Propeller Bolt Belleville Washer Installation Instructions

Marc J. Zeitlin
23501 Fir Drive
Tehachapi, CA 93561
(978) 502-5251
marc_zeitlin@alum.mit.edu

May 4th, 2023

Revision: U

Table of Contents

1) General Information

1.1) Preamble

1.1.1) Propeller Bolt Torque

Although variability exists in Propeller Bolt Torque Measurements and we would rather be able to directly measure bolt stretch and propeller hub compression, given the variability in hub stiffness and belleville washer manufacturing tolerances we will use prop bolt torque as a sufficient method for ensuring that we apply the correct compression to the hub and tension on the bolts.

1.1.2) Torque Variation Example

When I first installed the bolts with four Belleville washers, I got an average torque measurement of 29 ft-lb at 4 bolt turns. The next time, I got an average torque measurement of 60 ft-lb, at four turns - exactly the same washer compression (0.043 in./washer, within a couple of thousandths of an inch). Other users have also obtained anomalous torque numbers in a few trials. There sometimes exists a tenuous relationship between torque and washer compressive force – measured torque is dependent on many factors, such as cleanliness of threads, temperature, humidity, tightness of bolt in prop hub through holes, etc. Proper preparation of the propeller bolts becomes critical to correct installation.

1.1.3) Over-Tightening

It is possible to over-tighten bolts and crush the prop hub wood fibers. We'd like to always have at least 600 psi but no more than 900-1000 psi on the hub (depending upon the wood type). Excess pressure not only can harm the wood but also takes away from the ability of the washers to accommodate wood growth with moisture absorption. Tighter is **NOT** always better.

1.1.4) Appropriate Tightness Levels

The correct "tightness" for the bolts (as determined by the Belleville Washer compression measurements) is set by the Propeller Manufacturer's torque specification. The bolt torque may vary substantially with bolt tightening - it may vary from somewhat below the prop manufacturer's recommendation (if the bolt threads are clean and there's little friction between the washers during tightening) to more than twice that (if the converse is true, and the holes are tight due to cold/dry conditions).

We will use bolt torque as the main determinant of proper bolt "tightness" or washer compression.

1.1.5) Hub Compression

The compression of the prop hub, while theoretically 0.006 in./in. of thickness (for Hard Maple – other woods will have different compression values) can vary substantially (sort of like the torque). I believe that this is dependent upon how long the prop has had compressive force on it, as well as how long you let it relax after loosening the bolts, as well as the wood specie. It can take days or weeks for the wood to fully compress or relax. I

believe that wood has some hysteresis effect, as well as being far more variable as far as stiffness goes than any metal.

1.1.6) Appropriate Monitoring

The **main** thing that we need to monitor on an ongoing basis is the prop bolt torque, with compression of the Belleville Washers as a backup.

The Belleville Washer Compression is the number that sets the force on the crush plate/propeller hub and that force is what gives the driving friction - everything else - bolt torque, hub compression measurement, bolt stretch, even bolt turns - is just an **indirect** method of measuring the force on the hub, with varying accuracies.

1.2) General Bolt Length Determination

The propeller bolts must be long enough to ensure adequate thread engagement in the lugs (or nuts, if threaded lugs are not used) so that full thread strength without stripping is achieved. This will generally be approximately one bolt diameter of engagement – i.e, for ½-20 bolts, about ten full threads. For 3/8-24 bolts, it would be about eight to nine full threads of engagement.

The propeller bolts must also have a short enough shank (unthreaded) length so that they do not bottom out in the lug (or nut) prior to attaining full compression on the belleville washers.

These two conditions bound the requirements for bolt shank and overall length. The proper bolt length can only be determined for a given prop, crush plate belleville washer and flat washer stack and prop flange installation by knowing all those dimensions and calculating the maximum bolt shank length and minimum bolt overall length, or by trial and error.

This is no different than **ANY** propeller bolt installation – in no case can the prop bolts be allowed to bottom out on the threads, and they all must have enough thread engagement. In our case, with belleville washers, we just need to add the belleville/flat washer stack height to the overall length of the bolt.

