbide lapped pins (preferred) for mounting both the master and gear to be inspected.

Let’s assume that we wish to inspect a gear having the following characteristics:

64	Diametral pitch
20°	Pressure angle
.2500	+.0000/-.0002 bore
80	Teeth
1.2500	Theoretical pitch diameter
AGMA quality 12C	

First, select the proper master gear and correct size carbide gage pin to fit this master. Since the masters we use have a .5000" + .0001/-.0000 bore, we use a lapped pin of .4995 diameter to assure free movement without wobble.

We follow the same procedure in selecting a pin on which to mount the gear to be inspected. In this case, the lapped pin diameter would be .24975. The studs or pins are then mounted on the rolling fixture and caution is used to assure parallelism between the studs after mounting.

Next, set the rolling fixture to the proper testing pressure which in the case of 64 C.P. is 12 ounces, per gear standards. The testing pressure is an important factor in the rolling check to assure uniform pressure and correct mesh during the entire test.

The rolling fixture must now be set to the proper center distance by the uses of “jo-blocks”. The master gear we are using has a pitch diameter of 1.5000 and the gear to be inspected has a theoretical pitch diameter of 1.2500. These two pitch diameters are added together and divided by two. This gives us a figure of 1.375. Then, add together and divide by two the pin diameters on which the master gear and the test gear (.49995 + .24975 respectively) are mounted. This gives us a figure of .3749. The figure is subtracted from the 1.375 figure to arrive at our “jo-block” setting of 1.001”.

While holding the “jo-blocks” between the two studs or pins on the rolling fixture, the dial indicator is set to zero. This setting is the nominal or set up center distance and is made under the “testing pressure”. All gears being tested must read to the minus side of the indicator otherwise interference between mating gears, with a standard distance, may result at assembly.

Because the gear to be tested is 64 diametral pitch AGMA quality 12C, we refer to our data section to obtain the dial indicators limits.

We find in column 7 that the maximum limit is -.0005 and in column 8 the minimum is -.0015. Please note that all figures given are minus values. These limits can never be exceeded or the gears will not be in tolerance.

Figure 4 shows these limits as seen on a dial indicator as well as how they would be recorded on a paper chart. For the sake of clarity, however, we have not drawn the .0001” graduation lines across the chart.

It must be remembered that although our dial limits have a range of from -.0005 to -.0015, the total composite error of an AGMA 12C gear is .0005 as shown in column 4. This means that our dial fluctuation cannot exceed .0005 within the -.0005 to -.0015 dial limit range. Should the pointer movement not exceed the .0005 maximum total composite error, the gear would be an AGMA quality 10C. This is true even though the gear is within the dial limits on a quality 12C.

Figure 3 shows the limits for AGMA quality 10C gear. The same procedure as used to test for 12C is followed. It must be remembered that the dial indicator limits and the total composite error are greater (refer to previous page for limits).

Measuring & Checking Forces

When making measurement-over-wire measurements or when checking the gears on a variable-center-distance device, the amount of force applied to the measuring wires or applied to maintain intimate contact between the gear to be checked and the master gear shall be as listed in the table below.

Inch

Diametral Pitch	Checking Force Oz.
16	30 To 34
20	26 To 30
24	26 To 30
1/10	22 To 26
32	22 To 26
48	18 To 22
1/20	10 To 14
64	10 To 14
72	10 To 14
80	6 To 10
96	7 To 9
100	3 To 5
120	3 To 5
200	2 To 4

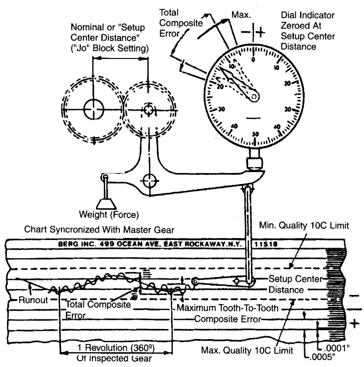


Figure 3 - AGMA Quality 10C Chart

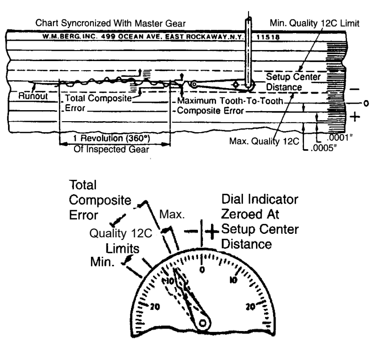
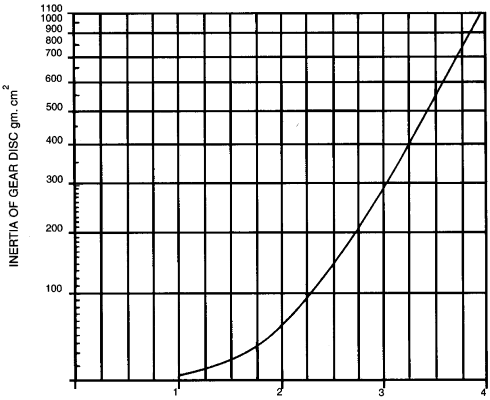


Figure 4 - AGMA Quality 12C Chart

GEAR REFERENCE GUIDE

Inertia of Gears

To obtain the inertia of 1/8 face width aluminum gears, read directly from the graph.



Diameter of Gear Discs

To obtain the inertia of gears with other face and/or made of stainless steel, read from the graph at the given diameter then multiply by the appropriate factor.

TABLE 7: Gear Discs in Inches

FACE WIDTH	1/16	3/32	.104	3/16	1/4	3/8	1/2
FACTOR	.5	.75	.83	1.5	2.0	3.0	4.0

MATERIAL	ALUMINUM	ST. STEEL
FACTOR	1	2.82

Example: 2" diameter - 1/4" face stainless steel gear
from graph 2" diameter is 56 gm cm^2
56 x 2.0 x 2.82 = 318 gm cm^2

TABLE 8: Inertia of Gear Clamps

CLAMP STK. NO.	INERTIA gm cm^2	CLAMP STK. NO.	INERTIA gm cm^2	CLAMP STK. NO.	INERTIA gm cm^2
CG1-4	1.91	CG1-18	61.55	CG2-5	4.95
CG1-5	2.30	CG1-19	61.55	CG2-6	4.95
CG1-8	8.86	CG1-20	0.28	CG3-1	2.01
CG1-9	11.84	CG1-21	1.50	CG3-2	2.01
CG1-11	8.86	CG2-1	2.00	CG3-3	4.01
CG1-12	11.84	CG2-2	2.00	CG3-4	4.01
CG1-14	32.35	CG2-3	2.91	CG3-5	4.97
CG1-15	61.55	CG2-4	2.91	CG3-6	4.97
CG1-17	32.35	-----	-----	CG4-1	0.18

TABLE OF PITCH DIAMETERS

TABLE 9: Pitch Diameters 6 to 53 Teeth

To find outside diameter add 2 teeth.

Theoretical P.D.s only. All gears cut to AGMA standards.

N = Number of teeth

NOTE: Applies to spur and bevel gears only (not to helical gears).

