FIRST Robotics Competition

Applications Using Gates Rubber Synchronous Belt Drives

Welcome from Gates Corporation

Gates Corporation is excited to be an Official Sponsor of the *FIRST* Robotics Competition!

Belt Benefits
Gates 5M PowerGrip® HTD® belts are ideally sized for drives and functional applications on a *FIRST* Robotics Competition robot.

- **Lightweight** – much lighter than chain and gearing systems for comparable loads
- **Useful** – PowerGrip HTD rubber belt drive systems are ideal not only for drives, but also for linear motion, lifts, game object conveying, positioning, and even for precisely flinging objects
- **Easy to Work With** – aluminum sprockets are easy to machine and belting can be wrapped, cemented, or riveted to the structure
- **Oil-Free** – these drives remain clean because oil is not needed and present a complete image of current technology
- **Quiet** – reduced noise as compared with other drive technologies such as chain and gears

Additional Information
If you require more assistance please go online to www.gates.com/FIRST to watch helpful videos, use online calculators, and download additional resources.

Part Information
Your belt drive chassis kit includes:

- Five Gates PowerGrip HTD belts

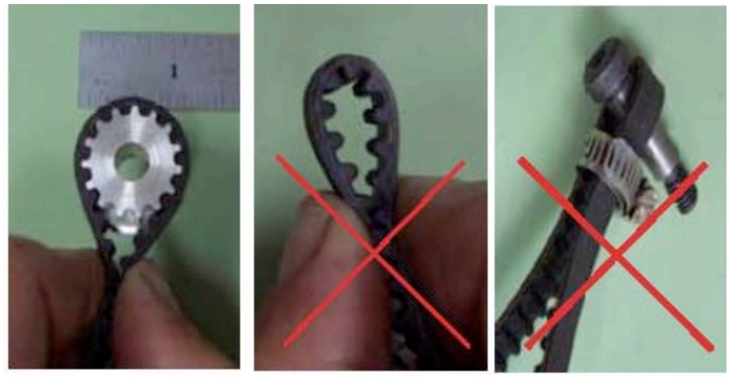
See Appendix B for part nomenclature.

Where to Get More
For details on getting additional or different Gates parts, please reference the *FIRST* Robotics Competition "Where to Get More" document or visit www.gates.com/first.

Best of luck in your *FIRST* Robotics Competition!

Appendix A: Belt Drive Application Tips

Best advice – One test is worth 1,000 calculations.

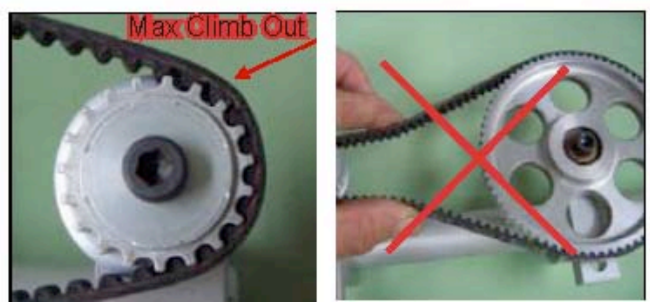


Handling the Belts – Do not bend belts smaller than the diameter of the 15 groove sprocket. A single tight bend or crimp will break the belt's fiberglass tensile member and cause loss of strength and potential premature failure of the belt.

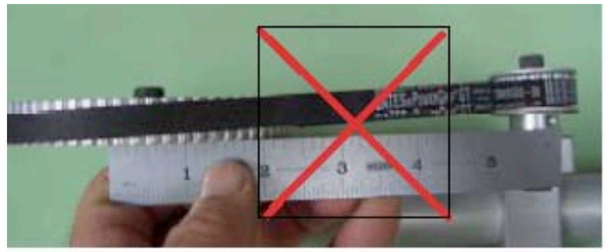
Do not pry belts onto or off sprockets. To correctly install or remove belts, create slack by adjusting center distance or moving belt tensioner. Do not roll belts onto or off sprockets either.

