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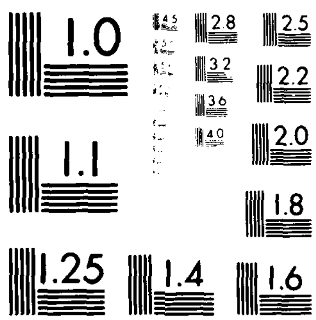

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Removal of BOUND METAL FASTENERS

RICHARD F. KRAMER

FINAL REPORT

A PROJECT OF THE
MANUFACTURING TECHNOLOGY PROGRAM
NAVAL SEA SYSTEMS COMMAND

Date: April 1981

Prepared by
SONOBOND CORPORATION

Contract No. :(N00140-79-C-1173)

The findings of this report are not to be construed as an official Department of the Navy position.

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This project explored the removal of bound metal fasteners through the use of ultrasonically assisted wrenches. Two wrenches were designed, fabricated and tested. Previous studies had indicated an increase in thread tension for a given torque application under the influence of ultrasonics. Based on this, the loosening of seized and corroded fasteners with the aid of ultrasonics was explored. Experimental data confirmed our prior analysis of the torque-tension relationship under the influence of

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) ultrasonics; however, our progress did not satisfy the requirements necessary to loosen seized studs in a shipyard environment.

TECHNICAL SUMMARY

Project Objectives

This program was undertaken to design, develop, fabricate and test an ultrasonic wrench to assist in the removal of fasteners bound as a result of the shipyard environment. A previous National Space and Aeronautics Administration study had indicated an increase in thread tension for a given torque application under the influence of ultrasonics. Based on this, it was anticipated that ultrasonics would reduce the breakaway torque, thus allowing loosening of corroded or seized Naval studs more readily than conventional wrenching.

Technical Approach

An axial and an open flexural wrench were manufactured based on design criteria established in the first part of the subject program. Sample fasteners were tightened to 150 in./lbs. of torque and then loosened with and without ultrasonic assistance. The breakaway torque values were recorded. In the next stage, seized fasteners were simulated by the application of Locktite. These fasteners were then loosened with and without ultrasonics and the results recorded. It was found that ultrasonics caused the Locktite to cavitate, precluding accurate data readings. At this point, a trip to the Philadelphia Naval Shipyard was made by the project engineer to obtain in situ samples of corroded fasteners. Trials with the axial wrench were performed on these seized studs. With and without ultrasonics, the shipyard environment studs were too corroded to be loosened. Since the loosening of the seized studs was not feasible, we decided to tighten fasteners to confirm the effect that ultrasonics has on the torque-tension relationship.

Achievements

Experimental data confirmed our prior analysis of the relationship of an increased thread tension for a given torque application with the influence of ultrasonics. However, the power necessary to meet the Naval application was beyond the parameters of the equipment dedicated to the subject program. A Navy-Sonobond conference was convened and the subject program was suspended pending Naval review of the findings to date.

PREFACE

This final report on the design, development, fabrication and testing of a prototype ultrasonic wrench to assist in the removal of bound fasteners was prepared by Sonobond Corporation, West Chester, Pennsylvania, under Navy contract No. N00140-79-C-1173. The effort was sponsored by the Naval Sea Systems Command Manufacturing Technology Office, SEA 05R2. The contract was executed from September 1979 to December 1980 under the direction of the Philadelphia Naval Shipyard, Philadelphia, Pennsylvania 19112 with Robert Tasch, Code 385.1, serving as project supervisor. The work performed at Sonobond Corporation was under the technical supervision of Richard F. Kramer.

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INTRODUCTION

The loosening of corroded fasteners, including hexagon cap screws, socket head cap screws and studs, ranging in size from 1/4 inch to 3/4 inch diameter in either coarse or the fine thread series, presents a Naval engineering problem. This program was undertaken to design, develop, fabricate and test a prototype ultrasonic wrench to assist in the removal of these bound metal fasteners.

This contract stems from the positive effects demonstrated under National Aeronautics and Space Administration, NASA, contract No. NAS 8-11965, entitled, "Ultrasonic Wrench for Flared Tubing Connections." The NASA contract successfully developed an ultrasonically activated wrench that could be used to tighten flared tubing connections to produce reliable hermetic seals with 6061-T6 aluminum alloy and with CRES 304 stainless steel, OD sizes ranging from 1/8 to 1 inch.