N	DIAMETRAL PITCH													N
	16	20	24	1/10	32	48	1/20	64	72	80	96	100	120	
6	.3750	.3000	.2500	.1909	.1875	.1250	.0954	.0937	.0833	.0750	.0625	.0600	.0500	6
7	.4375	.3500	.2916	.2228	.2187	.1458	.1114	.1093	.0972	.0875	.0729	.0700	.0583	7
8	.5000	.4000	.3333	.2546	.2500	.1666	.1273	.1250	.1111	.1000	.0833	.0800	.0666	8
9	.5625	.4500	.3750	.2864	.2812	.1875	.1432	.1406	.1250	.1125	.0937	.0900	.0750	9
10	.6250	.5000	.4166	.3183	.3125	.2083	.1591	.1562	.1388	.1250	.1041	.1000	.0833	10
11	.6875	.5500	.4583	.3501	.3437	.2291	.1750	.1718	.1527	.1375	.1145	.1100	.0916	11
12	.7500	.6000	.5000	.3819	.3750	.2500	.1909	.1875	.1666	.1500	.1250	.1200	.1000	12
13	.8125	.6500	.5416	.4138	.4062	.2708	.2069	.2031	.1805	.1625	.1354	.1300	.1083	13
14	.8750	.7000	.5833	.4456	.4375	.2916	.2228	.2187	.1944	.1750	.1458	.1400	.1166	14
15	.9375	.7500	.6250	.4774	.4687	.3125	.2387	.2343	.2083	.1875	.1562	.1500	.1250	15
16	1.0000	.8000	.6666	.5092	.5000	.3333	.2546	.2500	.2222	.2000	.1666	.1600	.1333	16
17	1.0625	.8500	.7083	.5411	.5312	.3541	.2705	.2656	.2361	.2125	.1770	.1700	.1416	17
18	1.1250	.9000	.7500	.5729	.5625	.3750	.2864	.2812	.2500	.2250	.1875	.1800	.1500	18
19	1.1875	.9500	.7916	.6047	.5937	.3958	.3023	.2968	.2638	.2375	.1979	.1900	.1583	19
20	1.2500	1.0000	.8333	.6366	.6250	.4166	.3183	.3125	.2777	.2500	.2083	.2000	.1666	20
21	1.3125	1.0500	.8750	.6684	.6562	.4375	.3342	.3281	.2916	.2625	.2187	.2100	.1750	21
22	1.3750	1.1000	.9166	.7002	.6875	.4583	.3501	.3437	.3055	.2750	.2291	.2200	.1833	22
23	1.4375	1.1500	.9583	.7321	.7187	.4791	.3660	.3593	.3194	.2875	.2395	.2300	.1916	23
24	1.5000	1.2000	1.0000	.7639	.7500	.5000	.3819	.3750	.3333	.3000	.2500	.2400	.2000	24
25	1.5625	1.2500	1.0416	.7957	.7812	.5208	.3978	.3906	.3472	.3125	.2604	.2500	.2083	25
26	1.6250	1.3000	1.0833	.8276	.8125	.5416	.4138	.4062	.3611	.3250	.2708	.2600	.2166	26
27	1.6875	1.3500	1.1250	.8594	.8437	.5625	.4297	.4218	.3750	.3375	.2812	.2700	.2250	27
28	1.7500	1.4000	1.1666	.8912	.8750	.5833	.4456	.4375	.3888	.3500	.2916	.2800	.2333	28
29	1.8125	1.4500	1.2083	.9230	.9062	.6041	.4615	.4531	.4027	.3625	.3020	.2900	.2416	29
30	1.8750	1.5000	1.2500	.9549	.9375	.6250	.4774	.4687	.4166	.3750	.3125	.3000	.2500	30
31	1.9375	1.5500	1.2916	.9867	.9687	.6458	.4933	.4843	.4305	.3875	.3229	.3100	.2583	31
32	2.0000	1.6000	1.3333	1.0185	1.0000	.6666	.5092	.5000	.4444	.4000	.3333	.3200	.2666	32
33	2.0625	1.6500	1.3750	1.0504	1.0312	.6875	.5252	.5156	.4583	.4125	.3437	.3300	.2750	33
34	2.1250	1.7000	1.4166	1.0822	1.0625	.7083	.5411	.5312	.4722	.4250	.3541	.3400	2833	34
35	2.1875	1.7500	1.4583	1.1140	1.0937	.7291	.5570	.5468	.4861	.4375	.3654	.3500	.2916	35
36	2.2500	1.8000	1.5000	1.1459	1.1250	.7500	.5729	.5625	.5000	.4500	.3750	.3600	.3000	36
37	2.3125	1.8500	1.5416	1.1777	1.1562	.7708	.5888	.5781	.5138	.4625	.3854	.3700	.3083	37
38	2.3750	1.9000	1.5833	1.2095	1.1875	.7916	.6047	.5937	.5277	.4750	.3958	.3800	.3166	38
39	2.4375	1.9500	1.6250	1.2414	1.2187	.8125	.6207	.6093	.5416	.4875	.4062	.3900	.3250	39
40	2.5000	2.0000	1.6666	1.2732	1.2500	.8333	.6366	.6250	.5555	.5000	.4166	.4000	.3333	40
41	2.5625	2.0500	1.7083	1.3050	1.2812	.8541	.6525	.6406	.5694	.5125	.4270	.4100	.3416	41
42	2.6250	2.1000	1.7500	1.3369	1.3125	.8750	.6684	.6562	.5833	.5250	.4375	.4200	.3500	42
43	2.6875	2.1500	1.7916	1.3687	1.3437	.8958	.6843	.6718	.5972	.5375	.4479	.4300	.3583	43
44	2.7500	2.2000	1.8333	1.4005	1.3750	.9166	.7002	.6875	.6111	.5500	.4583	.4400	.3666	44
45	2.8125	2.2500	1.8750	1.4323	1.4062	.9375	.7161	.7031	.6250	.5625	.4687	.4500	.3750	45
46	2.8750	2.3000	1.9166	1.4642	1.4375	.9583	.7321	.7187	.6388	.5750	.4791	.4600	.3833	46
47	2.9375	2.3500	1.9583	1.4960	1.4687	.9791	.7480	.7343	.6527	.5875	.4895	.4700	.3916	47
48	3.0000	2.4000	2.0000	1.5278	1.5000	1.0000	.7639	.7500	.6666	.6000	.5000	.4800	.4000	48
49	3.0625	2.4500	2.0416	1.5597	1.5312	1.0208	.7798	.7656	.6805	.6125	.5104	.4900	.4083	49
50	3.1250	2.5000	2.0833	1.5915	1.5625	1.0416	.7957	.7812	.6944	.6250	.5208	.5000	.4166	50
51	3.1875	2.5500	2.1250	1.6233	1.5937	1.0625	.8116	.7968	.7083	.6375	.5312	.5100	.4250	51
52	3.2500	2.6000	2.1666	1.6552	1.6250	1.0833	.8276	.8125	.7222	.6500	.5416	.5200	.4333	52
53	3.3125	2.6500	2.2083	1.6870	1.6562	1.1041	.8435	.8281	.7361	.6625	.5520	.5300	.4416	53

TABLE OF PITCH DIAMETERS

TABLE 10: Pitch Diameters 54 to 101 Teeth

To find outside diameter add 2 teeth.

Theoretical P.D.s only. All gears cut to AGMA standards.

N = Number of teeth

NOTE: Applies to spur and bevel gears only (not to helical gears).

