STANLEY®
Engineered Fastening

HELI-COIL®
Shock, Vibration and Fatigue

Technical Bulletin 71-2

HeliCoil®

INTRODUCTION
Heli-Coil® screw thread inserts strengthen tapped threads by providing a more balanced distribution of dynamic and static loads for the full length of engagement. The flexibility of the insert compensates for lead and angle errors and allows each coil to carry its share of the load. This improved load distribution is dramatically demonstrated using photo elastic stress analysis. The purpose of this bulletin is to summarize the results of three primary types of tests that substantiate the unique capability of Heli-Coil® inserts to equally distribute applied bolt load. These three types of tests cover shock, vibration and fatigue.

SHOCK
Shock testing of threaded assemblies is intended to determine the effect of severe impacts on the assemblies. These impacts or blows create extremely high loads that approach and then exceed the elastic limit (i.e., point at which a material will not return to its original form after the applied load is removed and therefore has taken a permanent set) of either the parent material or the screw. Due to the severe intensity of the loads, the number of shock impacts is usually quite small when failure occurs to either the parent material or the screw.

ADCOR ENVIRONMENTAL TESTING LABORATORY
(Heli-Coil® Report No. 72)
This test was conducted for G.E. Ordnance Company on the Mk 88 Fire Control Optical Alignment Unit for submarines. The test equipment was the High Impact Testing Machine per BuShips Plan No. 807-655947 (figures 9-1 and 9-2) and the mounting per MIL-S-901C. The 1 3/4 -16 insert assembly was made to simulate normal mounting condition and was subjected to vertical shock tests as follows:

1. Weight on anvil, 3721 pounds
2. Vertical drop, 1.75 ft. (blow no. 1)
3. Vertical drop, 2.75 ft. (blow no. 2)
4. Table travel, 3.0 inches (both blows)
5. Accelerometers were attached to the assemblies in four locations

TABLE 1: Results of Adcor Shock Tests

Location	Blow No.1 (g's)	Blow No. 2 (g's)	Remarks
Input	75	110	No damage to any of the insert assemblies while the casting cracked in several other areas. Heli-Coil® inserts approved for this application.
Support ADT casting	80	112	
Pentamirror block	88	135	
Indexing assembly	90	135	

PORTSMOUTH NAVAL SHIPYARD
Technical Report T-522
This test was one of the earliest shock tests conducted on Heli-Coil® inserts, and was the main reason why the U.S. Navy accepted inserts in sizes up to 1" for applications in submarine construction. The shock testing machine and test procedure were in accordance with MIL-S-901. The inserts tested were ½-13 stainless steel and phosphor bronze that were installed in both aluminum and steel test blocks. The assemblies were made in the typical manner except that weights of 100, 150, and then 250 pounds were successively attached to the end of the bolt. The insert, bolt, and weight were then subjected to a repeated series of blows in the axial direction. The 400-pound pendulum hammer weight was used to impart three blows of 400, 1200, and then 2000 foot-pounds.

Initially, the ultimate tensile strength of the bolt was 74,000 psi, which proved inadequate to produce failure of the insert assemblies. It was necessary to use high strength hardened steel bolts with ultimate tensile strength in excess of 190,000 psi to produce failure in the threaded area. In order to compare performance, standard tapped thread tests were run at the maximum impact levels and then the Heli-Coil® assemblies were subjected to blows of increasing severity until the failure point was reached. During the testing, it became obvious that the Heli-Coil® assemblies were superior to plain tapped holes, and the pre-conditioning or graduated application of weights was discontinued. Then tests of Heli-Coil® inserts were made at the maximum level. The actual results are listed in Table II for comparison.

TABLE II.