Based on these promising preliminary NASA results, it was anticipated that ultrasonic activation could be effective in loosening the corroded fasteners. This report covers the data and results obtained from the application of vibratory energy to seized shipyard fasteners.

EQUIPMENT

Theoretical Considerations

On the basis of past experimental efforts and experience, the design criteria evolved for the practical ultrasonic wrench to loosen seized fasteners included the following:

1. Compatibility with reasonable wrench geometries, particularly with regard to size and access to restricted or tight areas.

2. Mechanically removable and interchangeable wrench heads.

3. Operational frequency within the range of 20 to 28 kilohertz, kHz.

4. Ceramic transducer assemblies with a power capacity of 500 watts input.

5. Ultrasonic coupling system to activate the wrench in the axial and/or flexural open mode.

6. Force-insensitive mount on the transducer-coupling system to provide frequency stability and minimum vibratory loss to the wrench body and a torque indication system under variable force application.

7. Compact solid-state frequency converter to maximize portability and minimize weight, with an output of approximately 500 high-frequency electrical watts.

8. Ultrasonic power and power-step to be conveniently excited by the use of a foot switch.

9. Cables between the frequency converter and the transformer and between the transformer and the wrench of convenient length to allow flexibility during dewrenching operations.

On the basis of the above criteria, two ultrasonically assisted wrenches were designed, fabricated and tested.

Wrenching Apparatus

Two prototype wrenches were developed and manufactured in accordance with the design considerations established. The complete axial wrench is pictured in Figure 1 and the

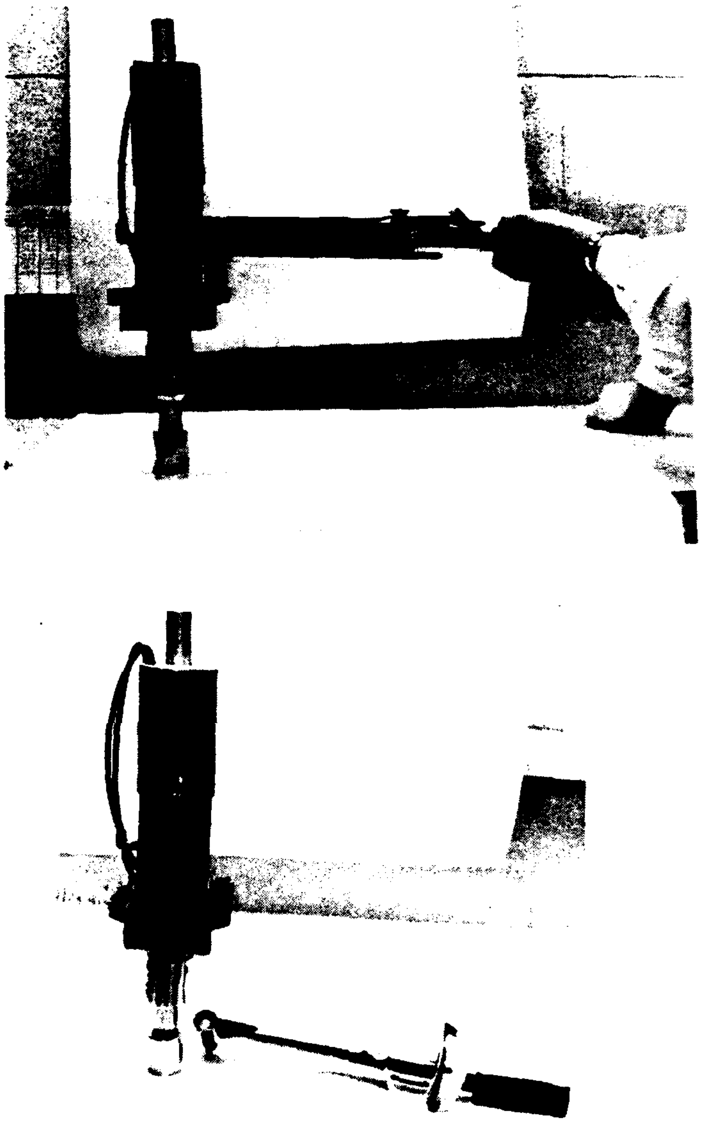


Figure 1. Axial or vertical wrench

open flexural wrench is pictured in Figure 2. The assemblies include the wrenching unit, the frequency converter and the interconnecting cables. Figure 3 shows the three vibratory modes examined in the NASA study. Based on the NASA results, the subject program explored the axial and open flexural modes which provide dynamic forces that act more or less perpendicular to the threaded surfaces, but differ in the distribution of the component force vectors.