N	DIAMETRAL PITCH													N
	16	20	24	1/10	32	48	1/20	64	72	80	96	100	120	
54	3.3750	2.7000	2.2500	1.7188	1.6875	1.1250	.8594	.8437	.7500	.6750	.5625	.5400	.4500	54
55	3.4375	2.7500	2.2916	1.7507	1.7187	1.1458	.8753	.8593	.7638	.6875	.5729	.5500	.4583	55
56	3.5000	2.8000	2.3333	1.7825	1.7500	1.1666	.8912	.8750	.7777	.7000	.5833	.5600	.4666	56
57	3.5625	2.8500	2.3750	1.8143	1.7812	1.1875	.9071	.8906	.7916	.7125	.5937	.5700	.4750	57
58	3.6250	2.9000	2.4166	1.8461	1.8125	1.2083	.9230	.9062	.8055	.7250	.6041	.5800	.4833	58
59	3.6875	2.9500	2.4583	1.8780	1.8437	1.2291	.9390	.9218	.8194	.7375	.6145	.5900	.4916	59
60	3.7500	3.0000	2.5000	1.9098	1.8750	1.2500	.9549	.9375	.8333	.7500	.6250	.6000	.5000	60
61	3.8125	3.0500	2.5416	1.9416	1.9062	1.2708	.9708	.9531	.8472	.7625	.6354	.6100	.5083	61
62	3.8750	3.1000	2.5833	1.9735	1.9375	1.2916	.9867	.9687	.8611	.7750	.6458	.6200	.5166	62
63	3.9375	3.1500	2.6250	2.0053	1.9687	1.3125	1.0026	.9843	.8750	.7875	.6562	.6300	.5250	63
64	4.0000	3.2000	2.6666	2.0371	2.0000	1.3333	1.0185	1.0000	.8888	.8000	.6666	.6400	.5333	64
65	4.0625	3.2500	2.7083	2.0690	2.0312	1.3541	1.0345	1.0156	.9027	.8125	.6770	.6500	.5416	65
66	4.1250	3.3000	2.7500	2.1008	2.0625	1.3750	1.0504	1.0312	.9166	.8250	.6875	.6600	.5500	66
67	4.1875	3.3500	2.7916	2.1326	2.0937	1.3958	1.0663	1.0468	.9305	.8375	.6979	.6700	.5583	67
68	4.2500	3.4000	2.8333	2.1645	2.1250	1.4166	1.0822	1.0625	.9444	.8500	.7083	.6800	.5666	68
69	4.3125	3.4500	2.8750	2.1963	2.1562	1.4375	1.0981	1.0781	.9583	.8625	.7187	.6900	.5750	69
70	4.3750	3.5000	2.9166	2.2281	2.1875	1.4583	1.1140	1.0937	.9722	.8750	.7291	.7000	.5833	70
71	4.4375	3.5500	2.9583	2.2600	2.2187	1.4791	1.1300	1.1093	.9861	.8875	.7395	.7100	.5916	71
72	4.5000	3.6000	3.0000	2.2918	2.2500	1.5000	1.1459	1.1250	1.0000	.9000	.7500	.7200	.6000	72
73	4.5625	3.6500	3.0416	2.3236	2.2812	1.5208	1.1618	1.1406	1.0138	.9125	.7604	.7300	.6083	73
74	4.6250	3.7000	3.0833	2.3554	2.3125	1.5416	1.1777	1.1562	1.0277	.9250	.7708	.7400	.6166	74
75	4.6875	3.7500	3.1250	2.3873	2.3437	1.5625	1.1936	1.1718	1.0416	.9375	.7812	.7500	.6250	75
76	4.7500	3.8000	3.1666	2.4191	2.3750	1.5833	1.2095	1.1875	1.0555	.9500	.7916	.7600	.6333	76
77	4.8125	3.8500	3.2083	2.4509	2.4062	1.6041	1.2254	1.2031	1.0694	.9625	.8020	.7700	.6416	77
78	4.8750	3.9000	3.2500	2.4828	2.4375	1.6250	1.2414	1.2187	1.0833	.9750	.8125	.7800	.6500	78
79	4.9375	3.9500	3.2916	2.5146	2.4687	1.6458	1.2573	1.2343	1.0972	.9875	.8229	.7900	.6583	79
80	5.0000	4.0000	3.3333	2.5464	2.5000	1.6666	1.2732	1.2500	1.1111	1.0000	.8333	.8000	.6666	80
81	5.0625	4.0500	3.3750	2.5783	2.5312	1.6875	1.2891	1.2656	1.1250	1.0125	.8437	.8100	.6750	81
82	5.1250	4.1000	3.4166	2.6101	2.5625	1.7083	1.3050	1.2812	1.1388	1.0250	.8541	.8200	.6833	82
83	5.1875	4.1500	3.4583	2.6419	2.5937	1.7291	1.3209	1.2968	1.1527	1.0375	.8645	.8300	.6916	83
84	5.2500	4.2000	3.5000	2.6738	2.6250	1.7500	1.3369	1.3125	1.1666	1.0500	.8750	.8400	.7000	84
85	5.3125	4.2500	3.5416	2.7056	2.6562	1.7708	1.3528	1.3281	1.1805	1.0625	.8854	.8500	.7083	85
86	5.3750	4.3000	3.5833	2.7374	2.6875	1.7916	1.3687	1.3437	1.1944	1.0750	.8958	.8600	.7166	86
87	5.4375	4.3500	3.6250	2.7692	2.7187	1.8125	1.3846	1.3593	1.2083	1.0875	.9062	.8700	.7250	87
88	5.5000	4.4000	3.6666	2.8011	2.7500	1.8333	1.4005	1.3750	1.2222	1.1000	.9166	.8800	.7333	88
89	5.5625	4.4500	3.7083	2.8329	2.7812	1.8541	1.4164	1.3906	1.2361	1.1125	.9270	.8900	.7416	89
90	5.6250	4.5000	3.7500	2.8647	2.8125	1.8750	1.4323	1.4062	1.2500	1.1250	.9375	.9000	.7500	90
91	5.6875	4.5500	3.7916	2.8966	2.8437	1.8958	1.4483	1.4218	1.2638	1.1375	.9479	.9100	.7583	91
92	5.7500	4.6000	3.8333	2.9284	2.8750	1.9166	1.4642	1.4375	1.2777	1.1500	.9583	.9200	.7666	92
93	5.8125	4.6500	3.8750	2.9602	2.9062	1.9375	1.4801	1.4531	1.2916	1.1625	.9687	.9300	.7750	93
94	5.8750	4.7000	3.9166	2.9921	2.9375	1.9583	1.4960	1.4687	1.3055	1.1750	.9791	.9400	.7833	94
95	5.9375	4.7500	3.9583	3.0239	2.9687	1.9791	1.5119	1.4843	1.3194	1.1875	.9895	.9500	.7916	95
96	6.0000	4.8000	4.0000	3.0557	3.0000	2.0000	1.5278	1.5000	1.3333	1.2000	1.0000	.9600	.8000	96
97	6.0625	4.8500	4.0416	3.0876	3.0312	2.0208	1.5438	1.5156	1.3472	1.2125	1.0104	.9700	.8083	97
98	6.1250	4.9000	4.0833	3.1194	3.0625	2.0416	1.5597	1.5312	1.3611	1.2250	1.0208	.9800	.8166	98
99	6.1875	4.9500	4.1250	3.1512	3.0937	2.0625	1.5756	1.5468	1.3750	1.2375	1.0312	.9900	.8250	99
100	6.2500	5.0000	4.1666	3.1830	3.1250	2.0833	1.5915	1.5625	1.3888	1.2500	1.0416	1.0000	.8333	100
101	6.3125	5.0500	4.2083	3.2149	3.1562	2.1041	1.6074	1.5781	1.4027	1.2625	1.0520	1.0100	.8416	101

TABLE OF PITCH DIAMETERS

TABLE 11: Pitch Diameters 102 to 149 Teeth

To find outside diameter add 2 teeth.

Theoretical P.D.s only. All gears cut to AGMA standards.

N = Number of teeth

NOTE: Applies to spur and bevel gears only (not to helical gears).