Everyone **MUST** verify these measurements on **THEIR** installation. This should first be verified with **NO** Belleville washers installed. Measure the distance between the two large area washers when the bolt **IS** bottomed out on the threads, and ensure that you cannot get four belleville washers into the space between the two large area washers (AN-970) even if the bellevilles were flattened (i.e., using the material thickness of the belleville as the gauge thickness..

If you **CAN** bottom the bolt, you can add extra AN-960 washers under the bolt head to take up the necessary space.

Ensure that you have proper thread engagement **WITH** the bellevilles installed and finger tight, as well as when tightened to the correct torque and Belleville washer compression target.

2) Bolt Installation Instructions

This section includes instructions for four bolt sizes.

2.1) Assumptions:

There are many different combinations of Propellers, Flanges, Crush Plates, Prop Hub Thicknesses, Prop Materials, and Bolts. In order to use this configuration of Belleville Washers, the following assumptions were made. If you have **ANY** questions regarding whether or not your configuration is appropriate for this installation, **ASK FIRST**.

2.1.1) Prop Mounting Flange Diameter / Specification

2.1.1.1) ½" Bolt Flange Information

The expectation for ½" bolts is that you will be using an SAE-6 flange with a 6" or 7" diameter face.

2.1.1.2) 7/16" Bolt Flange Information

The expectation for 7/16" bolts is that you will be using an SAE-4 or SAE-5 flange with a 6" or 7" diameter face. If this is not the case for your propeller, please contact me for guidance prior to installation.

2.1.1.3) 3/8" Bolt Flange Information

The expectation for 3/8" bolts is that you will be using an SAE-1, 2 or 3 flange with a 5.5" – 6.5" diameter. If this is not the case for your propeller, please contact me for guidance prior to installation.

2.1.1.4) 5/16" or 8 mm Bolt Flange Information

The expectation for 5/16" bolts is that you will be using a flange with a 4" – 5" diameter face. If this is not the case for your propeller, please contact me for guidance prior to installation.

2.1.2) Prop Crush Plate Diameter / Specification

The propeller crush plate diameter is usually the same diameter as the propeller mounting flange size, to ensure the same compressive loads on both sides of the propeller hub. If they are **NOT** the same, however, just using the prop MFG's bolt torque specification based on hub diameter and drive flange diameter will suffice..

2.1.3) Prop Hub Thickness

2.1.3.1) ½" Bolt Hub Thickness

In general, ½" bolt, SAE-6 flange propellers will have hub thicknesses in the 4" – 5" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.3.2) 7/16" Bolt Hub Thickness

In general, 7/16" bolt, SAE-4 or 5 flange propellers will have hub thicknesses in the 3.75" – 5" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.3.3) 3/8" Bolt Hub Thickness

In general, 3/8" bolt, SAE-1, 2 or 3 flange propellers will have hub thicknesses in the 3.75" – 5" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.3.4) 5/16" or 8 mm Bolt Hub Thickness

In general, 5/16" bolt propellers will have hub thicknesses in the 2" – 4" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.4) Prop Material

We assume that the core of the propeller, whether or not it has a composite overwrap as do the Hertzler and Catto props, is a hardwood such as Maple. If your wood specie is not Maple or the strength equivalent, please contact me for guidance prior to installation.

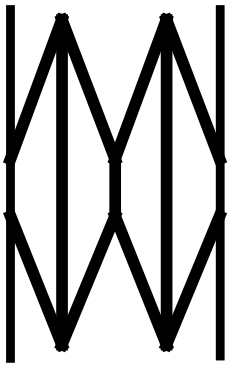
2.1.5) Bolt Count

Although there may be some propeller hubs somewhere that have bolt counts that aren't "six", I've never seen any. If you somehow have a configuration that doesn't have six prop bolts, contact me for guidance prior to installation.