Wrench Assembly

The wrench assembly incorporates a 20 and a 28 kilohertz ceramic (lead zirconate titanate) transducer assembly. The axially excited wrench operated at 20 kilohertz and the open flexurally excited wrench at 28 kilohertz. The transducer assembly was supported on the wrench body via a force insensitive mount, to minimize frequency shift and loss of vibratory energy to the torque wrench beams. Air cooling channels were provided in the transducer assembly to prevent overheating which depolarizes the ceramic transducer.

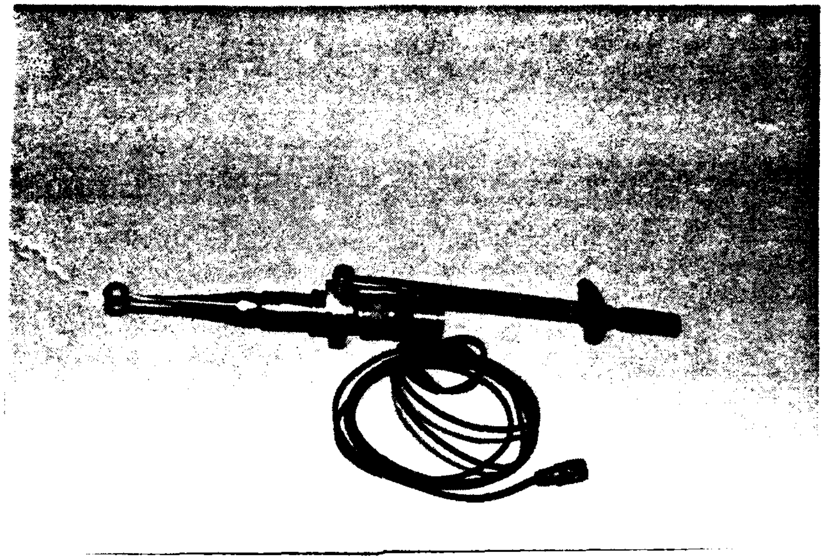
Frequency Converters

The 20 kilohertz frequency converter, used in the axial or vertical wrenching trials, is a solid-state device which converts 60-hertz electrical line power to high-frequency electrical power and delivers it to the transducer in the wrench assembly. It operates from 110 volt AC, 50-60 hertz, single-phase, line power.

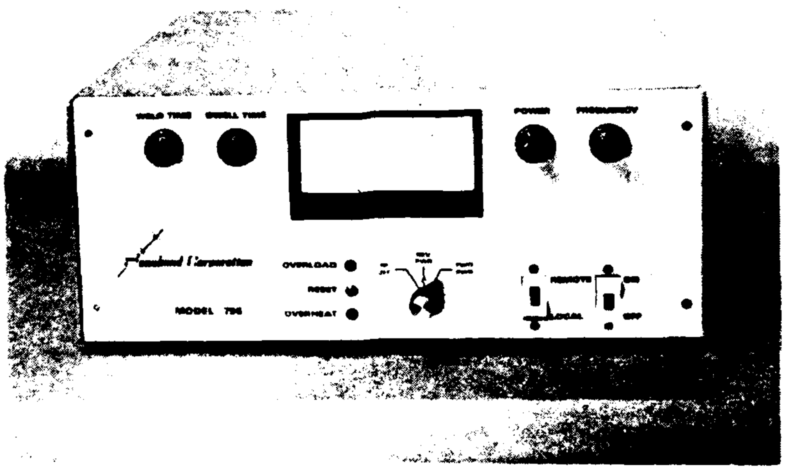
The frequency converter contains a phase lock loop so that the nominal 20 kilohertz operating frequency can be adjusted for precise matching to the transducer frequency. An amplitude limit control, in the circuit, controls the power output. Circuit breakers are incorporated to protect the frequency converter from overload or overheating.

The unit is housed in a standard rack cabinet, to facilitate easy placement near the wrenching assembly. A cooling fan provides forced circulation of air through the interior of the cabinet. The rear panel of the frequency converter contains the connectors to the wrench assembly, the thermal reset circuit breakers and the AC primary power line.