N	DIAMETRAL PITCH													N
	16	20	24	1/10	32	48	1/20	64	72	80	96	100	120	
102	6.3750	5.1000	4.2500	3.2467	3.1875	2.1250	1.6233	1.5937	1.4166	1.2750	1.0625	1.0200	.8500	102
103	6.4375	5.1500	4.2916	3.2785	3.2187	2.1458	1.6392	1.6093	1.4305	1.2875	1.0729	1.0300	.8583	103
104	6.5000	5.2000	4.3333	3.3104	3.2500	2.1666	1.6552	1.6250	1.4444	1.3000	1.0833	1.0400	.8666	104
105	6.5625	5.2500	4.3750	3.3422	3.2812	2.1875	1.6711	1.6406	1.4583	1.3125	1.0937	1.0500	.8750	105
106	6.6250	5.3000	4.4166	3.3740	3.3125	2.2083	1.6870	1.6562	1.4722	1.3250	1.1041	1.0600	.8833	106
107	6.6875	5.3500	4.4583	3.4059	3.3437	2.2291	1.7029	1.6718	1.4861	1.3375	1.1145	1.0700	.8916	107
108	6.7500	5.4000	4.5000	3.4377	3.3750	2.2500	1.7188	1.6875	1.5000	1.3500	1.1250	1.0800	.9000	108
109	6.8125	5.4500	4.5416	3.4695	3.4062	2.2708	1.7347	1.7031	1.5138	1.3625	1.1354	1.0900	.9083	109
110	6.8750	5.5000	4.5833	3.5014	3.4375	2.2916	1.7507	1.7187	1.5277	1.3750	1.1458	1.1000	.9166	110
111	6.9375	5.5500	4.6250	3.5332	3.4687	2.3125	1.7666	1.7343	1.5416	1.3875	1.1562	1.1100	.9250	111
112	7.0000	5.6000	4.6666	3.5650	3.5000	2.3333	1.7825	1.7500	1.5555	1.4000	1.1666	1.1200	.9333	112
113	7.0625	5.6500	4.7083	3.5969	3.5312	2.3541	1.7984	1.7656	1.5694	1.4125	1.1770	1.1300	.9416	113
114	7.1250	5.7000	4.7500	3.6287	3.5625	2.3750	1.8143	1.7812	1.5833	1.4250	1.1875	1.1400	.9500	114
115	7.1875	5.7500	4.7916	3.6605	3.5937	2.3958	1.8302	1.7968	1.5972	1.4375	1.1979	1.1500	.9583	115
116	7.2500	5.8000	4.8333	3.6923	3.6250	2.4166	1.8461	1.8125	1.6111	1.4500	1.2083	1.1600	.9666	116
117	7.3125	5.8500	4.8750	3.7242	3.6562	2.4375	1.8621	1.8281	1.6250	1.4625	1.2187	1.1700	.9750	117
118	7.3750	5.9000	4.9166	3.7560	3.6875	2.4583	1.8780	1.8437	1.6388	1.4750	1.2291	1.1800	.9833	118
119	7.4375	5.9500	4.9583	3.7878	3.7187	2.4791	1.8939	1.8593	1.6527	1.4875	1.2395	1.1900	.9916	119
120	7.5000	6.0000	5.0000	3.8197	3.7500	2.5000	1.9098	1.8750	1.6666	1.5000	1.2500	1.2000	1.0000	120
121	7.5625	6.0500	5.0416	3.8515	3.7812	2.5208	1.9257	1.8906	1.6805	1.5125	1.2604	1.2100	1.0083	121
122	7.6250	6.1000	5.0833	3.8833	3.8125	2.5416	1.9416	1.9062	1.6944	1.5250	1.2708	1.2200	1.0166	122
123	7.6875	6.1500	5.1250	3.9152	3.8437	2.5625	1.9576	1.9218	1.7083	1.5375	1.2812	1.2300	1.0250	123
124	7.7500	6.2000	5.1666	3.9470	3.8750	2.5833	1.9735	1.9375	1.7222	1.5500	1.2916	1.2400	1.0333	124
125	7.8125	6.2500	5.2083	3.9788	3.9062	2.6041	1.9894	1.9531	1.7361	1.5625	1.3020	1.2500	1.0416	125
126	7.8750	6.3000	5.2500	4.0107	3.9375	2.6250	2.0053	1.9687	1.7500	1.5750	1.3125	1.2600	1.0500	126
127	7.9375	6.3500	5.2916	4.0425	3.9687	2.6458	2.0212	1.9843	1.7638	1.5875	1.3229	1.2700	1.0583	127
128	8.0000	6.4000	5.3333	4.0743	4.0000	2.6666	2.0371	2.0000	1.7777	1.6000	1.3333	1.2800	1.0666	128
129	8.0625	6.4500	5.3750	4.1061	4.0312	2.6875	2.0530	2.0156	1.7916	1.6125	1.3437	1.2900	1.0750	129
130	8.1250	6.5000	5.4166	4.1380	4.0625	2.7083	2.0690	2.0312	1.8055	1.6250	1.3541	1.3000	1.0833	130
131	8.1875	6.5500	5.4583	4.1698	4.0937	2.7291	2.0849	2.0468	1.8194	1.6375	1.3645	1.3100	1.0916	131
132	8.2500	6.6000	5.5000	4.2016	4.1250	2.7500	2.1008	2.0625	1.8333	1.6500	1.3750	1.3200	1.1000	132
133	8.3125	6.6500	5.5416	4.2335	4.1562	2.7708	2.1167	2.0781	1.8472	1.6625	1.3854	1.3300	1.1083	133
134	8.3750	6.7000	5.5833	4.2653	4.1875	2.7916	2.1326	2.0937	1.8611	1.6750	1.3958	1.3400	1.1166	134
135	8.4375	6.7500	5.6250	4.2971	4.2187	2.8125	2.1485	2.1093	1.8750	1.6875	1.4062	1.3500	1.1250	135
136	8.5000	6.8000	5.6666	4.3290	4.2500	2.8333	2.1645	2.1250	1.8888	1.7000	1.4166	1.3600	1.1333	136
137	8.5625	6.8500	5.7083	4.3608	4.2812	2.8541	2.1804	2.1406	1.9027	1.7125	1.4270	1.3700	1.1416	137
138	8.6250	6.9000	5.7500	4.3926	4.3125	2.8750	2.1963	2.1562	1.9166	1.7250	1.4375	1.3800	1.1500	138
139	8.6875	6.9500	5.7916	4.4245	4.3437	2.8958	2.2122	2.1718	1.9305	1.7375	1.4479	1.3900	1.1583	139
140	8.7500	7.0000	5.8333	4.4563	4.3750	2.9166	2.2281	2.1875	1.9444	1.7500	1.4583	1.4000	1.1666	140
141	8.8125	7.0500	5.8750	4.4881	4.4062	2.9375	2.2440	2.2031	1.9583	1.7625	1.4687	1.4100	1.1750	141
142	8.8750	7.1000	5.9166	4.5200	4.4375	2.9583	2.2600	2.2187	1.9722	1.7750	1.4791	1.4200	1.1833	142
143	8.9375	7.1500	5.9583	4.5518	4.4687	2.9791	2.2759	2.2343	1.9861	1.7875	1.4895	1.4300	1.1916	143
144	9.0000	7.2000	6.0000	4.5836	4.5000	3.0000	2.2918	2.2500	2.0000	1.8000	1.5000	1.4400	1.2000	144
145	9.0625	7.2500	6.0416	4.6154	4.5312	3.0208	2.3077	2.2656	2.0138	1.8125	1.5104	1.4500	1.2083	145
146	9.1250	7.3000	6.0833	4.6473	4.5625	3.0416	2.3236	2.2812	2.0277	1.8250	1.5208	1.4600	1.2166	146
147	9.1875	7.3500	6.1250	4.6791	4.5937	3.0625	2.3395	2.2968	2.0416	1.8375	1.5312	1.4700	1.2250	147
148	9.2500	7.4000	6.1666	4.7109	4.6250	3.0833	2.3554	2.3125	2.0555	1.8500	1.5416	1.4800	1.2333	148
149	9.3125	7.4500	6.2083	4.7428	4.6562	3.1041	2.3714	2.3281	2.0694	1.8625	1.5520	1.4900	1.2416	149

TABLE OF PITCH DIAMETERS

TABLE 12: Pitch Diameters 150 to 197 Teeth

To find outside diameter add 2 teeth.

Theoretical P.D.s only. All gears cut to AGMA standards.

N = Number of teeth

NOTE: Applies to spur and bevel gears only (not to helical gears).

