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LIGO In-vacuum Fastener Galling Experiment

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Abstract

Fasteners with Class 2 and Class 3 threads were experimentally evaluated for their anti-galling properties. Hex head (Class 2) and socket head (Class 3) fasteners manufactured from variously coated Stainless Steel (SST) and Carbon-Steel Alloy were tested in threaded Aluminum and Stainless Steel plates. Galling characteristics were determined by a process of repeatedly screwing and unscrewing the fasteners into the receiving plates.

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LIGO PROJECT

Table of Contents

List of Tables

1. Summary

This document presents the results of an experiment configured to evaluate the anti-galling properties of threaded fasteners and determine their suitability for application in the LIGO in-vacuum chamber. The fasteners were screwed into tapped holes with increasing torque levels, removed at a specified torque and examined for indication of galling. Different tap and tap drill sizes gave a complete profile of the performance given by the various fastener types and coatings.

Unfortunately, we did not have a GO/NO-GO gauge at the time of the testing to see if the 3/8-24 (3/8 inch diameter, 24 threads per inch) fasteners met tolerance specifications. Allied Engineering performed similar tests that revealed the class 3 fasteners did not pass the gauge[1]. The specified torque for 3/8-24 fasteners for LIGO is 276 in-lb[2].

Threaded holes (1/4-20) were tested with a GO/NO-GO gauge certified by MSC, Inc. with a GO P. D. of 0.2175 inch. It was discovered that several tapped holes did not meet the pass specification. These will be identified in the test results. The recommended torque for ¼-20 fasteners for LIGO is 65 in-lb.

2. Fastener Specimen Descriptions

2.1 3/8-24 fasteners

Plain carbon steel alloy and stainless steel (SST) class 3 socket head screws 3/8-24 UNF-3A X 1.25LG were tested. The SST fasteners were of class 18-8 and were tested without coating and with a coating of Titanium Nitride (TiN).

Coated stainless steel 18-8 hex head cap screws 3/8-24 UNF-2A X 1.25LG were tested. The coatings consisted of silver (Ag), tungsten disulfide (WS2), and molybdenum disulfide (MoS2).

2.2 1/4-20 fasteners

Class 3 stainless steel 18-8 socket head screws 1/4-20 UNC-3A X 1LG without a coating and with a coating of silver and titanium nitride (1½LG) were tested. Carbon steel alloy fasteners were tested as well.

3. Tapped Plate Descriptions

Three tapped drilled and tapped plates were supplied by Allied Engineering. The first plate was made of 1 inch stainless steel and was drilled and tapped with 12 holes. Six holes were tap drilled to 0.350 inch diameter and tapped with a standard 3/8-24 tap. The remaining holes were tap drilled to 0.340 inch diameter and tapped with a standard 3/8-24 tap. The second plate was made of 1 inch stainless steel and was drilled and tapped with 12 holes. Six holes were tap drilled to .358 inch diameter and tapped with a standard roll tap. The remaining six holes were drilled to .339 inch diameter and tapped with an oversize tap (.005inch). The third plate was made of 0.75 inch aluminum and was drilled and tapped with 32 holes. Nine holes each were made with a standard drill and tap,

standard drill and roll tap, oversize drill and standard tap and standard drill and oversize tap.

4. Test Procedure

A pretest procedure consisted of soaking all specimens in an acetone bath, followed by a rinse in an isopropyl alcohol bath and blown with dry compressed air. The specimens were then stored in plastic bags and clean aluminum foil until use. Each test was conducted with a new fastener. The test procedure then consisted of the following steps:

1) Finger tighten until head contacts plate or as far as possible,
2) Apply tightening torque load (successively higher each iteration),
3) Apply loosening torque load until fastener releases and begins to turn,
4) Back out by hand until ½ in. of thread is exposed,
5) Repeat with increasing load to maximum recommended load.

5. Discourse on Unified screw threads

5.1 Class 2A and 2B threads

Classes 2A and 2B are the most commonly used for general applications, including production of bolts, screws, nuts, and similar fasteners.