2.2) Installation Overview:

2.2.1) Bolt Washer Arrangement #1 - Single Washer/Group

For each bolt, the bellevilles will usually be arranged in two opposition pairs, with the **SMALL** end against the two wide area washers. Like this:



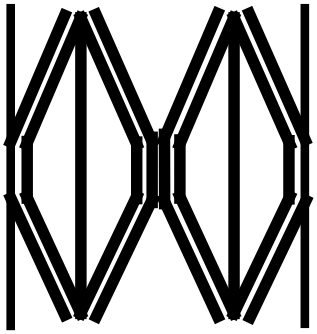
AN-970 wide area washer, four bellevilles, AN-970 wide area washer in sequence with the bellevilles opposing one another.

Some folks use two belleville washers rather than four in certain cases – that can also be acceptable as long as the matching configuration of the washers stays the same.

Note that there are single washers in opposition within each washer group. Washers using this configuration are:

- All ½" diameter bolt bellevilles
- ⅜" diameter bolt belleville - Solon - 620125177 (non-Catto props)

2.2.2) Bolt Washer Arrangement #2 - Nested Washer/Group



For each bolt, the bellevilles are arranged in two opposition sets for a total of eight bellevilles (or one set with four), with the **SMALL** end against the two wide area washers.

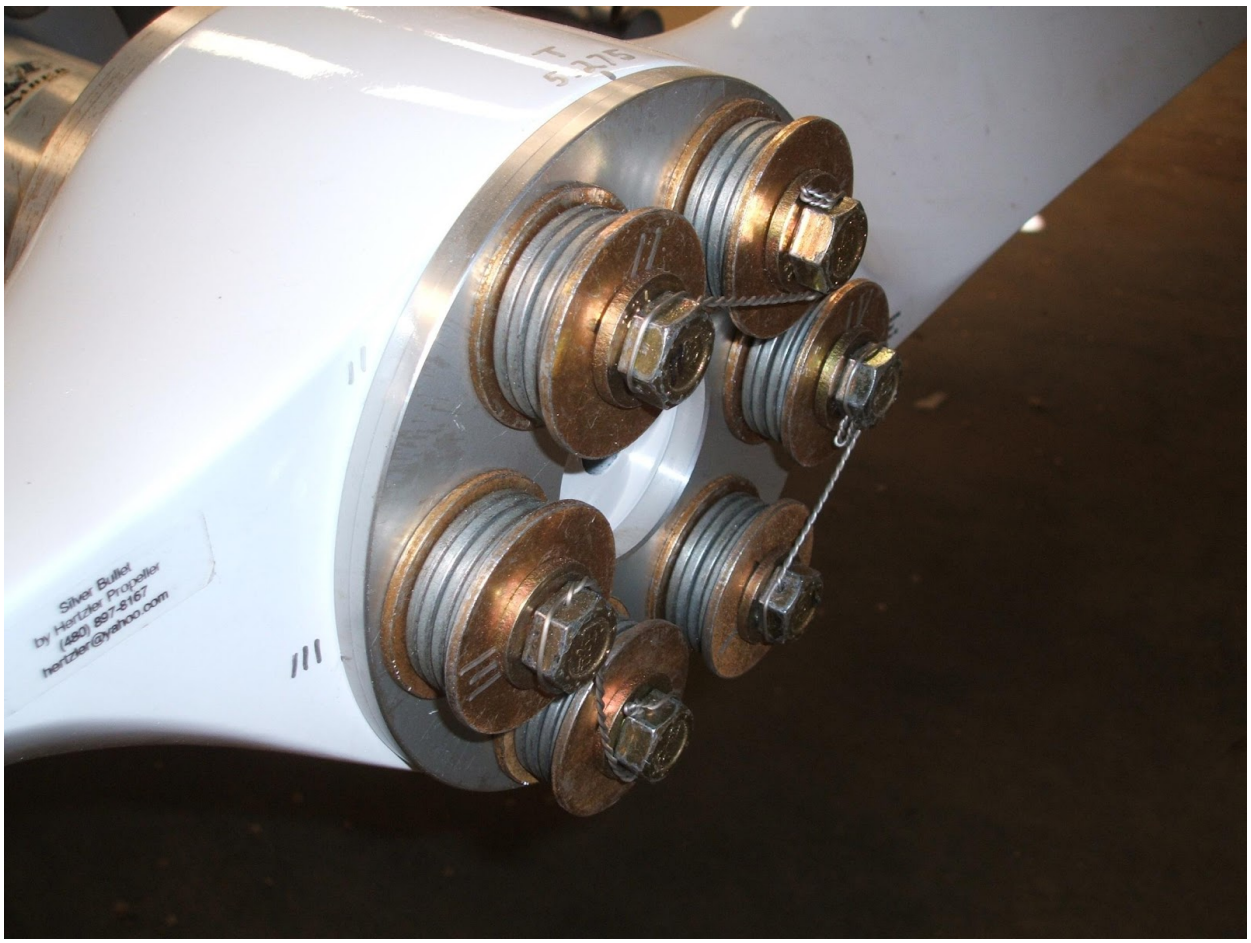
AN-970 wide area washer, eight (or four) bellevilles, AN-970 wide area washer in sequence with the bellevilles opposing one another in nested pairs.