N	DIAMETRAL PITCH													N
	16	20	24	1/10	32	48	1/20	64	72	80	96	100	120	
150	9.3750	7.5000	6.2500	4.7746	4.6875	3.1250	2.3873	2.3437	2.0833	1.8750	1.5625	1.5000	1.2500	150
151	9.4375	7.5500	6.2916	4.8064	4.7187	3.1458	2.4032	2.3593	2.0972	1.8875	1.5729	1.5100	1.2583	151
152	9.5000	7.6000	6.3333	4.8383	4.7500	3.1666	2.4191	2.3750	2.1111	1.9000	1.5833	1.5200	1.2666	152
153	9.5625	7.6500	6.3750	4.8701	4.7812	3.1875	2.4350	2.3906	2.1250	1.9125	1.5937	1.5300	1.2750	153
154	9.6250	7.7000	6.4166	4.9019	4.8125	3.2083	2.4509	2.4062	2.1388	1.9250	1.6041	1.5400	1.2833	154
155	9.6875	7.7500	6.4583	4.9338	4.8437	3.2291	2.4669	2.4218	2.1527	1.9375	1.6145	1.5500	1.2916	155
156	9.7500	7.8000	6.5000	4.9656	4.8750	3.2500	2.4828	2.4375	2.1666	1.9500	1.6250	1.5600	1.3000	156
157	9.8125	7.8500	6.5416	4.9974	4.9062	3.2708	2.4987	2.4531	2.1805	1.9625	1.6354	1.5700	1.3083	157
158	9.8750	7.9000	6.5833	5.0292	4.9375	3.2916	2.5146	2.4687	2.1944	1.9750	1.6458	1.5800	1.3166	158
159	9.9375	7.9500	6.6250	5.0611	4.9687	3.3125	2.5305	2.4843	2.2083	1.9875	1.6562	1.5900	1.3250	159
160	10.0000	8.0000	6.6666	5.0929	5.0000	3.3333	2.5464	2.5000	2.2222	2.0000	1.6666	1.6000	1.3333	160
161	10.0625	8.0500	6.7083	5.1247	5.0312	3.3541	2.5623	2.5156	2.2361	2.0125	1.6770	1.6100	1.3416	161
162	10.1250	8.1000	6.7500	5.1566	5.0625	3.3750	2.5783	2.5312	2.2500	2.0250	1.6875	1.6200	1.3500	162
163	10.1875	8.1500	6.7916	5.1884	5.0937	3.3958	2.5942	2.5468	2.2638	2.0375	1.6979	1.6300	1.3583	163
164	10.2500	8.2000	6.8333	5.2202	5.1250	3.4166	2.6101	2.5625	2.2777	2.0500	1.7083	1.6400	1.3666	164
165	10.3125	8.2500	6.8750	5.2521	5.1562	3.4375	2.6260	2.5781	2.2916	2.0625	1.7187	1.6500	1.3750	165
166	10.3750	8.3000	6.9166	5.2839	5.1875	3.4583	2.6419	2.5937	2.3055	2.0750	1.7291	1.6600	1.3833	166
167	10.4375	8.3500	6.9583	5.3157	5.2187	3.4791	2.6578	2.6093	2.3194	2.0875	1.7395	1.6700	1.3916	167
168	10.5000	8.4000	7.0000	5.3476	5.2500	3.5000	2.6738	2.6250	2.3333	2.1000	1.7500	1.6800	1.4000	168
169	10.5625	8.4500	7.0416	5.3794	5.2812	3.5208	2.6897	2.6406	2.3472	2.1125	1.7604	1.6900	1.4083	169
170	10.6250	8.5000	7.0833	5.4112	5.3125	3.5416	2.7056	2.6562	2.3611	2.1250	1.7708	1.7000	1.4166	170
171	10.6875	8.5500	7.1250	5.4430	5.3437	3.5625	2.7215	2.6718	2.3750	2.1375	1.7812	1.7100	1.4250	171
172	10.7500	8.6000	7.1666	5.4749	5.3750	3.5833	2.7374	2.6875	2.3888	2.1500	1.7916	1.7200	1.4333	172
173	10.8125	8.6500	7.2083	5.5067	5.4062	3.6041	2.7533	2.7031	2.4027	2.1625	1.8020	1.7300	1.4416	173
174	10.8750	8.7000	7.2500	5.5385	5.4375	3.6250	2.7692	2.7187	2.4166	2.1750	1.8125	1.7400	1.4500	174
175	10.9375	8.7500	7.2916	5.5704	5.4687	3.6458	2.7852	2.7343	2.4305	2.1875	1.8229	1.7500	1.4583	175
176	11.0000	8.8000	7.3333	5.6022	5.5000	3.6666	2.8011	2.7500	2.4444	2.2000	1.8333	1.7600	1.4666	176
177	11.0625	8.8500	7.3750	5.6340	5.5312	3.6875	2.8170	2.7656	2.4583	2.2125	1.8437	1.7700	1.4750	177
178	11.1250	8.9000	7.4166	5.6659	5.5625	3.7083	2.8329	2.7812	2.4722	2.2250	1.8541	1.7800	1.4833	178
179	11.1875	8.9500	7.4583	5.6977	5.5937	3.7291	2.8488	2.7968	2.4861	2.2375	1.8645	1.7900	1.4916	179
180	11.2500	9.0000	7.5000	5.7295	5.6250	3.7500	2.8647	2.8125	2.5000	2.2500	1.8750	1.8000	1.5000	180
181	11.3125	9.0500	7.5416	5.7614	5.6562	3.7708	2.8807	2.8281	2.5138	2.2625	1.8854	1.8100	1.5083	181
182	11.3750	9.1000	7.5833	5.7932	5.6875	3.7916	2.8966	2.8437	2.5277	2.2750	1.8958	1.8200	1.5166	182
183	11.4375	9.1500	7.6250	5.8250	5.7187	3.8125	2.9125	2.8593	2.5416	2.2875	1.9062	1.8300	1.5250	183
184	11.5000	9.2000	7.6666	5.8569	5.7500	3.8333	2.9284	2.8750	2.5555	2.3000	1.9166	1.8400	1.5333	184
185	11.5625	9.2500	7.7083	5.8887	5.7812	3.8541	2.9443	2.8906	2.5694	2.3125	1.9270	1.8500	1.5416	185
186	11.6250	9.3000	7.7500	5.9205	5.8125	3.8750	2.9602	2.9062	2.5833	2.3250	1.9375	1.8600	1.5500	186
187	11.6875	9.3500	7.7916	5.9523	5.8437	3.8958	2.9761	2.9218	2.5972	2.3375	1.9479	1.8700	1.5583	187
188	11.7500	9.4000	7.8333	5.9842	5.8750	3.9166	2.9921	2.9375	2.6111	2.3500	1.9583	1.8800	1.5666	188
189	11.8125	9.4500	7.8750	6.0160	5.9062	3.9375	3.0080	2.9531	2.6250	2.3625	1.9687	1.8900	1.5750	189
190	11.8750	9.5000	7.9166	6.0478	5.9375	3.9583	3.0239	2.9687	2.6388	2.3750	1.9791	1.9000	1.5833	190
191	11.9375	9.5500	7.9583	6.0797	5.9687	3.9791	3.0398	2.9843	2.6527	2.3875	1.9895	1.9100	1.5916	191
192	12.0000	9.6000	8.0000	6.1115	6.0000	4.0000	3.0557	3.0000	2.6666	2.4000	2.0000	1.9200	1.6000	192
193	12.0625	9.6500	8.0416	6.1433	6.0312	4.0208	3.0716	3.0156	2.6805	2.4125	2.0104	1.9300	1.6083	193
194	12.1250	9.7000	8.0833	6.1752	6.0625	4.0416	3.0876	3.0312	2.6944	2.4250	2.0208	1.9400	1.6166	194
195	12.1875	9.7500	8.1250	6.2070	6.0937	4.0625	3.1035	3.0468	2.7083	2.4375	2.0312	1.9500	1.6250	195
196	12.2500	9.8000	8.1666	6.2388	6.1250	4.0833	3.1194	3.0625	2.7222	2.4500	2.0416	1.9600	1.6333	196
197	12.3125	9.8500	8.2083	6.2707	6.1562	4.1041	3.1353	3.0781	2.7361	2.4625	2.0520	1.9700	1.6416	197

GEAR WEAR & LUBRICATION

Wear

Another factor to consider in the successful design of a gear train is tooth surface wear. It can take on many forms but always leads to reduced accuracy and loss of smooth operation. Wear can eventually cause enough deterioration to introduce dynamic forces that are strong enough to break or bend gear teeth. The most common types of wear are pitting, scuffing and scoring.