The frequency converter used in the open flexurally activated wrenching trials has a broadband design, permitting adjustment of the nominal 20 kilohertz operating frequency. We operated this converter at 28 kilohertz. It utilizes



A. Open Flexural Wrench



B. 28 Kilohertz Frequency Converter

Figure 2. Open Flexural Wrench and Frequency Converter

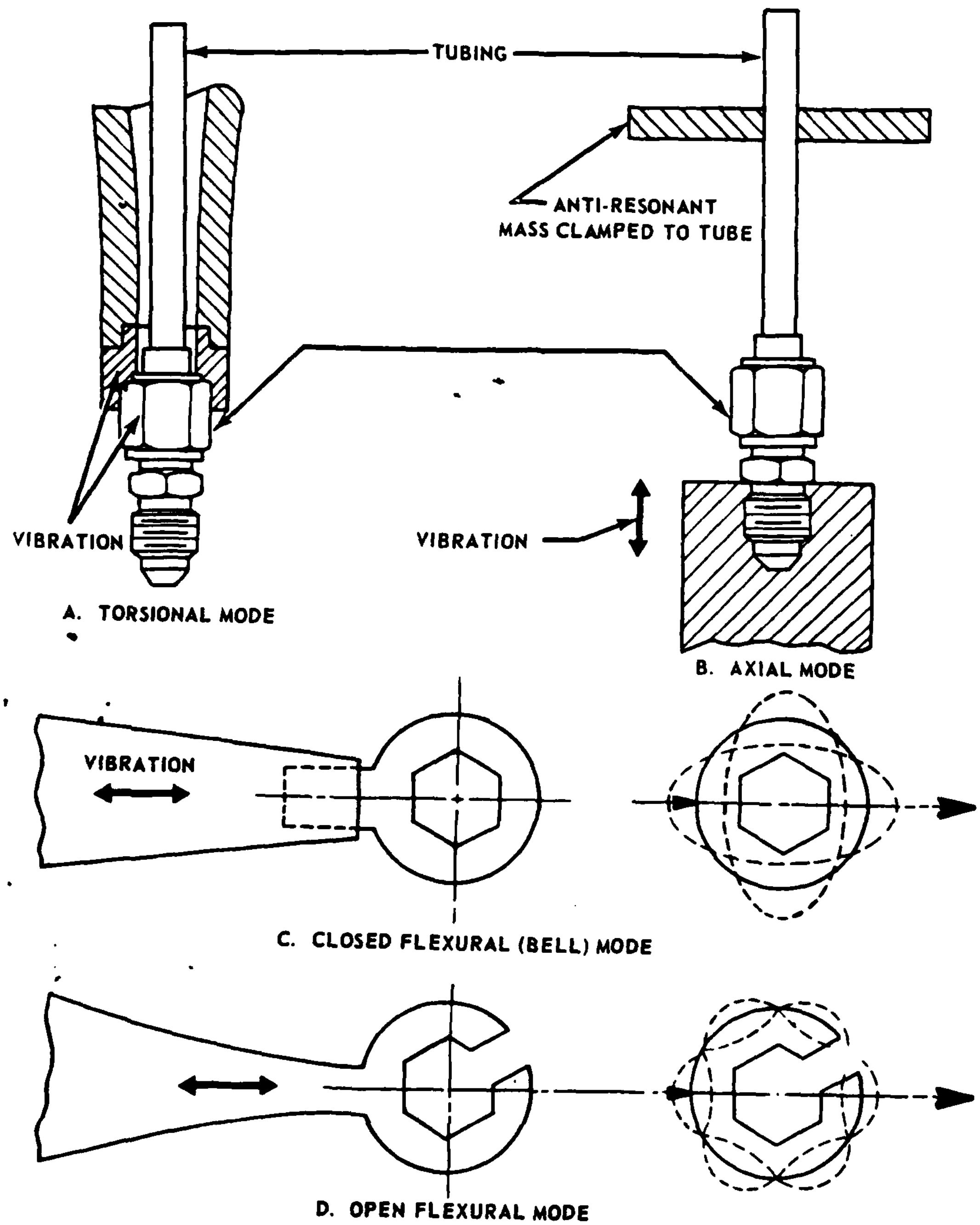


FIGURE 3. VIBRATORY MODES

115-volt AC line power and the high-frequency output is variable from approximately 20 to 1200 peak RF watts. The unit is also housed in a standard rack cabinet which may be placed in the vicinity of the wrench assembly.