Note that there are two nested washers in opposition within each washer group.

Washers using this configuration are:

- All 7/16” diameter bolt bellevilles
- ⅜” diameter bolt belleville - Solon - 6H80177
- ⅜” diameter bolt belleville - AB386-1188-95-177
- ⅜” diameter bolt belleville - Solon - 620125177 with Catto props (high bolt torque)
- All 5/16” diameter bolt bellevilles
- All 8mm diameter bolt bellevilles

This is approximately what your installation will eventually look like:



2.3) Installation Steps:

2.3.1) Arrange Components

Arrange all the parts (hard washer [if necessary for spacing and available - if not, use a standard AN-960 washer], AN-970 large area washer, bellevilles as indicated in the correct order as shown above, AN-970 large washer) onto each of the six bolts.

2.3.2) Thread Preparation

Ensure the bolt threads and lug threads are clean and lubricate the lug threads with light oil or per the propeller manufacturer's instructions for installation.

2.3.3) Prop Extension Positioning

Position the propeller extension/engine at engine cylinder #1 TDC for future reference. Install the prop and clock it per the prop manufacturer's instructions on the prop extension, ensuring that the prop is flush against the extension face.

2.3.4) Bolt Insertion / Tightening

Insert the bolts into the prop and tighten each bolt to ¾ of the MFG's recommended torque with a wrench to get the propeller seated against the extension – ensure that the propeller cannot move away from the flange.

Some users have found that the prop hub will "relax" overnight, possibly due to not pre-tightening adequately, or due to hub settling. You may want to allow the prop to sit for a few hours (or overnight) prior to loosening the bolts to ensure the wood is compressed adequately.

Then loosen the bolts until the AN-970 washers are again just **BARELY** loose. Do **NOT** pull the propeller off of the extension, or otherwise move the propeller.

At this point, tighten the bolts using the propeller MFG's recommended bolt torque specification and a calibrated torque wrench. Use a **"Beam Type"** torque wrench if available – it's far easier to determine intermediate torque levels. A "Clicker Type" torque wrench can be used if that's all that's available.

Using a standard tightening pattern (1, 4, 2, 5, 3, 6), tighten each bolt first to ½ of the MFG's torque setting. Next, tighten to ¾ of the MFG's torque specification using a second bolt tightening sequence:

Pass 2: 6, 3, 5, 2, 4, 1

And lastly, tighten to the MFG's full torque specification using a third bolt tightening sequence:

Pass 3: 3, 6, 5, 2, 1, 4

2.3.5) Bolt Tightening – Caution:

Always ensure that you tighten every bolt to the Propeller Manufacturer's Bolt Torque specification level.

Having either too high a torque level (or too high a washer compression or exceeding the wood compressive stress margin) may put excessive compressive stress on the prop hub, may crush the wood fibers and may give inadequate relief space in the belleville washer stack to allow for prop hub expansion.