Pitting is caused by localized metal fatigue on the surface of the gear. Microscopic cracks are forced to propagate which causes small metal chunks to break off. The best ways to avoid this are:

- Reduce contact stress
- Use hardened gears
- Use proper lubrication

Scuffing is caused by small surface irregularities that can rub each other as gear teeth come into and out of mesh. It is caused by the plastic deformation of microscopic surface protrusion. The best ways to avoid scuffing are:

- Use gears that are cut to a high quality surface finish
- “Run in” with 1/2 load for the first 10 hours
- Use proper lubrication at all times

Scoring is caused by small particles in the lubrication that get caught in the meshing teeth. This causes scratches that can extend from the roof to the tip. These can be quite deep. The best ways to avoid scoring are:

- Proper high quality lubrication
- Change the lubrication after the “run in” period
- Change or filter the lubrication as needed

Lubrication

Using the proper lubrication can extend the life of your gear train by a factor of 4 or more. The lubrication will form a thin layer between the teeth in contact. This will reduce all types of tooth wear which will keep your gear running smoothly. This is especially important with worm gear sets and helical gear sets as these types of gears operate with more of a sliding motion than a rolling motion (as in spur gears).

There are many lubrications that work extremely well with gear sets. The one you choose depends on your application.

For lightly loaded, low speed systems, a light coating of grease can be brushed on during assembly. The grease will not fly oil or overheat, and should be replaced regularly to ensure optimal life.

For higher speed systems, an oil bath is recommended. Oil is more effective than other lubrications at dissipating heat. The gears will always be in contact with the oil, so flying off is not a problem. The oil should be replaced after the “run in” period and regularly thereafter.

Many other lubricants exist for applications in which oil and greases could present a problem. They vary greatly in price, durability, thickness, consistency and lubricity. For low torque and low speed systems where dry running is essential, you might make use of plastic gears against a metal pinion. Generally, this offers a low enough co-efficient of friction to ensure long life.

GEAR MOUNTING

There are several ways to mount a gear to a shaft. The method you choose will depend on your application. Berg supplies gears that will accommodate a variety of mounting methods. Our pin hub gears can be mounted in three ways:

1. We suggest using the set screw to secure the gear in the proper location, then using the spot drill to drill through the hub and shaft. Then the gear can be mounted with any one of a variety of pins (Berg carries a full line of pins).
2. For light load applications, you can rely solely on the set screw. This works best if the shaft is a relatively soft material so that the screw can form its own seat.
3. For precision applications, a light press fit could be appropriate. This would insure good concentricity between the gear, shaft and indirectly, the bearings. You must take precaution not to damage the gear during the press procedure.

Formula for Press Fit

$$Pmax = \frac{emaxE}{2d}\left(1- \left(\frac{d}{D}\right)^2\right) \qquad Pmax = \frac{eminE}{2d}\left(1- \left(\frac{d}{D}\right)^2\right)$$

$T = 1/2\ p\ ^{fP}min\ ld^2$
P = Unit pressure of max. or min. interfering surfaces (psi)
T = Torque required to slip (in lbs.)
e = Max. or min. interference (in.)
E = Modulus of elasticity of the softer material (psi), see Mechanical Properties table
d = Shaft diameter (in.)
D = Hub diameter (in.)
f = Coefficient of static friction (approximately 0.1 -0.15)
l = Length of fit (in.)

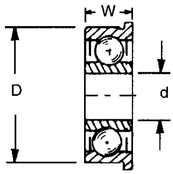
It is important to keep the maximum interfering pressure less than the yield strength in order for these formulae to remain valid. A good rule of thumb is for each 1" of diameter the interfering distance (e) should be about .001". This number tends to get smaller as d gets larger. For example, a 3" diameter uses an allowance of approximately .0025".

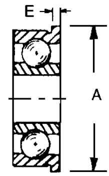
Our clamp hub gears allow you to securely mount a gear with the ability to reposition it as required. Consult catalog section I to determine which clamp of our large variety will work best with your gear selection.

BEARING TOLERANCES

The Annular Bearing Engineers Committee (ABEC) has established standards that divide precision ball bearings into quality classes. For most applications, ABEC 1 or ABEC 3 bearings will offer significant accuracy. However, there are times when highly precise position is required. In these applications, ABEC 5 or ABEC 7 bearings should be specified.

This page refers to ABEC tolerances that affect the mounting dimensions of ball bearings. The following page discusses tolerances that influence the operation of the bearings.





Outer Ring Tolerances

		Tolerance															
Outside Diameter (D)		D +0.0000				W +0.0000				A				E +0.0000			
OVER	INCL.	ABEC 1	ABEC 3	ABEC 5	ABEC 7	ABEC 1	ABEC 3	ABEC 5	ABEC 7	ABEC 1	ABEC 3	ABEC 5	ABEC 7	ABEC 1	ABEC 3	ABEC 5	ABEC 7
0	.7087	-.0003	-.0003	-.0002	-.0002	-.0050	-.0050	-.0010	-.0010	—	+.0050 -.0020	+.0000 -.0010	+.0000 -.0010	—	-.0020	-.0020	-.0020
.7087	1.1811	-.0004	-.0003	-.0002	-.0002	-.0050	-.0050	-.0010	-.0010	—	+.0050 -.0020	+.0000 -.0010	+.0000 -.0010	—	-.0020	-.0020	-.0020
1.1811	1.9685	-.0005	-.0003	-.0002	-.0002	-.0050	-.0050	-.0010	-.0010	—	+.0050 -.0020	+.0000 -.0010	+.0000 -.0010	—	-.0020	-.0020	-.0020
1.9685	3.1496	-.0005	-.0004	-.0003	-.0002	-.0050	-.0050	-.0015	-.0010	—	—	—	—	—	—	—	—

Inner Ring Tolerances

		Tolerance							
Bore Diameter (d)		d +0.0000				W +0.0000			
OVER	INCL.	ABEC 1	ABEC 3	ABEC 5	ABEC 7	ABEC 1	ABEC 3	ABEC 5	ABEC 7
0	.3937	-.0003	-.0002	-.0002	-.0002	-.0050	-.0050	-.0010	-.0010
.3937	.7087	-.0003	-.0002	-.0002	-.0002	-.0050	-.0050	-.0010	-.0010
.7087	1.1811	-.0004	-.0002	-.0002	-.0002	-.0050	-.0050	-.0010	-.0010
1.1811	1.9685	-.0005	-.0003	-.0002	-.0002	-.0050	-.0050	-.0010	-.0010

BEARING TOLERANCES

The following tolerances illustrate the differences between ABEC quality classes that could affect the performance of your assembly. These tolerances should be strongly considered if a high precision gear train is your goal.

Outer Ring Tolerances

		Tolerance															
Outside Diameter (D)		Radial Runout (max.)				Width Variation (max.)		Outside Cylindrical Surface Runout with Reference Side (max.)		Groove Runout with Reference Side (max.)		Outer Diameter 2 Point Out Of Round (max.)		Outer Diameter Taper (max.)	
OVER	INCL.	ABEC 1	ABEC 3	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7
0	.7087	.0006	.0004	.0002	.00015	.0002	.0001	.0003	.00015	.0003	.0002	.0001	.0001	.0001	.0001
.7087	1.1811	.0006	.0004	.0002	.00015	.0002	.0001	.0003	.00015	.0003	.0002	.0001	.0001	.0001	.0001
1.1811	1.9685	.0008	.0004	.0002	.00015	.0002	.0001	.0003	.00015	.0003	.0002	.0001	.0001	.0001	.0001
1.9685	3.1496	.0010	.0005	.0003	.0002	.0002	.00015	.0003	.00015	.0004	.0002	—	—	—	—