Sprocket Flanges – Provide flanges on either both sides of one sprocket or one side on the driver and the opposite side on the driven sprocket. All belts naturally migrate to one side of the sprocket. You must use flanges as described.

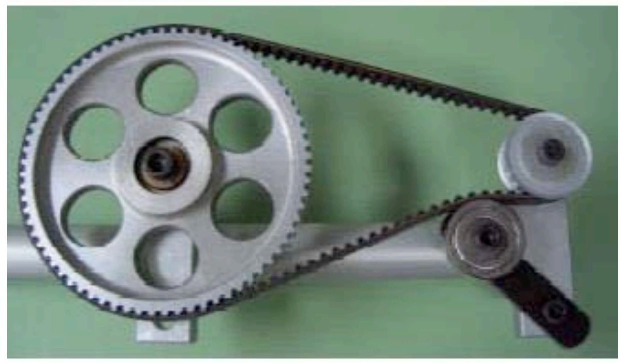
Belt Tensioning – Tension the belt so that when the drive is under full anticipated load (including shock loads) the belt does not get slack on one side, or the belt teeth try to climb out of the sprocket grooves. Make sure the mounting structure does not deflect when either tensioning the belt or under operating conditions. If you lose tension, the belt will jump teeth. Keep belt shafts parallel and sprockets in line with each other. Apply as much tension to the belt as possible without damaging any equipment.



Belt Alignment – Sprockets must be aligned and shafts parallel in both planes. Alignment can easily be checked using a straight edge.



Belt Wrap – Keep a minimum of 6 belt teeth fully in mesh on the circumference of each sprocket. This will allow a properly tensioned belt to perform at 100% of its load rating. A backside idler can be useful for both tensioning the drive and increasing the belt wrap around the sprocket. The idler is used on the slack side of a belt drive and must be 1.25” in diameter for 5mm pitch PowerGrip HTD belts.



Guarding & Debris Protection – A piece of flat plastic supported in between the belt spans is a simple way to eliminate pinch points and keep debris out of the drive.

Product Ratings – Load capacity of the belts is proportional to their width. Gates belt ratings are set to guarantee long life on industrial applications. For *FIRST* Robotics Competition applications, your load capability is going to be determined by the shaft-to-sprocket connections, belt wrap, and the ability to pre-tension the drive so that the belt does not jump teeth. With adequate belt wrap and proper installation tension, you will be surprised by the durability of this product!

Splicing Belts – Belts or belting should not be field connected or spliced together by any means other than connecting the belts with clamp plates. You need to use the correct pitch length belt.

Appendix B: Component Specifications

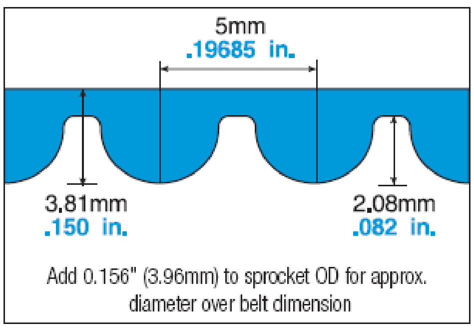
Components are categorized by "pitch", which is the distance from the center of one tooth to the center of the next tooth on a belt.

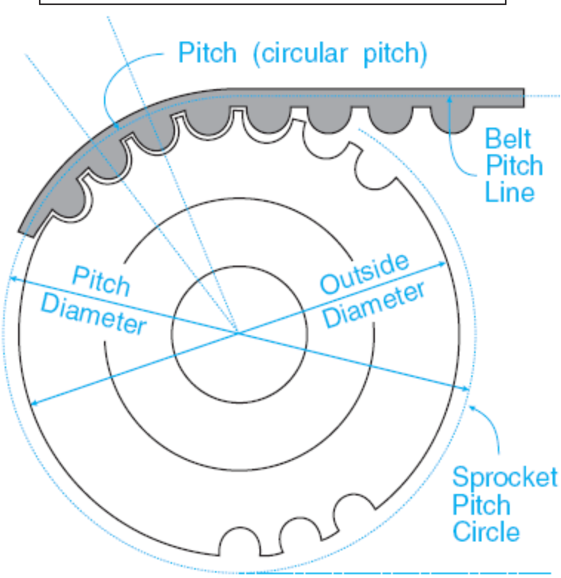
Gates belts are identified by length, pitch, and width. Example: the 520-5M-15 is a belt with a 520 mm length, 5 mm pitch, and 15 mm width.