Connecting Cables

The cables for transmitting the ultrasonic power and the control signals from the frequency converter to the transducer were enclosed in light-weight, rubber-coated tubing. A RF cable, 110/115 volts, 15 amperes, ran to the frequency converter and another cable ran from the wrench assembly to the foot switch.

WRENCHING TRIALS

Overview

For any given fastener, torque is the amount of twisting or the force applied, measured in units of force, over the length of the wrenching arm, measured in units of length. Tension is the internal degree of tightening in a fastener. Tension is directly proportional to torque, but this proportion can be varied by frictional resistance or dirt in the threads. If the amount of torque required to achieve a specified tension can be decreased, then one of the variables, i.e., friction or the amount of dirt, has been changed. It has been demonstrated that the amount of torque required to reach a desired tension is less when the wrench is ultrasonically activated. It is believed that ultrasonics reduces the frictional component and hence improves the torque to tension ratio.

Since it has been demonstrated that ultrasonics reduces the torque necessary to attain a given tension, the converse should also be true. That is, with the aid of ultrasonics, a seized fastener should be more readily loosened, at a reduced torque application.

Preliminary Wrenching Trials

Based on the above anticipated results, sample fasteners were tightened to 150 in./lb. of torque and then loosened with and without ultrasonic assistance. The following parameters were used:

Frequency = 30.15 kHz

Power = 550 watts

Impedance = 36 ohms

Using a NASA-type wrench, that is excited in the flexural open mode with the acoustic transmission directed down the length of the wrench, the following positive results were obtained. (See Table 1.) As anticipated, the breakaway torque values were significantly less when the wrench was ultrasonically activated. Without ultrasonics, the breakaway torque value for 150 in./lb. of torque was 135 in./lb. With ultrasonics, the breakaway torque values, when the

Sample	Torque	No U/S Breakaway	U/S torque	Comments
A	150	135	122	U/S untuned
B	150	135	88	good phase
C	150	135	115	
D	150	135	94.5	
E	200	175	175	U/S untuned
F	200	175	122	
G	200	175	128	
H	200	175	142	
I	200	175	128	

Table 1. Comparison of breakaway torque values with and without ultrasonics

equipment was properly tuned, were 88, 94.5 and 115 in./lb. for 150 in./lb. of torque.

Subsequently, the torque on the screw was tightened or increased to 200 in./lb. and similar results were obtained. (See Table 1.) Without ultrasonics, the breakaway torque value for 200 in./lb. of torque was 175 in./lb. With ultrasonics, this value decreased to 122, 128 and 142 in./lb.

Since ultrasonics effected a reduction in the breakaway torque values in these preliminary trials, the subject program proceeded to the next phase.

Wrenching Trials

In addition to the prototype wrench based on the NASA design, a prototype wrench with the vertical or axial mode of transmission was designed and fabricated for this phase of the subject program.

This phase involved the simulation of seized fasteners by the application of Locktite. A 1/2 inch plate of cold rolled steel was drilled and tapped with seven 1/4-20 holes and seven 3/8-16 holes. Four 1/4-20 fasteners were installed at 12.5 ft.lbs. of torque and three 1/4-20 fasteners were installed with Locktite at the same torque. Similarly, four 3/8-16 fasteners without Locktite and three 3/8-16 fasteners with Locktite were installed at 45 ft.lbs. of torque.

When the ultrasonics was activated, the Locktite bubbled out of the threads. The ultrasonics caused the Locktite to cavitate, thus hampering its ability to simulate a seized fastener, if it is used in conjunction with ultrasonic power. Therefore, the positive results obtained, (See Table 2,) may not be an accurate indication of the ability of ultrasonics to decrease the breakaway torque for seized fasteners.

Nonetheless, a reduction in the breakaway torques for the fasteners without Locktite when ultrasonically wrenched was observed. This appears to confirm prior studies that ultrasonics can affect a reduction in the breakaway torque for a given application. After 11 trials, the wrench cracked and fractured. Although we did not test the 3/8-16 fasteners with Locktite and ultrasonic activation, based on previous

Fastener Size	Locktite	Ultrasonics	Breakaway torque (Ft#)
1/4-20	yes	no	10
1/4-20	yes	yes	2
1/4-20	yes	yes	10
1/4-20	no	no	10
1/4-20	no	no	12
1/4-20	no	yes	1-2
1/4-20	no	yes	1-2
3/8-16	no	no	18
3/8-16	no	no	18
3/8-16	no	yes	18
3/8-16	no	yes	18

Table 2. Comparison of breakaway torque during attempts to simulate a seized fastener

characteristics of Locktite under the influence of ultrasonics, we decided to perform the remainder of the loosening trials with the axial wrench instead of remanufacturing the NASA-type wrench.