Description of Assembly and Length of Engagement	Standard Tapped Thread, ½ - 13		Specimen Number	Heli-Coil® Insert Assembly, ½-13	
	Weight Attached (lbs.)	Number of Blows		Weight Attached (lbs.)	Number of Blows
1 diameter in steel	250	4*	1	100	12
				150	12
				250	10*
			2	100	3
				150	12
				250	8*
1½ diameters in steel	250	7**	1	250	11**
			2	250	10**
1½ diameters in aluminum	250	3*	1	100	12
				150	12
				250	12 (OK)
				2100	12
				150	12
				250	3*
2 diameters in aluminum	250	10**	1	250	12 (OK)
			2	250	12 (OK)

Types of failure: * Threads stripped **Bolt broke

- Based on the test results, this report concluded:
- Heli-Coil® inserts, whether stainless steel or bronze, develop more than the full strength of a standard bolt (74,000 psi ultimate tensile strength) for an engagement of 1 diameter in steel and 1-½ diameters in aluminum.
- Heli-Coil® inserts, whether stainless steel or bronze, develop more than the full strength of a hardened steel bolt (192,000 psi ultimate tensile strength) for engagements of 1-½ diameters in steel and 2 diameters in aluminum.
- "With similar engagement, the Heli-Coil® insert can withstand greater impact stress than the block material when the bolt is threaded directly into it."
- In both aluminum and steel, there not only were a significant improvement in strength of the threads, but also an increase in the life of the bolt or stud that is assembled into the insert.
- "It is recommended that Heli-Coil® inserts be considered acceptable for submarine and other naval installation."

U.S. NAVY UNDERWATER SHOCK TESTS

These tests were conducted to determine the acceptability of Heli-Coil® inserts in the size range 1" to and including 2". As a result of the previous test, Heli-Coil® inserts in sizes up to 1" had been approved. The test procedure consisted of making actual assemblies in a Shock Test Vehicle and subjecting the vehicle to underwater explosions of extremely severe intensity. The exact details of the magnitude of acceleration, shock loading, explosive force of the charge, distance from the hull, etc., must remain classified information; however, the results of the test can be revealed.

Test 1

This test utilized 2"-8 insert assemblies to hold down the 18,000-pound steam turbine which is bolted to the main support frame. The support frame consisted of two 1-½" thick structural steel plates welded together. The test vehicle was submerged and subjected to many explosions of increasing intensity until the ultimate strength of the structure was reached. In several areas, the welded support frame shifted severely, bending the screws by creating shear loads far in excess of the elastic limit. A measurement of the deformation of the 2"-8 steel bolt showed a permanent set of approximately .025 inch lateral displacement.

Test 2
Six 1 1/4 -8 x 1.875 Heli-Coil® Screw-Lock inserts were employed for the generator stator hold-down bolting. Using the same procedure as in Test 1, the assemblies were subjected to shock loads in excess of the elastic limit of the steel bolts and dowel pins, and they too were deformed by these severe shocks.

The final report on these tests indicated: "During both applications, the Heli-Coil® inserts performed satisfactorily under shock loads."

U.S. NAVAL AIR ENGINEERING CENTER

For quite some time, Navy aircraft carriers have been experiencing a high failure rate of tapped holes and screws in applications that are subjected to repeated high shock and impact loads. Most of the applications have been for threaded holes in deck plate steel. In 1968, the Arresting Gear Group and the Catapult Launching Group began simultaneous evaluation of Heli-Coil® inserts to alleviate this problem. After a thorough evaluation, it is determined that with Heli-Coil® inserts:

- The incidence of tapped thread failure was reduced to virtually nothing.
- Screw failure was reduced significantly.
- The presence of the stainless steel insert eliminated the screw removal problems created by rusting and galling.

Also, the equal load distribution prevented deformation of the screw threads, thus maintaining the proper lead that allows damaged screws to be removed without binding.

As a result of this evaluation, documents NAEC-NE-623 (covering catapults, jet blast deflectors, and arresting gears) and NAEC-NE-722 (Mark 7 Arresting Gear Service Change No. 258) have been issued. These documents specify the use of Heli-Coil® Screw-Lock inserts in all problem area threads in sizes ¼" to 1-½" NC and NF because they "…are a definite improvement over the above condition and will provide for a more positive locking action." Special kits have been supplied to retrofit those threaded assemblies that are subjected to high shock and impact loads.