The maximum diameters of Class 2A (external) uncoated threads are less than basic by the amount of the allowance. The allowance minimizes galling and seizing in high-cycle wrench assembly, or it can be used to accommodate plated finishes or other coating. However, for threads with additive finish, the maximum diameters of Class 2A may be exceeded by the amount of the allowance; for example, the 2A maximum diameters apply to an unplated part or to a part before plating whereas the basic diameters (the 2A maximum diameter plus allowance) apply to a part after plating. The minimum diameters of Class 2B (internal) threads, whether or not plated or coated, are basic, affording no allowance or clearance in assembly at maximum metal limits.

Certain applications require an allowance to permit application of the proper lubricant when making up the assembly, particularly with pressure vessels and steel pipe flanges, fittings, and valves for high-temperature, high-pressure service. For such applications Class 2A, which has an allowance, and Class 2B are recommended[1]. Table I provides a summary of class 2A and 2B thread data.

Size	Class	Allow-ance	Basic Dia.	Major Dia.		Basic Pitch	Pitch Dia.		Minor Dia.
				Max	Min		Max	Min	
3/8-24 UNF	2A	0.0011	0.3750	0.3739	0.3667	0.3479	0.3468	0.3430	0.3228
3/8-24 UNF	2B	0.0011	0.3750	0.340	0.330	0.3479	0.3528	0.3479	0.3299

Table I: Class 2a and class 2B thread data. (dimensions in inches)

5.2 Class 3A and 3B threads

Classes 3A and 3B may be used if closer tolerances are desired than those provided by Classes 2A and 2B. The maximum diameters of Class 3A (external) threads and the minimum diameters of Class 3B (internal) threads, whether or not plated or coated, are basic, affording no allowance or clearance for assembly of maximum metal components[1]. Class 3A and 3B thead data appear in Table II.

Size	Class	Allow-ance	Basic Dia.	Major Dia.		Basic Pitch	Pitch Dia.		Minor Dia.
				Max	Min		Max	Min	
3/8-24 UNF	3A	0.0000	0.3750	0.3750	0.3678	0.3479	0.3479	0.3450	0.3239
3/8-24 UNF	3B	0.0000	0.375	0.3372	0.3300	0.3479	0.3516	0.3479	0.3299
¼-20 UNC	3A	0.0000	0.250	0.250	0.2419	0.2175	0.2175	0.2147	0.1887
¼-20 UNC	3B	0.0000	0.250	0.2067	0.1960	0.2175	0.2211	0.2175	0.1959

Table II: Class 3A and 3B thread data from reference 1.

5.3 Coated threads

Class 2A provides both a tolerance and an allowance. Many thread requirements call for coatings such as those deposited by electro-plating processes and, in general, the 2A allowance provides adequate undercut for such coatings. There may be variations in thickness and symmetry of coating resulting from commercial processes but after plating the threads should be accepted by a basic size GO thread ring gage or equivalent functional gage.

Class 3A does not include an allowance so it is suggested that the limits of size before plating be reduced by the amount of the 2A allowance whenever that allowance is adequate[1].

6. Test Results

Test results are defined by a rating from 1 to 5 in regard to the ease of either tightening or loosening a fastener. The ratings are defined as:

1 Very easy and smooth
2 Some scratchy spots, but otherwise OK
3 Rough, but still able to finger tighten/loosen
4 Very rough, necessary to use wrench to back out/back in
5 Fastener has frozen in place

Tables III through XII summarize the test results for the various fastener/plate combinations tested. The tabulated numbers refer to the rating system outlined above. Detailed test results may be found in reference 2.

Tapped Hole	Hole #	100 in-lb		200 in-lb		300 in-lb	
		In	Out	In	Out	In	Out
.358 Hole	1	4	4	4	4	4	5
Std. Tap	2	4	4	4	5	-	-
.339 Hole	3	4	5	-	-	-	-
Over Tap	4	4	5	-	-	-	-
.350 Hole	1	5	-	-	-	-	-
Std. Tap	2	5	-	-	-	-	-
.340 Hole	3	5	-	-	-	-	-
Std. Tap	4	5	-	-	-	-	-