The axial wrench was tested to determine if the vertical acoustic design had any effect on the equipment's wrenching ability and if so, how did this configuration vary the torque-tension relationship? Three 3/8-16 fasteners, without Locktite were tightened to 50 ft.lbs. Without ultrasonically activating the wrench, a 20 ft.lb. breakaway torque value was recorded. When the ultrasonics was activated, it required 30 and 32 ft.lbs. to reach the breakaway point.

This data was contrary to our previous findings. It was determined that the frequency converter used to operate the axial wrench was under powered for this application and further, a poor impedance match was noted. We switched frequency converters to a power-on-demand unit that operated at 20 kHz with a capacity for 600 watts.

A trip to the Philadelphia Naval Shipyard was made by our project engineer to obtain in situ samples of corroded fasteners. He returned with an assortment of corroded studs, complete with nuts, from the shipyard environment. Trials with the axial wrench were performed on the seized studs. With and without ultrasonics, the shipyard environment studs were too corroded to be loosened by the axial wrench.

Since the loosening of seized studs was not feasible, we decided to tighten fasteners to confirm the effect that ultrasonics has on torque-tension relationships. Trials were performed by tightening eight 1/2-20 fasteners to 50 ft.lbs. of torque with and without ultrasonic assistance. Subsequent readings for tension, see Table 3, confirmed previous data. For a given torque, the tension in the thread was observed to increase if the fastener was ultrasonically tightened. (See Figure 4.)

At this point, it was mutually agreed that although experimental data to date confirmed our prior analysis of the relationship of an increased tension for a given torque application with the influence of ultrasonics, the power necessary to meet the Naval application was beyond the parameters of the equipment dedicated to the subject program. A Navy-Sonobond conference was convened and the subject program was suspended pending Navy review of the findings to date.

Sample	Tension (psi) U/S	Tension (psi) No U/S	Comments
1	16,500	15,000	
2	16,000	15,500	
3	11,000	12,500	Loose horn
4	11,000	11,000	
5	14,500	9,000	
6	11,000	7,000	
7	12,500	8,000	

Table 3. Comparison of tension in the bolt when torqued to 50 ft.-lbs.