VIBRATION

Vibration testing consists of applying a load that is less than that required to exceed the elastic limit of the materials, and repeating this up to one-half million cycles. Obviously, the number of combinations of load and number of cycles is virtually unlimited and it is impossible to test for every combination. However, a great many tests have been conducted with Heli-Coil® screw thread assemblies and a few of the more typical ones are reported here.

Essentially, the objective of these tests was to determine if Heli-Coil® Screw-Lock inserts could withstand vibration, maintain the clamping load, and eliminate the need for lock washers and lock wiring. Several methods of testing were used, ranging from sophisticated shake tables with accelerometers or vibration meters to a simple jackhammer motor.

NORTH AMERICAN AVIATION REPORT NO. NA57H-592

(Heli-Coil® Report No. 34)
This test was conducted using 3591-4CN375 inserts and screws that retained the aileron balance weight. An additional aspect was to determine if any loosening occurred when lubrication was added to the assembly. The test was conducted on a resonant beam facility in which a tensile force of 131 pounds and a shear force of 117 pounds produced a resultant force of 175.6 pounds. The screws were tightened to 70 inch-pounds torque and the entire assembly was vibrated to achieve a loading equivalent to 40 g's.

TABLE III.

Insert Specimen Number	Total Cycles at 40 g's	Frequency (cpm)	Remarks	Results
1	503,000	3020-2900	Dry Bolt	No Movement
2	505,031	3010-2770	Dry Bolt	No Movement
3	505,950	2965-2785	Dry Bolt	No Movement
4	510,400	2850-2830	Antiseize applied	No Movement
5	502,295	2875-2845	Antiseize applied	No Movement

On the basis of the preceding test, it was concluded that Screw-Lock inserts are satisfactory and that the presence of the antiseize compound had no adverse effect.

SPERRY FARRAGUT COMPANY
Heli-Coil® Report No. 23)
Tests were conducted by Sperry Farragut to determine if external lock washers could be replaced by Screw-Lock inserts on electronic equipment in missile applications. As a result of these tests, Heli-Coil® Screw-Lock inserts were found to be acceptable and were incorporated in the original design to replace the Standard (free running) inserts. The table below summarizes the results.

TABLE IV.

Insert Part Number	Frequency (cpm)	g Loading	Time (min)	Results
3585-2CN125 (8-32)	10-30	8	10	No Movement
	30-500	12	10	
		16	10	
		24	10	
3585-2CN234 (8-32)	10-500	8	5	No Movement
	20-35	8	10	
	20-500	12	10	
	20-500	16	10	

WESTINGHOUSE ELECTRIC CORP., UNDERSEAS DIVISION
The 3591-3CN285 (10-32) inserts were tested in aluminum parent material as follows:

1. Tighten screws to 30 inch-pounds
2. Loosen screws and run fifteen cycle prevailing locking torque test
3. Tighten screws to 30 inch-pounds
4. Vibration test sequence:
   a. 10 to 30 cps — .060 amplitude — 30 minutes
   b. 31 to 60 cps — 3 g's — 60 minutes
   c. 61 to 150 cps — 5 g's — 60 minutes
5. Check breakaway torque

After the above conditioning, none of the screws loosened, and the breakaway torque on the clamped screws was equal to or higher than the torque applied prior to vibration. Heli-Coil® inserts were accepted for this application.

TRW STRUCTURES DIVISION

This test was for the Saturn IV B attitude control engine. The 3591-3CN285 inserts were assembled into the cast aluminum frame and the stainless steel screws assembled into the inserts formed the main connection between the front and rear halves of the engine. The high g level test consisted of sinusoidal and random vibration excursions through each of the principle engine axes. The sinusoidal test was completed separately from the random test.

Sinusoidal
The sweep rate was logarithmic between 5 and 2000 cps and return, with a 21.8 g input between 300 and 2000 cps. Amplification factors observed ran between 1.6 and 39 during this test.