Gates sprockets are identified by tooth count, pitch, width, and material. Example: P16-5M-15AL is a 16 tooth sprocket, 5 mm pitch, 15 mm width and made of aluminum.

NOTE: 25mm wide sprockets are not available as a stock part through Gates.

5mm Pitch – Reference Dimensions





Belt & Sprocket Compatibility

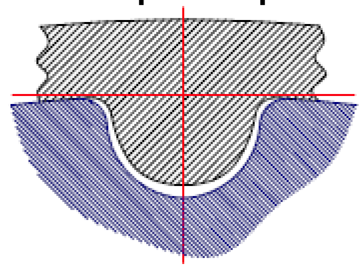
It's possible that some teams have received Gates PowerGrip® GT®2 belts and sprockets in the past, which should not be confused with PowerGrip HTD components (GT2 and HTD describe two different tooth profiles or shapes).

Gates recommends only using belt types with their corresponding sprocket types. PowerGrip GT2 belts can be used in PowerGrip HTD sprockets, **but it's not recommended.**

DO NOT USE POWERGRIP HTD BELTS IN POWERGRIP GT2 SPROCKETS.

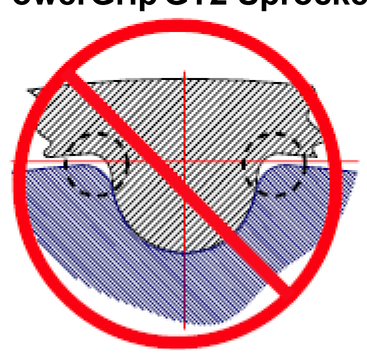
The figures below illustrate the tooth meshing characteristics of the two belt/sprocket combinations.

5M PowerGrip GT2 Belt in PowerGrip HTD Sprocket



Not Recommended
- Reduced performance
- The sprocket/bushing capacity may be too low for new designs

5M PowerGrip HTD Belt in PowerGrip GT2 Sprocket



No Compatibility
- The belt tooth is too large to fully seat in the sprocket groove

Appendix C: Selecting Your Drive Components

1. Determine your speed ratio. (Do your shaft's rpms need to stay the same, speed up, or slow down?) Find the closest speed ratio value on the center distance table in Appendix D.

2. For that speed ratio, check to see which size of sprockets is most desirable for the drive package size on your robot. (Note that using larger sprockets will give a higher torque rating for the belt drive)

3. See which belt length (based on your center distance) is the best choice.

4. If you know your loading requirements then you can use the power ratings tables in Appendix E to check your drive's torque rating against your peak loads.

Example:
Your robot has a motor on it that has an output of 600 rpm, which you want to connect to another shaft that's roughly 16" away, which you want to rotate at 200 rpm. You want to transfer 1000 oz-in at 600rpm.

1. To calculate your desired speed ratio, divide your driveR speed by your desired driveN speed. (600/200 =3.0).

2. Using the chart, you only have one sprocket combination that can give you a 3.0 speed ratio (using a 20 and 60 tooth sprockets)

3. Going across the chart, you see that the closest center distance available is 15.70" using a 1000-5M-15 belt.

4. Checking the belt drive torque rating
   - Looking at the Power Rating Table, you need to find the rating of the smaller pulley at its respective rpm. For this example you're looking for the 20 tooth pulley running at 600 rpm. Looking at the table there is no listing for 600 rpm so you will need to interpolate this value using the torque ratings from 500 rpm and 800 rpm. After interpolating you should get a torque rating of 683 oz-in @ 600 rpm.
   - Now you must apply the length correction factor to the torque rating. Referencing the length correction factor chart below the torque rating chart, you will see the correction factor for a 1000-5M-15 belt is 1.1. The final torque rating for the belt drive is then:

683 oz-in x 1.1 = 751 oz-in

5. So your design order should consist of:
   - 1000-5M-15 Belt
   - P20-5M-15AL Sprocket
   - P60-5M-15AL Sprocket

Appendix D: Center Distance Table

Sprocket #1		Sprocket #2		Speed Ratio	Belt Lengths						
Teeth	Pitch Ø (in)	Teeth	Pitch Ø (in)		300-5M-15	400-5M-15	500-5M-15	600-5M-15	800-5M-15	1000-5M-15	1270-5M-15
15	0.94	15	0.94	1.00	4.43	6.40	8.37	10.34	14.27	18.21	23.52
18	1.128	18	1.128	1.00	4.13	6.10	8.07	10.04	13.98	17.91	23.23
20	1.253	20	1.253	1.00	3.94	5.91	7.88	9.84	13.78	17.72	23.03
25	1.567	25	1.567	1.00	3.45	5.41	7.38	9.35	13.29	17.22	22.54
30	1.88	30	1.88	1.00	2.95	4.92	6.89	8.86	12.80	16.73	22.05
40	2.506	40	2.506	1.00		3.94	5.91	7.88	11.81	15.75	21.07
60	3.76	60	3.76	1.00				5.91	9.84	13.78	19.10
18	1.128	20	1.253	1.11	4.04	6.00	7.97	9.94	13.88	17.82	23.13
15	0.94	18	1.128	1.20	4.28	6.25	8.22	10.19	14.12	18.06	23.38
25	1.567	30	1.88	1.20	3.20	5.17	7.13	9.10	13.04	16.98	22.29
20	1.253	25	1.567	1.25	3.69	5.66	7.63	9.60	13.53	17.47	22.79
15	0.94	20	1.253	1.33	4.18	6.15	8.12	10.09	14.03	17.96	23.28
30	1.88	40	2.506	1.33	2.44	4.42	6.39	8.36	12.30	16.24	21.55
18	1.128	25	1.567	1.39	3.78	5.75	7.72	9.69	13.63	17.57	22.88
20	1.253	30	1.88	1.50	3.43	5.41	7.38	9.35	13.28	17.22	22.54
40	2.506	60	3.76	1.50			4.88	6.86	10.81	14.75	20.07
25	1.567	40	2.506	1.60	2.67	4.65	6.63	8.60	12.54	16.48	21.80
15	0.94	25	1.567	1.67	3.92	5.90	7.87	9.84	13.78	17.71	23.03
18	1.128	30	1.88	1.67	3.52	5.50	7.47	9.44	13.38	17.32	22.64
15	0.94	30	1.88	2.00	3.66	5.64	7.61	9.59	13.53	17.47	22.78
20	1.253	40	2.506	2.00	2.89	4.88	6.86	8.84	12.78	16.72	22.04
30	1.88	60	3.76	2.00		3.31	5.33	7.32	11.28	15.23	20.55
18	1.128	40	2.506	2.22	2.97	4.97	6.96	8.93	12.88	16.82	22.14
25	1.567	60	3.76	2.40		3.52	5.55	7.55	11.51	15.46	20.79
15	0.94	40	2.506	2.67	3.10	5.11	7.09	9.07	13.02	16.96	22.28
20	1.253	60	3.76	3.00		3.73	5.77	7.77	11.75	15.70	21.03
18	1.128	60	3.76	3.33		3.81	5.86	7.86	11.84	15.79	21.12
15	0.94	60	3.76	4.00		3.93	5.99	8.00	11.98	15.93	21.26

Appendix E: Power Rating Tables

Rated Torque (Oz-in) For Small Sprocket							
Speed	**Small Sprocket Tooth Count**						
rpm	15	18	20	25	30	40	60
0 (stall)	624	777	886	1176	1495	2208	3671
300	624	705	801	1061	1344	1972	3254
500	511	623	708	933	1176	1709	2793
800	449	556	632	827	1039	1500	2425
1000	426	526	599	782	980	1406	2266
1600	383	472	532	692	865	1231	1955
2000	363	445	502	655	812	1152	1816
2500	343	420	475	612	765	1077	1674
3000	328	402	454	587	725	1013	1559

*The rating for a belt drive is calculated at the smallest sprocket traveling at the fastest rotational speed.