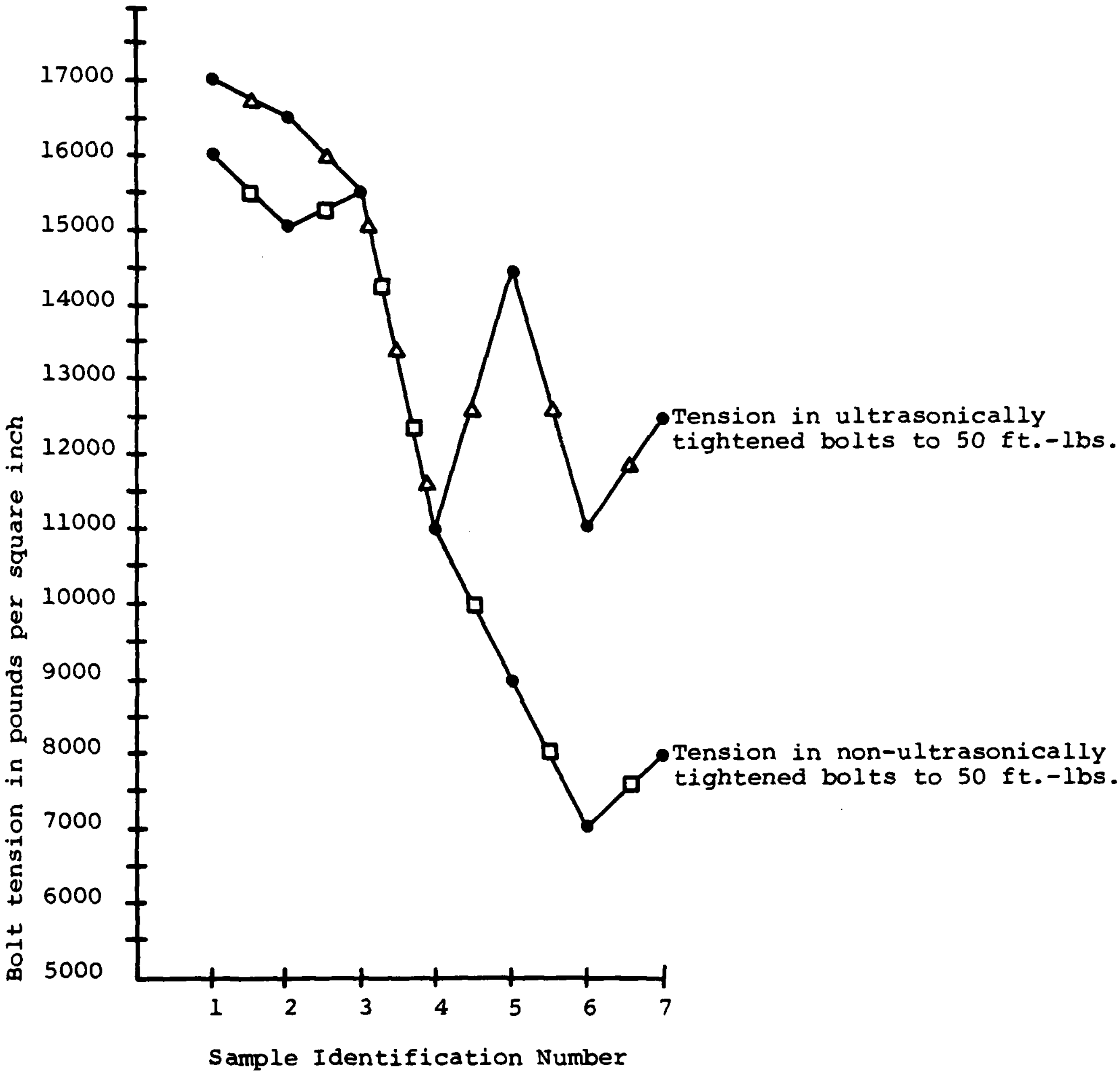


Figure 4. Tension in ultrasonically and non-ultrasonically tightened bolts.

DISCUSSION OF PRELIMINARY BOLT WRENCHING

Encouraged by early success in ultrasonic wrenching of the flared tube assemblies, Sonobond undertook a brief investigation of the wrenching of bolt-nut assemblies, using 3/8-16 steel bolts three inches long.

Using a strain-gage-instrumented torquing array with and without ultrasonic activation in the torsional mode, strip-chart records of the tension preload developed in the nut versus time showed a pattern typified in Figure 5. After non-ultrasonic torquing at 60 inch-pounds, an ultrasonic pulse at 500 RF watts power permitted additional rotation of the nut and substantially increased the bolt tension without increasing the torquing load.

The magnitude of the effect increased with increasing ultrasonic power. Figure 6 shows data obtained at three ultrasonic power levels in comparison with non-ultrasonic control assemblies.

Based in part on this study, the subject program was initiated. The relationship during tightening of an increase in tension for a given torque application with ultrasonics was once again observed. However, due to the extremely seized nature of the shipyard studs, these same results during loosening could not be demonstrated. Further, the effect that ultrasonics has on Locktite preempted our ability to simulate a seized fastener. It is anticipated that ultrasonics would decrease the breakaway torque during loosening in fasteners smaller than the Naval yard studs or in larger fasteners which were not bound as a result of the shipyard environment.