Having too **LITTLE** compression on the wood or the washers may lead to prop slippage, bolt breakage, and a need for a glider rating.

3) Common Installation Steps

3.1) Prop Tip Tracking

At this point in the procedure, track your prop tips per your normal procedure. If you need to adjust the propeller tip position, you may tighten the two or three bolts nearest one tip or loosen the two or three bolts nearest the other tip. Tightening bolts is preferable to loosening. You may tighten or loosen prop bolts **BY NO MORE THAN 10% OF TOTAL TORQUE IN EITHER DIRECTION.**

For example, if the MFG's torque setting is 30 ft-lb, you may decrease torque to 27 ft-lb or increase torque to 33 ft-lb, but no more or less.

3.2) Safety Wire Bolt Heads

Safety wire all bolts in pairs – I do not recommend using a single safety wire for all six bolts, or for any more than two. Ensure that you do an excellent job of safety wiring, and that the wires are tight.

3.3) Test Sighting of Bellevilles

Note that if you sight down vertically between the bellevilles, you will be able to see a tiny bit of light between the convex surfaces of the bellevilles - they must **NOT** be bottomed out or touching along the whole face.

3.4) Go Fly

You should **NOT** notice a difference – as far as the prop, bolts and engine are concerned there is no difference from the standard methodology of installation. All you're doing is giving yourself a large safety margin in the case that the prop hub grows or shrinks. However, if there's **ANY** vibration that's different than normal, land immediately and check everything.

3.5) Post Flight Measurements

After the first 10 hours of flight or engine running, remove the safety wire from the prop bolts and dynamically measure the torque on each bolt (back off the bolt by ¼ turn, then re-tighten to the correct torque). Do the same after 25 hours post installation. From that point on, a torque check will only be necessary at each yearly condition inspection to look for any changes.

4) Conclusions

By using belleville washers on propeller bolts with wood core propellers, we can substantially increase the safety margin with relation to prop hub shrinkage (leading to prop damage and possible loss), or prop hub expansion (leading to prop hub wood core fiber damage from crushing). We can lower the maintenance requirements and will only need to check the propeller bolt torque once/year, at the yearly Condition Inspection.

Both Gary Hertzler (now, Joe Person, of Persson Props, maker of the "Silver Bullet" line of propellers) and Craig Catto of Catto Props strongly recommend using belleville washers on all of their propeller installations. Other than a very slight weight increase and the need for slightly longer prop bolts, there are no downsides to the installation of belleville washers.

5) Questions / Feedback

Any questions or feedback on the procedures or theory espoused here is **MORE** than welcome.

6) Appendix A: Belleville Washer MFG Data

Manufacturer #1: **Solon MFG**
425 Center Street
P.O. Box 207
Chardon, Ohio 44024-0207
Phone (800) 323-9717
(440) 286-7149
Fax (440) 286-9047

Ordering Info: Solon MFG is the manufacturer of these washers, not a distributor. They may only want to sell directly to companies (not individuals), but they DO take credit cards for phone orders. If you give them a business name for shipping purposes, you should be able to order them directly. If not, you may need to find a distributor. Apparently Fastenal is a distributor of some Solon part numbers - the known Fastenal P/Ns are listed below.

Manufacturer #2: **Key Bellevilles Inc.**
100 Key Lane
Leechburg, PA 15656
(724) 295-5111

Manufacturer #3: **American Belleville**
8059 Crile Road
Concord, OH 44077
(440) 721-8350