Length Correction Factor							
For Belt #	300-5M	400-5M	500-5M	600-5M	800-5M	1000-5M	1270-5M
Factor	0.8	0.8	0.9	1.0	1.0	1.1	1.2

Appendix F: Frequently Asked Questions (FAQ)

Q: *How do I figure out what belt/sprocket combination I need?*
A: First, determine what your desired speed ratio is, and the distance between the two shafts (also known as the center distance) is. Once you have this determined, use the center distance tables to determine the appropriate belt / sprocket combination, along with belt length. Then use the power rating tables to determine the capacity of the drive you have selected.

Q: *How will my sprocket size selection affect my shaft rotational speeds?*
A: If you have a belt connecting two different shafts, the change in speed is proportional to the ratio of the sprocket diameters. This change in speed is called the "speed ratio". For example, if one shaft has a 2" pulley and the other shaft has a 6" pulley, the shaft with the 2" pulley will rotate three times to every one rotation of the 6" pulley, or the drive has a speed ratio of 3.0 down. This means the driven shaft is being slowed down by a factor of 3 compared to the input (driver) shaft.

$$\text{Speed Ratio} = \frac{\text{rpm (faster)}}{\text{rpm (slower)}} = \frac{PD}{pd} = \frac{N}{n}$$

Where: rpm = Revolutions per minute
PD = Larger pitch diameter
pd = Smaller pitch diameter
N = Larger sprocket grooves
n = Smaller sprocket grooves

Q: *I have a performance curve for the motor that I wanted to use with my belt drive. What values should I use to size my belt drive?*
A: There are a few things that should be considered when sizing a belt drive. When looking at a performance curve, it's tempting to size the drive for the stall torque or for the max power available, but that might not be correct. For example, you should keep in mind if you are limited in the electrical power of your system, i.e. are you required to use a fuse / circuit breaker? If so, then the loads you should design around should be on the performance curve below the maximum Amp output.

Q: *How do I determine the correct belt length?*
A: Use the Center Distance table provided, calculators at www.gates.com/first, design software (available at www.gates.com/drivedesign), or use belt length equation shown.

The exact belt pitch length, in inches, can be found as follows:

$$\text{Pitch Length} = 2(CD)(\cos\phi) + \frac{(PD + pd)}{2} + \frac{\phi\,(PD - pd)}{180}$$

$$\phi = \sin^{-1}\left(\frac{PD - pd}{2CD}\right)$$

Where: CD = Drive center distance, in.
PD = Large pitch diameter, in.
pd = Small pitch diameter, in.

The approximate center distance in inches can be found as follows:

$$\text{Center Distance} = \frac{K + \sqrt{K^2 - 32(PD - pd)^2}}{16}$$

$$K = 4PL - 6.28\,(PD + pd)$$

Where: PD = Large pitch diameter, in.
pd = Small pitch diameter, in.
PL = Belt pitch length, in.

Q: *I am unable to adjust my center distance to tension my belt drive: does Gates have an idler that they suggest I use?*
A: Gates does not offer a one-piece idler for the 5mm PowerGrip HTD belts. If you do not have enough adjustment to put adequate tension on the belt, it is recommended to use a flat pulley pushing on the backside of the belt. Also known as a backside idler, this is the easiest way to apply tension to the belt. Unfortunately Gates does not have a backside idler available through the product line; however an idler pulley is easy to fabricate if a machinist is available. You may also purchase an idler from the following:

- B&B Manufacturing: 1-888-889-1896
    - Part No: 22-5M15SP25
    - P22-5M-15 Pulley with pressed bearings.
    - $18.50 each
    - Sprockets, belts, and idlers available from B&B

- Fenner Drives: www.fennerdrives.com
    - PowerMax Idler
    - Part No: FA2010
    - 2.0" OD flat idler with pressed bearings (17mm ID)
    - Must use with 17mm mounting adapters (sold separately).
        - Available in a variety of mounting bores. Example Part No: CB0001
    - Available at Motion Industries (www.motionindustries.com), Applied Industrial Technology (www.applied.com), and other power transmission distributors.