Random
Random vibration was conducted for three minutes through a continuous excitation ranging from 20 to 2000 cps and maximum acceleration equivalent to 25 g's. Amplification factors for any given frequency within this spectrum were the same as those observed during the sinusoidal tests.

The Heli-Coil® Screw-Lock insert was found to be acceptable and was incorporated in this rocket engine.

NASM-8846 PROCUREMENT DOCUMENT FOR HELI-COIL® INSERTS

This specification outlines the materials' physical properties, testing procedures, and product performance requirements for both Free-Running and Screw-Lock inserts. One of the qualification requirements for Screw-Lock inserts is a very severe vibration test. This test procedure is a duplication of the original locknut testing procedure. The Screw-Lock insert is installed into the nut body and the bolt is assembled through the drilled hole in the arbor and sleeve into the nut body. The test rig is a Model 309-X1 Stanley Electric Hammer supported in the vertical position with an arbor and sleeve assembled as shown in MS26531. The vibration test is conducted to determine if the inserts meet the requirements specified in Table V.

TABLE V.

Bolt or Screw Size	Average Vibration Life (Hours)
0.190-32 (10-32)	0.6
0.250-28 (1/4-28)	1.0
0.3125-24 (5/16-24)	3.5
0.375-24 (3/8-24)	6.0
0.4375-20 (7/16-20)	8.0
0.500-20 (1/2-20)	9.5

Heli-Coil® Screw-Lock inserts have qualified and meet the requirements of this specification.

TABLE VI.

Bolt or Screw Size	Average Torque (lbf-in)
0.190-32 (10-32)	30
0.250-28 (1/4-28)	60
0.3125-24 (5/16-24)	120
0.375-24 (3/8-24)	160
0.4375-20 (7/16-20)	200
0.500-20 (1/2-20)	300

The cylinders have a flange and are assembled with a washer to retain them in the slots of the fixture. The fixture is then vibrated with an essentially sinusoidal wave form at a frequency of 1750 to 1800 cpm and a double amplitude of .450 inch. The assemblies are vibrated for 30,000 cycles. This test is as severe as the Stanley Hammer rig, but is far more accurate and reliable. In both tests, Heli-Coil® Screw-Lock inserts exceed the requirements for qualification.

FATIGUE

Fatigue is encountered when parts are subjected to comparatively small loads that are repeated for a total of 500,000 to 10,000,000 cycles. The failure of a ductile member (such as an aluminum structure) caused by repeated loads is not accomplished by noticeable yielding; rather the failure is a gradual or progressive fracture. The fracture starts at some point where the stress is localized and at its maximum. It then proceeds to spread until the whole structure fractures without any measurable yielding. In this regard, fatigue failure of a ductile material is similar to static failure of a brittle material.

The tests described in this section explore two factors: the effect of the presence of a Heli-Coil® insert on the fatigue life of the mating screw; and the comparative effects of various types of inserts on the fatigue life of the parent material.

LESSELLS FATIGUE TESTS

(Technical Reports 618/C41 and 668/C44)
These tests were conducted to determine the effect on the fatigue life of MS20006 3/8-24 (160 ksi) bolts when assembled in 1191-6CN562 inserts that were installed into 7075-T6 aluminum and low carbon steel. The test procedure was in accordance with NAS1069, "Tension Fatigue Test Procedure for Aeronautical Fasteners." The test equipment used was a Baldwin Sonntag unit of 20,000-pound capacity and a frequency of 1600 cpm. The maximum load applied to the bolt ranged from 10,500 pounds (60% of bolt ultimate strength) to 5,250 pounds. The minimum load was 10% of the maximum load level. The conclusions and comments are as follows:

- Bolt fatigue strength in the aluminum specimens was essentially identical for assemblies with and without inserts, proving that the Heli-Coil® inserts' flexible coils do allow the excellent ductility characteristics of the aluminum parent material to be transferred to the bolt. Good ductility is one factor in improving fatigue life. Rigid solid bushings, unlike the flexible Heli-Coil® inserts, cannot distribute the load over the entire length of the engaged threads, so bolt fatigue life is reduced.
- For assemblies in steel specimens, it was determined that for failure beyond 500,000 cycles, the bolt fatigue life with Heli-Coil® inserts was 15% greater than in assemblies without inserts.
- Comparison of endurance curves of Heli-Coil® insert assemblies with aircraft standard requirements indicates that test results exceeded the fatigue life requirements specified in MIL-B-7838 for 160 ksi internal wrenching bolts and for NAS 624 180 ksi 12 point external wrenching bolts.