Table III: 3/8-24 SST Socket Head (Class 3) in SST Plate test results

Tapped Hole	Hole #	100 in-lb		200 in-lb		300 in-lb	
		In	Out	In	Out	In	Out
.358 Hole	1	5	-	-	-	-	-
Std. Tap	2	5	-	-	-	-	-
.339 Hole	3	5	-	-	-	-	-
Over Tap	4	5	-	-	-	-	-
.350 Hole	1	2	1	1	2	2	3
Std. Tap	2	2	1	1	2	2	3
.340 Hole	3	5	-	-	-	-	-
Std. Tap	4	5	-	-	-	-	-

Table IV: 3/8-24 TiN Socket Head (Class 3) in SST Plate

Tapped Hole	Hole #	100 in-lb		200 in-lb		300 in-lb	
		In	Out	In	Out	In	Out
.358 Hole	1	3	3	3	3	3	2
Std. Tap	2	3	3	3	3	3	2
.339 Hole	3	1	1	1	1	1	1
Over Tap	4	3	5	-	-	-	-
.350 Hole	1	1	4	1	2	2	2
Std. Tap	2	1	4	1	2	2	2
.340 Hole	3	1	1	1	2	2	2
Std. Tap	4	1	1	1	2	2	2

Table V: 3/8-24 Alloy Socket Head (Class 3) in SST Plate

Tapped Hole	Hole #	100 in-lb		200 in-lb		300 in-lb	
		In	Out	In	Out	In	Out
.358 Hole	1	1	1	1	1	1	1
Std. Tap	2	1	1	1	1	1	1
.339 Hole	3	1	1	1	1	1	1
Over Tap	4	1	1	1	1	1	1
.350 Hole	1	1	1	1	1	1	1
Std. Tap	2	1	1	1	1	1	1
.340 Hole	3	1	1	1	1	1	1
Std. Tap	4	1	1	1	1	1	1

Table VI: 3/8-24 Ag Hex Head (Class 2) in SST Plate.

Tapped Hole	Hole #	100 in-lb		200 in-lb		300 in-lb	
		In	Out	In	Out	In	Out
.358 Hole	1	1	1	1	2	2	1
Std. Tap	2	1	1	1	2	2	1
.339 Hole	3	1	1	1	2	2	2
Over Tap	4	1	1	1	2	2	2
.350 Hole	1	1	1	1	1	1	2
Std. Tap	2	1	1	1	1	1	1
.340 Hole	3	1	1	1	1	1	1
Std. Tap	4	1	1	1	1	1	1

Table VII: 3/8-24 WS2 Hex Head (Class 2) in SST Plate.

Tapped Hole	Hole #	100 in-lb		200 in-lb		300 in-lb	
		In	Out	In	Out	In	Out
.358 Hole	1	1	2	1	3	2	2
Std. Tap	2	1	2	1	3	2	2
.339 Hole	3	1	1	1	2	2	1
Over Tap	4	1	1	1	2	2	1
.350 Hole	1	1	1	1	1	1	1
Std. Tap	2	1	1	1	1	1	1
.340 Hole	3	1	1	1	1	1	1
Std. Tap	4	1	1	1	1	1	1

Table VIII: 3/8-24 MoS2 Hex Head (Class 2) in SST Plate

Tapped Hole	Hole #	25 in-lb		50 in-lb		70 in-lb	
		In	Out	In	Out	In	Out
Std. Drill Std. Tap	1	2	4	4	4	4	5
	3	2	4	4	4	4	5
	4	2	4	4	4	4	4
	5	4	4	4	4	4	5
Std. Drill Roll Tap	1*	4	4	4	5	-	-
	2	4	4	4	4	4	4
	3*	4	4	4	5	-	-
	4*	4	4	4	5	-	-
Over Drill Std. Tap	2	4	4	4	4	4	5
	3*	4	4	4	5	-	-
	4*	4	4	4	5	-	-
	5*	4	4	4	5	-	-
Std. Drill Over Tap	1	2	2	2	3	2	3
	2	1	4	4	4	4	5
	3	1	5	-	-	-	-
	4	2	2	2	4	4	4

Table IX: 1/4-20 Ag Socket Head (Class 3) in Al Plate

* Indicates hole did pass go/nogo gauge.