Q: *Do I need to have flanges on my belt drive?*
A: Yes, at least 2 on one sprocket, or one flange on both sprockets. Belt drives will track to one side, so you need flanges to make sure the belt doesn't come off of the pulley.

Q: *How do I convert torque in units of ounce-inches (oz-in) to horsepower (hp)?*
A: Convert the units of oz-in to units of pound-inches (lb-in). There are 16 ounces in 1 pound, so simply divide your torque in oz-in by 16. Now that you have units of lb-in, you can use the following equation.

$$\textbf{Horsepower} = \frac{(Q)\,(rpm)}{63025}$$

Where: Q = Torque, lb-In

rpm = Revolutions per minute

Be sure to use torque and rpm values at the same shaft; do not mix torque and rpm values from different shafts.

Q: *Are there any guidelines for boring out minimum plain bore (MPB) sprockets?*
A: See Appendix G.

Appendix G: Minimum Plain Bore (MPB) Sprockets

When using MPB PowerGrip®GT®2 sprockets in power transmission systems, important guidelines should be followed for proper product finishing and application. Due to the high load carrying capacity and high operating tensions often found in PowerGrip® belt drive systems, it is imperative to use and adhere to industry standard practices. When finishing MPB sprockets for high performance belt drive systems, care should be taken to ensure proper functionality and performance. General re-bore instructions and specifications are as follows:

1. Materials used in PowerGrip® HTD sprockets are 6061 – T6 aluminum grade.

2. The maximum bore diameter specified by the manufacturer for each sprocket size should NOT be exceeded, or a keyway used which reduces the hub thickness to less than its minimum allowable value. See the Sprocket Specification Tables for a listing of recommended bore ranges by sprocket size. Bores exceeding the maximum recommended value for a particular sprocket size can adversely affect the structural integrity, thereby reducing their load-carrying capability. The minimum metal thickness between the keyway and hub O.D. should be no less than the set screw diameter specified for the corresponding sprocket size. See Figure 1 below.

    - A listing of minimum set screw diameters is included below.
        - P18-5M: 8-32
        - P19-5M thru P22-5M: 10-32
        - P23-5M thru P32-5M: 1/4
        - P34-5M thru P38-5M: 5/16
        - P40-5M thru P50-5M: 3/8

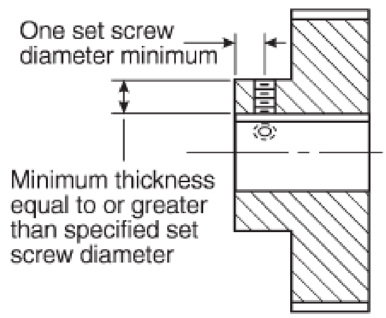


Figure 1 — Minimum Hub Thickness And Set Screw Placement Guidelines

3. The fit between a finished sprocket bore and its mating shaft in a power transmission system must not allow relative movement between the bore and the shaft when the drive is subjected to belt tension and torque loads. This is accomplished, in the case of plain bore sprockets, with the use of set screws and keys and by controlling the fit or clearance between the sprocket bore and it's mating shaft. Cyclical, pulsating, or reversing loads may wear the sprocket bore and/or keyway due to the relative movement between the contacting surfaces of the shaft and the bore. The resulting wear may increase the clearance further, if an interference fit is not used. In order to maximize the performance of high capacity belt drives using plain bore style sprockets, the following for recommendations presented in Table 2 (below) should be followed: Class 1 Clearance Fits should be used when the transmitted load is smooth in nature. Interference Fits should be used for PowerGrip HTD curvilinear drives transmitting cyclical, pulsating, or reversing loads.