Inner Ring Tolerances

		Tolerance													
Bore Diameter (d)		Radial Runout (max.)				Width Variation (max.)		Reference Runout with Bore (max.)		Groove Runout with Reference Side (max.)		Bore 2-Point Out Of Round (max.)		Bore Taper (max.)	
OVER	INCL.	ABEC 1	ABEC 3	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7	ABEC 5	ABEC 7
0	.3937	.0003	.0002	.00015	.0001	.0002	.0001	.0003	.0001	.0003	.0001	.0001	.0001	.0001	.0001
.3937	.7087	.0004	.0003	.00015	.0001	.0002	.0001	.0003	.0001	.0003	.0001	.0001	.0001	.0001	.0001
.7087	1.1811	.0005	.0003	.00015	.00015	.0002	.0001	.0003	.00015	.0003	.00015	.0001	.0001	.0001	.0001
1.1811	1.9685	.0006	.0004	.0002	.00015	.0002	.0001	.0003	.00015	.0003	.00015	—	—	—	—

METRIC CONVERSIONS & QUALITY SPECIFICATIONS

FRACTIONAL INCHES CONVERTED TO DECIMAL INCHES AND MILLIMETERS					
Fraction of Inch	Decimal of Inch	Decimal Millimeters	Fraction of Inch	Decimal of Inch	Decimal Millimeters
1/64	.015625	0,39688	33/64	.515625	13,09688
1/32	.03125	0,79375	17/64	.53125	13,49375
3/64	.046875	1,19063	35/64	.546875	13,89063
1/16	.0625	1,5875	9/16	.5625	14,2875
5/64	.078125	1,98438	37/64	.578125	14,68438
3/32	.09375	2,38125	19/32	.59375	15,08125
7/64	.109375	2,77813	39/64	.609375	15,47813
1/8	.125	3,175	5/8	.625	15,875
9/64	.140625	3,57188	41/64	.640625	16,27188
5/32	.15625	3,96875	21/32	.65626	16,66875
11/64	.171875	4,36563	43/64	.671875	17,06563
3/16	.1875	4,7625	11/16	.6875	17,4625
13/64	.203125	5,15938	45/64	.703125	17,85938
7/32	.21875	5,55625	23/32	.71875	18,25625
15/64	.234375	5,95313	47/64	.734375	18,65313
1/4	.25	6,35	3/4	.75	19,05
17/64	.265625	6,74688	49/64	.765625	19,44688
9/32	.28125	7,14375	25/32	.78125	19,84375
19/64	.296875	7,54063	51/64	.796875	20,24063
5/16	.3125	7,9375	13/16	.8125	20,6375
21/64	.328125	8,33438	53/64	.828125	21,03438
11/32	.34375	8,73125	27/32	.84375	21,43125
23/64	.359375	9,12813	55/64	.859375	21,82813
3/8	.375	9,525	7/8	.875	22,225
25/64	.390625	9,92188	57/64	.890625	22,62188
13/32	.40625	10,31875	29/32	.90625	23,01875
27/64	.421875	10,71563	59/64	.921875	23,41563
7/16	.4375	11,1125	15/16	.9375	23,8125
29/64	.453125	11,50938	61/64	.953125	24,20938
15/32	.46875	11,90625	31/32	.96875	24,60625
31/64	.484375	12,30313	63/64	.984375	25,00313
1/2	.5	12,7	1"	1.0	25,4

Gears

BERG QUALITY CLASS	AGMA 390.03	DIN SPECIFICATIONS
QA	4	12
QD	7	10
QE	8	9
QF	9	8
QG	10	7
QJ	12	5
QM	14	3

Bearings

BERG QUALITY CLASS	AGMA ABEC	ISO 492 SPECIFICATIONS
QU	5	CLASS 5
QW	7	CLASS 4

AGMA - American Gear Manufacturers Association
DIN - Deutsches Instit fur Normung
AFBNA - Anti Friction Bearings Manufacturers Association
ABEC - Annular Bearing Engineering Committee
ISO - International Organization for Standardization

Conversion Factors

39.37 0.3937	INCHES/METER INCHES/CM	14.223	LBS/IN^2 KG/CM^2
0.03937	INCHES/mm	1.4503 X 10^4	PSI/Pascal
3.2808 1 X 10^6	FT/M METERS/MICRON	5.71 X 103	LBS/IN N/M
1 X 10^3 2.2046	mm/MICRON LBS/KG	8.85	LBS-INCHES N-M
2.204 X 10^3 3.527 X 10^2	LBS/GM OZ/GM	0.0885	LBS-INCHES N-CM
0.0108	OZ/FT GM/M	1.416	OZ-INCHES N-CM
0.2248	LBS/N	0.0338	OZ/CC
0.102	KG/N	5.4668 X 10^3	OZ-IN^2/GM-CM^3

DRILL & TAP REFERENCE DATA

Unified American National Screws

Drill & Tap Reference Data

SCREW SIZE		NUMBER OF THREADS PER INCH	TAP DRILL		CLEARANCE HOLE DRILL			
					CLOSE FIT		FREE FIT	
NUMBER	DECIMAL		DR. SIZE	DECIMAL	DR. SIZE	DECIMAL	DR. SIZE	DECIMAL
#000	.034	120	#71	.026	#63	.037	#57	.0430
#00	.047	96	#62	.038	#55	.052	#53	.0595
#0	.060	80	#56	.0465	#52	.0635	#50	.0700
#1	.073	64	#53	.0595	#48	.0760	#46	.0810
#1	.073	72	#53	.0595	#48	.0760	#46	.0810
#2	.086	56	#50	.0700	#43	.0890	#41	.0960
#2	.086	64	#50	.0700	#43	.0890	#41	.0960
#3	.099	48	#47	.0785	#37	.1040	#35	.1100
#3	.099	56	#45	.0820	#37	.1040	#35	.1100
#4	.112	40	#43	.0890	#32	.1160	#30	.1285
#4	.112	48	#42	.0935	#32	.1160	#30	.1285
#5	.125	40	#38	.1015	#30	.1285	#29	.1360
#5	.125	44	#37	.1040	#30	.1285	#29	.1360
#6	.138	32	#36	.1065	#27	.1440	#25	.1495
#6	.138	40	#33	.1130	#27	.1440	#25	.1495
#8	.164	32	#29	.1360	#18	.1695	#16	.1770
#8	.164	36	#29	.1360	#18	.1695	#16	.1770
#10	.190	24	#25	.1495	#9	.1960	#7	.2010
#10	.190	32	#21	.1590	#9	.1960	#7	.2010
#12	.216	24	#16	.1770	#2	.2210	I	.2280
#12	.216	28	#14	.1820	#2	.2210	I	.2280
1/4	.250	20	#7	.2010	F	.2570	H	.2660
1/4	.250	28	#3	.2130	F	.2570	H	.2660
5/16	.3125	18	F	.2570	P	.3230	Q	.3320
5/16	.3125	24	I	.2720	P	.3230	Q	.3320
3/8	.375	16	5/16	.3125	W	.3860	X	.3970
3/8	.375	24	Q	.3320	W	.3860	X	.3970
7/16	.4375	14	U	.3680	29/64	.4531	15/32	.4687
7/16	.4375	20	25/64	.3906	29/64	.4531	15/32	.4687
1/2	.500	13	27/64	.4219	33/64	.5156	17/32	.5312
1/2	.500	20	29/64	.4531	33/64	.5156	17/32	.5312