Bolt Size	Part Number	O.D.	Material	Max. Deflection	Thickness	Max. Load
½ inch	Solon - 828131 (Fastenal P/N 11504041) Key Bellevilles - A44050-024-01 American Belleville - AB515-1750-134	1.75”	6150 Steel	0.051”	0.134”	7,000 lb.
7/16 inch	Solon - 7H89 American Belleville - AB450-1188-91	1.188”	6150 Steel	0.025”	0.091”	3800 lb.
3/8 inch	Solon - 620125177 (Fastenal P/N 11504125) American Belleville - AB386-1250-125-177	1.25”	17-7PH SS	0.022”	0.125”	5,000 lb.
3/8 inch	American Belleville - AB386-1188-95-177	1.188”	17-7PH SS	0.027”	0.095”	3,300 lb.
3/8 inch	Solon - 6H80177	1.063”	17-7PH SS	0.024”	0.082”	2,400 lb.
5/16 inch	Solon - 5EH80 American Belleville - AB322-1063-82	1.063”	6150 Steel	0.032”	0.083”	2800 lb.
5/16 inch	Solon - 5EH80177 American Belleville - AB322-1063-83-177	1.063”	17-7PH SS	0.023”	0.083”	2300 lb.
8 mm	Solon - 5EH80	1.063”	6150 Steel	0.032”	0.083”	2800 lb.
8 mm	Solon - 5EH80177	1.063”	17-7PH SS	0.023”	0.083”	2300 lb.

7) Appendix B: Revision History

Revision	Description	Date
Draft	Original write-up – adaptation for ½" and 3/8" bolts	9/2008
A	1. Add Title Page 2. Add TOC 3. Add 7/16" Bolt size 4. Rearrange per bolt size 5. General reformatting – ready for release 6. Remove "**Draft**" Watermark	2/6/2009
B	1. Adjust **ALL** sections for latest compression calculations	2/21/2009
C	1. Fix 7/16" Washer arrangement text and pictures – sections **2.2.2** and **4.3** 2. Minor wording issues in other sections	2/27/2009
D	1. Changed 7/16" washer part number from 7H89301 to 7H89 2. Condensed sections 2, 3, 4 3. Included references to Washer calculator spreadsheet to determine number of turns	4/3/2009
E	1. Fix section **4.X** wording of changes in compression	8/30/2011
F	1. Added Solon MFG contact information – Appendix A 2. Added Solon MFG ordering information – Appendix A	9/25/2011
G	1. Added 5/16" bolt washer instructions 2. Revised SAE flange information 3. Rewrote "Over-Tightening" section 4. Removed torque references 5. Added Solon MFG info for 5/16" bolts washers	12/29/2011
H	1. Fix Heading 2 formatting 2. Renamed "Bolt Bottoming" to "General Bolt Length Determination" in section **1.2** 3. Added additional Bolt Length determination instructions	4/28/2012
I	1. Update for addition of 8 mm bolts 2. Update for changes to spreadsheet	12/22/2012

Revision	Description	Date
J	1. Fix minor typos	12/29/2012
K	Update for changes in spreadsheet to emphasize washer compression, not bolt turns 1. Re-arranged spreadsheet usage to earlier in document 2. Added **Error: Reference source not found** graphic	9/30/2013
M	1. Prop Extension Positioning – added "cylinder #1" for accuracy 2. Bolt Insertion – change ½ to ¾ of estimated bolt turns; Add paragraph about "relaxation" 3. First Pass – remove reference to "noting # of bolt turns" 4. Bolt Tightening, Continued – fixed "Y" to be "X" in second image; reformatted section for pagination 5. Bolt Tightening sections – added reference to "Measurement" tab in spreadsheet – multiple places 6. Notification – added "if you desire"	11/19/2014
N	1. Modified **1.1.1**, **1.1.2**, **1.1.4** and **1.1.6** to accept torque as backup tool for hub compression 2. Update instructions to reflect usage of torque wrenches and torque measurements 3. Change safety wire requirement to recommendation in **3.2**	06/21/2015
P	1. Remove 720125177 7/16" washers – don't exist	8/23/2015
R	1. Simplify instructions for torque as primary measurement – remove measurement instructions	9/12/2017
S	1. Add information for 2nd / 3rd Washer Vendor for various washer diameters	8/15/2022
T	1. Add information for alternative ⅜" washers 2. Remove references to spreadsheet	12/15/2022
U	1. Add Fastenal Part Numbers for ½" and ⅜" Solon Washers	5/4/2023