4. DO NOT chuck or center the sprocket on guide flanges. Soft jaws should be used when chucking on the sprocket teeth. Center (indicate) the sprocket using the sprocket tooth O.D.I f chucked on the Rim I.D. or Hub O.D., the sprocket should be centered with respect to the sprocket tooth O.D. Guide flanges are permanently mounted and should not be re-moved. If original flanges must be removed, they should be replaced with NEW flanges. New guide flanges should be attached securely with care using mechanical fasteners such as screws. Note: Improper guide flange reassembly may cause serious personal injury and/or mechanical damage.

Table 2 - Recommended Shaft / Bore Fits (Inches)							
		Clearance Fits		Interference Fits			
		Class 1- Smooth Load		Cyclical, Pulsating, Reversing Load			
Nominal Bore Range Over - To (Incl.)	Shaft Tol. (minus)	Bore Tol. (Plus)	Fit Tol. (Plus)	Bore Tolerance Range (Minus)		Fit Tolerance Range (Minus)	
0.4375 - 0.5626	0.0005	0.0010	0.0015	0.0005	0.0010	0.0000	0.0010
0.5625 - 0.8750	0.0005	0.0010	0.0015	0.0005	0.0010	0.0000	0.0010
0.8750 - 1.2500	0.0005	0.0010	0.0015	0.0005	0.0010	0.0000	0.0010
1.2500 - 1.3750	0.0005	0.0010	0.0015	0.0005	0.0010	0.0000	0.0010
1.3750 - 1.500	0.0005	0.0010	0.0015	0.0005	0.0010	0.0000	0.0010
1.5000 - 1.7500	0.0010	0.0010	0.0020	0.0010	0.0020	0.0000	0.0020

Table 2 was extracted in part from AGMA Standard for Bores and Keyways for Flexible Couplings (Inch Series) AGMA 9002-A86 Table.

5. Set screw holes in the sprocket hub must be placed properly for maximum holding strength. For both standard and shallow key seats, two (2) set screws should be used as illustrated in Figure 2. The total holding strength of the set screws is dependent upon their placement and design. Generally, one screw should be placed directly over the keyway, and the other screw at ninety degrees (90°) from the keyway, or at sixty-five degrees (65°) from the keyway—a more recent practice that improves holding power. Sometimes four set screws (or two pair) are used for increased holding strength.

   - Each set screw should be placed axially—a minimum of one set screw diameter from the end of the sprocket hub extension. See Figure 1. For recommended set screw tightening torque values see Table 3 below.

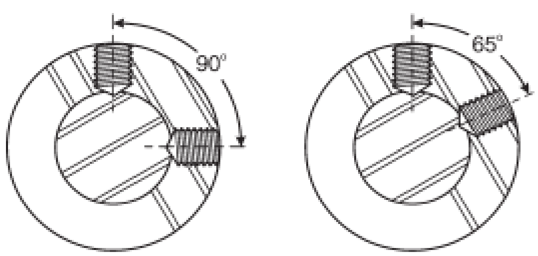


Figure 2 - Set Screw Angles

Table 3–Recommended Tightening Torque Values For Set Screws		
Set Screw Size	Hex Key Size (in)	Approximate Installation Torque Values (lb-in)
8-32	5/64	20
10-32	3/32	35
1/4	1/8	80
5/16	5/32	160
3/8	3/16	275
7/16	7/32	430
1/2	1/4	615
5/8	5/16	1315

6. Standard square or rectangular keys should be used. See below for standard key dimensions.

Standard Keyseat Dimensions				
	Keyseat (in)		Key (in)	
Shaft Diam. (In)	Width	Depth	Width	Depth
0.313-0.438	3/32	3/64	3/32	3/32
0.500-0.563	1/8	1/16	1/8	1/8
0.625-0.875	3/16	3/32	3/16	3/16
0.938-1.250	1/4	1/8	1/4	1/4
1.313-1.375	5/16	5/32	5/16	5/16
1.438-1.750	3/8	3/16	3/8	3/8
1.813-2.250	1/2	1/4	1/2	1/2