ALMAY RESEARCH AND TESTING CORPORATION

(Report No. C8296)

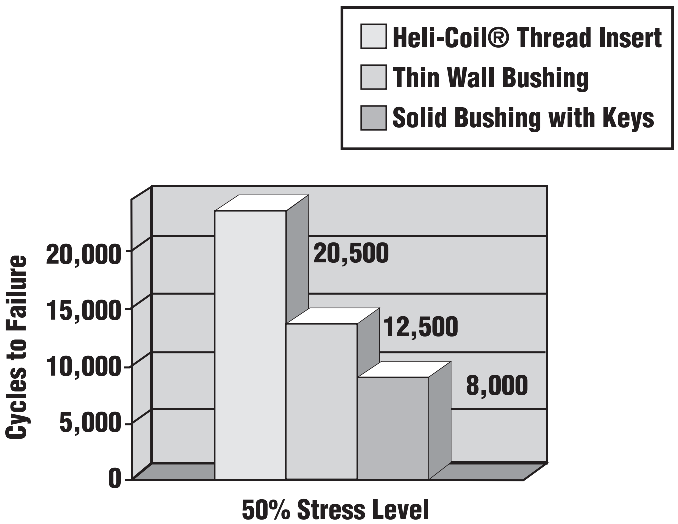
The purpose of this test was to compare the effect on fatigue life of 7075-T651 aluminum under the following conditions:

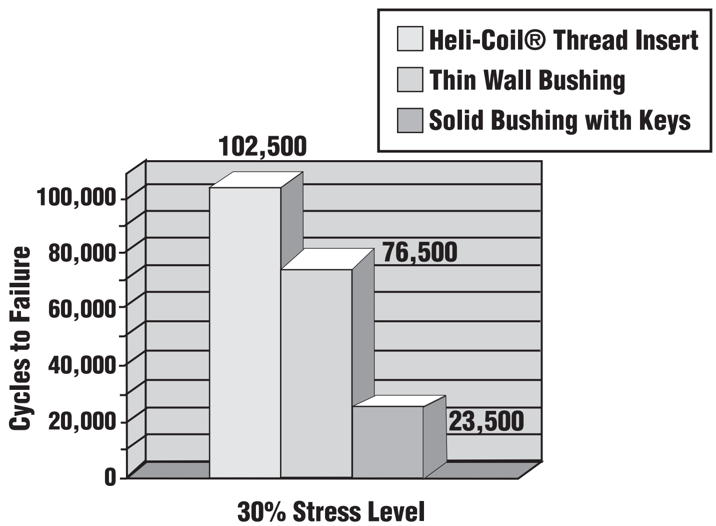
1. Plain tapped thread
2. Heli-Coil® inserts installed in cut thread tapped holes
3. Heli-Coil® inserts installed in rolled (cold formed) tapped holes
4. Thin wall solid bushing with swaged collar
5. Solid bushing with keys

The test procedure involved the use of test coupons that were designed to provide a wall thickness of approximately twice the insert diameter. The specimens were all ½" thick to allow the installation of ¼-28 screw locking inserts to 1 ½ diameter length. The tension-tension cyclic fatigue test was then conducted on the Amsler Vibrophore Fatigue Tester. The maximum loads were established at 50% and 30% of the ultimate tensile strength of the aluminum. The minimum load was established at 5% of the maximum load. These relatively high load values were chosen so that the large number of specimens in the study could be tested in a reasonable amount of time.