NO.	SIZE	NO.	SIZE	NO.	SIZE	NO.	SIZE	NO.	SIZE	NO.	SIZE
#1	.2280	#17	.1730	#33	.1130	#49	.0730	#65	.0350	A	.234
#2	.2210	#18	.1695	#34	.1110	#50	.0700	#66	.0330	B	.238
#3	.2130	#19	.1660	#35	.1100	#51	.0670	#67	.0320	C	.242
#4	.2090	#20	.1610	#36	.1065	#52	.0635	#68	.0310	D	.246
#5	.2055	#21	.1590	#37	.1040	#53	.0595	#69	.0295	E	.250
#6	.2040	#22	.1570	#38	.1015	#54	.0550	#70	.0280	F	.257
#7	.2010	#23	.1540	#39	.0995	#55	.0520	#71	.0260	G	.261
#8	.1990	#24	.1520	#40	.0980	#56	.0465	#72	.0250	H	.266
#9	.1960	#25	.1495	#41	.0960	#57	.0430	#73	.0240	I	.272
#10	.1935	#26	.1470	#42	.0935	#58	.0420	#74	.0225	J	.277
#11	.1910	#27	.1440	#43	.0890	#59	.0410	#75	.0210	K	.281
#12	.1890	#28	.1405	#44	.0860	#60	.0400	#76	.0200	L	.290
#13	.1850	#29	.1360	#45	.0820	#61	.0390	#77	.0180	M	.295
#14	.1820	#30	.1285	#46	.0810	#62	.0380	#78	.0160	N	.302
#15	.1800	#31	.1200	#47	.0785	#63	.0370	#79	.0145	O	.316
#16	.1770	#32	.1160	#48	.0760	#64	.0360	#80	.0135	P	.323

MECHANICAL PROPERTIES

Mechanical Properties from “Machine Design in Mechanical Design” by Robert L. Mott

Material	Hardness (Rockwell)	Tension Modulus (E)	Tensile Strength	Yield Strength	Shear Strength	Endurance Limit
303 Stainless Steel	B75-90	28 X 10^6 PSI	90 X 10^3 PSI	35 X 10^3 PSI	75 X 10^3 PSI	35 X 10^3 PSI
17-4 PH Stainless Steel	C28-35	28.5 X 10^6 PSI	150 X 10^3 PSI	125 X 10^3 PSI	83 X 10^3 PSI	90 X 10^3 PSI
416 Stainless Steel	C26-36	29 X 10^6 PSI	75 X 10^3 PSI	40X 10^3 PSI	75 X 10^3 PSI	40 X 10^3 PSI
416 Stainless Steel - Hardened	C36-42	29 X 10^6 PSI	135 X 10^3 PSI	105 X 10^3 PSI	75 X 10^3 PSI	40 X 10^3 PSI
12 L14 Steel	B75-90	30 X 10^6 PSI	78 X 10^3 PSI	60 X 10^3 PSI	50 X 10^3 PSI	–
2024T4 Aluminum	–	10.6 X 10^6 PSI	68 X 10^3 PSI	47 X 10^3 PSI	40 X 10^3 PSI	–
464 Brass Alloy	–	18 X 10^6 PSI	57 X 10^3 PSI	25 X 10^3 PSI	40 X 10^3 PSI	–
360 Brass Alloy	–	14 X 10^6 PSI	49 X 10^3 PSI	18 X 10^3 PSI	30 X 10^3 PSI	–

MILITARY SPECIFICATIONS & MANUFACTURING TOLERANCES

MATERIAL		FINISH		USED ON
MATERIAL DESIGNATION	MIL. or FED. SPECIFICATION	BERG FINISH DESIGNATION	MIL. FINISH SPECIFICATION	
303 STAINLESS STEEL (BAR)	ASTM A484 ASTM A582	—	QQ-P-35	GEARS, SHAFTS
302 STAINLESS STEEL (Spring Temp.)	MIL-W-6713 Comp. B	—	QQ-P-35	SPRINGS, RETAINER RINGS
416 STAINLESS STEEL (BAR)	ASTM A484 ASTM A582	—	QQ-P-35	RACKS-HEAT TREATABLE
440 STAINLESS STEEL (BAR)	QQ-S-763/C Class 10 Type A	CLEAR PASSIVATE	QQ-P-35	BALL BEARINGS (Hardened)
2024 ALUMINUM (BAR)	QQ-A-225/6 Cond. T4	CHROMIC ACID ANODIZED	MIL-A-8625 Type 1	GEARS, HANGERS, ETC.
2024 ALUMINUM (SHEET)	QQ-A-268 Cond. T4	BLACK ANODIZED	MIL-A-8625 Type 11	DIALS
108 ALUMINUM (CAST)	QQ-A-601 Comp. 8 Cond. T55	CHROMIC ACID OR BLACK ANODIZED	MIL-A-8625 Type 1 + Type 11	BREADBOARD COMPONENT
BRONZE (NAVAL BRASS)	QQ-B-637 Alloy 464	—	—	WORM WHEELS
BRASS-POROUS (OIL LESS)	MIL-B-5687 Type 1 Comp. A	LUBRICATED WITH S.A.E. 40 OIL	—	BEARINGS
BRASS (LAMINATED)	MIL-S-22499 Comp. 2CL.1	—	—	SHIMS
BERYLLIUM COPPER	MIL-C-6942	—	—	RETAINER RINGS
NYLON	MIL-M-20693 Type 1 Comp. A	—	—	GEARS
POLYURETHANE	—	—	—	GEARS, ROLLERS, BRG'S
PLEXIGLASS (CLEAR)	MIL-P-5425 Finish A	—	—	DIAL INDEX'S
STAINLESS STEEL CABLE	MIL-W-83420	—	—	BELTS & CHAINS
GALVANIZED ST CABLE	MIL-C-1511A-4	GALVANIZED	—	—
OIL	MIL-L-6085	—	—	GEARS & BEARINGS -65°F TO +250°F
GREASE	MIL-G-23827	—	—	GEARS & BEARINGS -65°F TO +250°F

Manufacturing Tolerances (unless otherwise specified):

Fractional ± 1/32
2 Place Decimal ± 1/64
3 Place Decimal ± .010
4 Place Decimal ± .001

NOTE: Certification for materials and finishes are available on request - charges may apply.

MATERIAL SPECIFICATIONS

STAINLESS STEEL				
AISI; AA Material Designation	DIN Specs	U.S. Specs	UNS	ISO
303 Stainless Steel Rockwell B75-B90	1.4305	MIL-S-862	S30300	–
302 Stainless Steel (18-8)	1.4300	MIL-S-862	S30200	–
302 Stainless Steel - Spring Temper	–	MIL-W-6713	–	–
17-7PH Rockwell C38-C44	–	–	S17700	–
17-4PH Rockwell C32-C38	–	–	S17400	–
416 Rockwell C26 to C36	1.4005	MIL-S-862	S41600	–
416 Rockwell C36 to C42	–	–	–	–
410 Stainless Steel	1.4006	MIL-S-862	S41000	–
440 Stainless Steel	1.4112	MIL-S-763	S41003	–
420 Stainless Steel	1.4021	MIL-S-862	S42000	–
301 Stainless Steel	1.4310	MIL-S-5059	S30100	–
304 Stainless Steel	1.4301	MIL-S-862	S30400	–
316 Stainless Steel, Sintered	–	–	–	–
316 Stainless Steel, Sintered	1.4401	MIL-S-5059	S31600	–
NON-FERROUS METALS				
2024 T4 Aluminum	3.1355	–	–	AICu4MgI
2024 T351 Aluminum	–	–	–	–
6063 T5 Aluminum	3.3206	–	–	AIMgSi
6061 T6 Aluminum	–	–	–	AIMgISiCu
Phosphor Bronze	–	–	C50500	–
Bronze, Sintered	–	MIL-B-5687	–	–
Brass, Naval, Alloy 464	–	QQ-B-637	C46200	–
713.0 Aluminum Casting, Tenzaloy	–	–	–	–
Zinc Alloy B86, AG40A (Zamak-3)	–	–	–	–
Beryllium Copper	–	MIL-C-6942	–	–
STEEL				
52100 Chrome Steel, Rockwell 062-C66	1.3505	MIL-S-980	G52986	–
12L14 Steel	1.0718	–	G12144	–
4140 Steel, Rockwell C48-C52	–	–	G41400	–
1095 Steel	–	–	G10750	–
1060 Steel Rockwell C60-C63	1.0601	MIL-S-16974	G10600	–
8620 Steel	1.6523	MIL-S-16974	G86200	–
PLASTIC				
Polyacetal				
Polyacetal, with lubricant fibers				
Polycarbonate				
Polycarbonate, Glass filled-10%, Black				

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