Tapped Hole	Hole #	25 in-lb		50 in-lb		70 in-lb	
		In	Out	In	Out	In	Out
Std. Drill Std. Tap	2*	4	4	4	4	4	4
	4	2	2	2	2	2	2
	6*	4	4	4	4	4	4
	7	4	4	4	4	4	4
Std. Drill Roll Tap	1*	4	4	4	4	4	4
	2	2	3	3	3	3	3
	5*	4	4	4	5	-	-
	6*	4	4	4	5	-	-
Over Drill Std. Tap	1*	2	2	2	2	2	3
	6	4	2	2	2	2	2
	7	1	1	1	2	2	2
	8	1	1	1	2	2	2
Std. Drill Over Tap	1	1	1	1	1	1	1
	5	1	1	1	2	2	2
	6	1	1	1	1	1	1
	7	1	1	1	1	1	1

Table X: 1/4-20 TiN Socket Head (Class 3) in Al Plate

Tapped Hole	Hole #	25 in-lb		50 in-lb		70 in-lb	
		In	Out	In	Out	In	Out
Std. Drill Std. Tap	6*	1	1	1	2	2	3
	7	2	1	2	4	3	4
	8	1	1	1	4	4	4
	9*	1	1	2	4	4	4
Std. Drill Roll Tap	2	2	2	2	2	2	2
	7*	4	4	4	4	4	4
	8*	4	4	4	4	4	4
	9*	4	4	4	4	4	4
Over Drill Std. Tap	1*	1	2	2	3	2	4
	7	2	4	3	2	2	2
	8	4	4	4	4	4	4
	9	1	2	3	2	2	2
Std. Drill Over Tap	6	1	1	1	1	1	2
	7	1	1	1	2	2	3
	8	1	1	1	2	2	2
	9	1	1	1	2	2	2

Table XI: 1/4-20 Alloy Socket Head (Class 3) in Al Plate

Tapped Hole	Hole #	25 in-lb		50 in-lb		70 in-lb	
		In	Out	In	Out	In	Out
Std. Drill Std. Tap	6*	2	2	2	2	2	2
	7	2	2	2	2	2	3
	8	2	2	2	2	2	2
	9*	2	2	2	3	2	3
Std. Drill Roll Tap	2	1	1	1	2	2	2
	7*	2	2	2	2	2	2
	8*	2	2	2	2	2	2
	9*	1	1	1	2	2	2
Over Drill Std. Tap	1*	2	3	3	3	3	3
	6	2	2	2	2	2	2
	7	2	2	2	2	2	2
	8	2	2	2	2	2	2
Std. Drill Over Tap	4	1	1	1	2	2	2
	5	1	1	1	1	1	2
	6	1	1	1	1	1	2
	7	1	1	1	2	2	2

Table XII: 1/4-20 SST Socket Head (Class 3) in Al Plate

7. Cost analysis

Cost analysis of 3/8-24 X 1.25LG fasteners	
Type of fastener	**Cost per fastener (dollars)**
Alloy	.24
SST	.98
SST, TiN coating	2.23
SST, Ag coating	2.48
SST, MoS2 coating	1.87
SST, WS2 coating	3.01

8. Conclusions

It was determined that for the SST plates, fasteners with class 2 threads (hex head) outperformed fasteners with class 3 threads (socket head) in their ability to be repeatedly torqued and backed-out. There may be various minor reasons for this, one cause is that the tapped threads just didn't make allowance for coated external threads. Of the coatings tested for the hex head (class 2) fasteners, silver seemed to be best overall because if it's lubricating qualities. None of the class 2 fasteners showed any signs of galling even when torqued past the recommended max value.

For the aluminum plate, in which only class 3 threads were tested, it was determined that titanium nitride (TiN) was the most suitable coating. Silver, which performed well in SST, became very sticky in the aluminum plate.

Our testing resulted in a change to the manufacturer callout on the support tubes for both the BSC and HAM. The hardware will be fabricated to 3/8-24 with + .005in. tap and ."T" (.358inch) drill size. We anticipate any titanium nitride or silver plating fastener of class 2 variety will work fine.

9. References

1. Oberg, Jones, Horton, Machinery's Hand Book 22nd Revised Edition, Industrial Press Inc. New York, 1984
2. Thompson, Romero, Hytec, Inc. Laboratory Notebook, 1998

Note 1, Linda Turner, 09/03/99 02:54:33 PM
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