To simulate a typical assembly, NAS 1351 Series cadmium plated alloy steel cap screws and washers were assembled into the inserts and tightened to 70 inch-pounds. The clamping load on the screw develops stresses in the parent material that are typical of actual assemblies.

- Test results comparing the effects of the presence of the various inserts are shown in the graphs (below).
- Heli-Coil® insert assemblies were also compared to the plain tapped hole that in ductile aluminum represents the theoretically perfect model where the load is distributed equally to all threads, thus minimizing stress concentration. At a stress level of 30% - a very high value for practical applications - the fatigue life for both types of assemblies was virtually identical. These comparisons prove that in typical applications where the stress levels are in the normal ranges, the Heli-Coil® insert distributes the load as effectively as the ductile aluminum parent material.
- Heli-Coil® insert assemblies in normal cut thread tapped holes were compared to cold formed tapped holes. The results were interesting in that the fatigue life for cold formed threads was reduced by 65% at the 50% stress level and by 45% at the 30% stress level. The obvious conclusion is that the cold forming preparation of tapped threads creates high residual stresses in the parent material that significantly reduce the fatigue life of that material.





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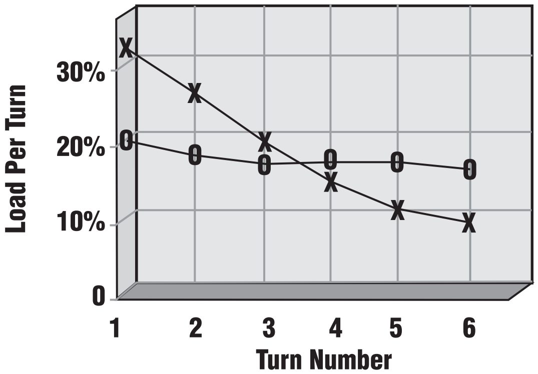
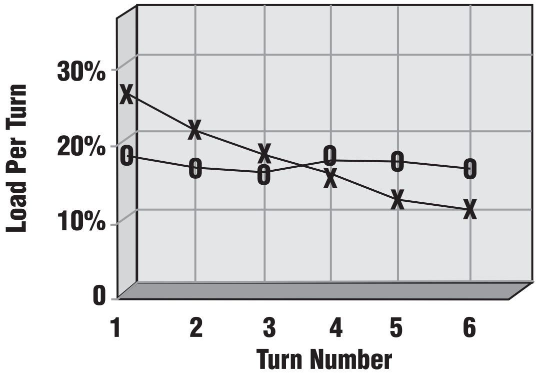
IN ANOTHER TYPICAL FATIGUE STUDY, the load per turn has been shown to be far better distributed with Heli-Coil® inserts than in plain tapped holes. The actual percent improvement of stress distribution is shown in the following graphs taken from the report on this study.*

TYPICAL DISTRIBUTION OF LOAD IN PERCENT OF TOTAL STRESS

Parent Material Alloy Steel 100,000 psi



Parent Material Wrought Aluminum 60,000 psi



0 = Assembly with Heli-Coil®
X = Assembly without Heli-Coil®

(*) "Fatigue of Threaded Joints with Thread Inserts," G.B. Iosilivich; Russian Engineering Journal, Issue No. 12.

Summary

In shock tests, the Heli-Coil® insert was shown to be superior to plain tapped holes in both ductile parent materials such as cast magnesium and aluminum, and hard (less ductile) parent materials such as cast iron, mild steel, and wrought aluminum.

Vibration and fatigue tests proved that in ductile parent materials the flexible coils of Heli-Coil® inserts transfer virtually 100% of the parent materials' ductility to the mating threads. In hard and less ductile parent materials, Heli-Coil® inserts have a very significant effect on improving the vibration and fatigue life of both the tapped hole and the mating screw or stud.

In the broad range of shock, vibration, and fatigue testing of Heli-Coil® insert assemblies, the equal distribution of both static and dynamic loads to all engaged threads has proved both theoretically and practically significant.

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