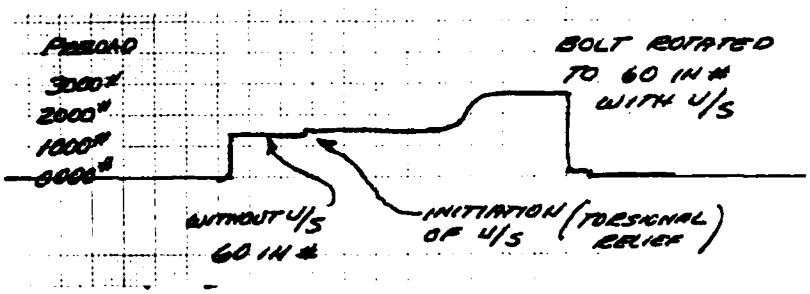


Figure 5. Effect of ultrasonics on breakaway torque of 3/8-16 steel bolts

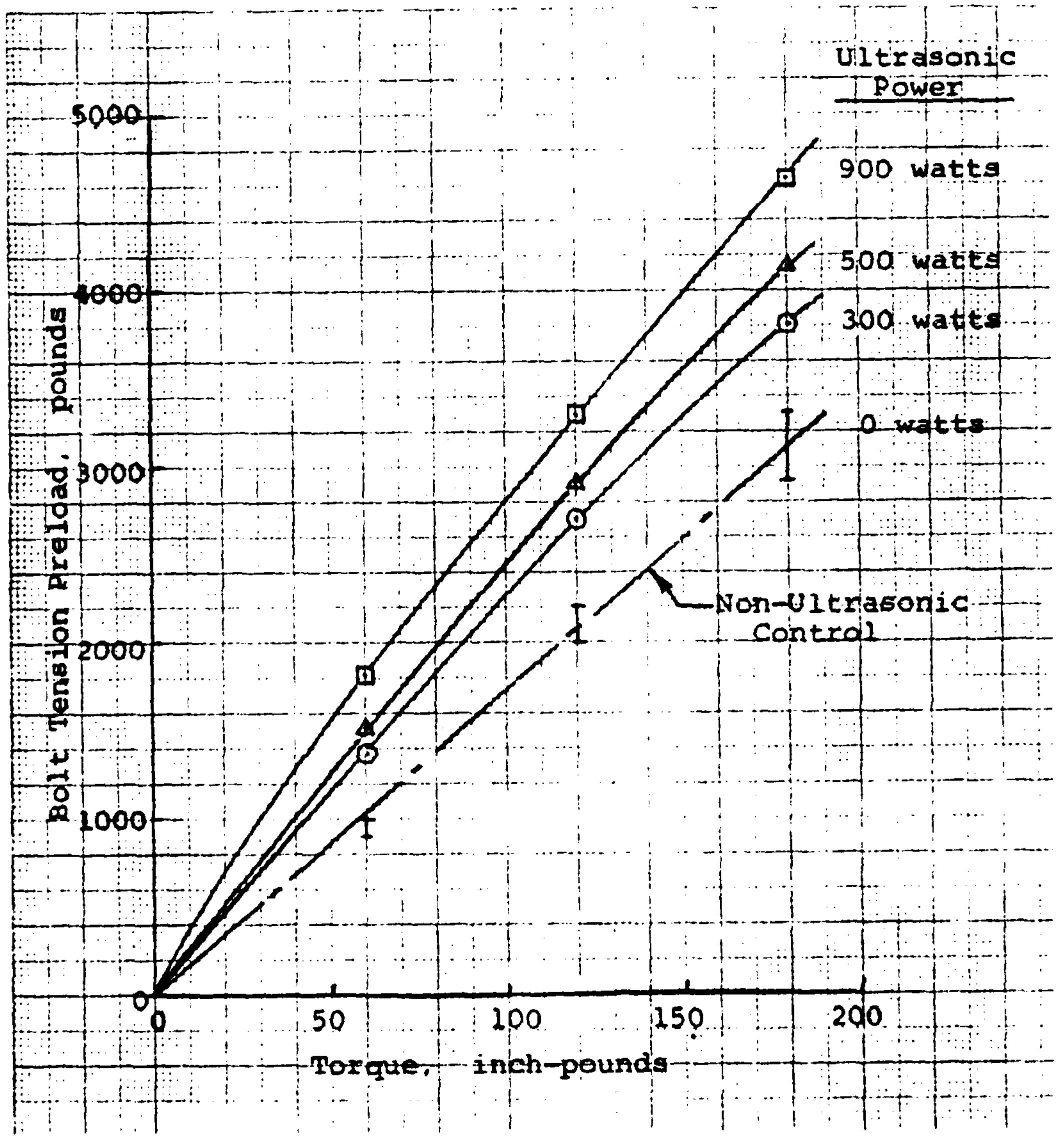


Figure 6

ULTRASONIC EFFECT ON BOLT TENSION
AS A FUNCTION OF APPLIED TORQUE
AND ULTRASONIC POWER LEVEL

Bolts: 3/8-16 Steel

CONCLUSIONS AND RECOMMENDATIONS

Ultrasonics has a definitive positive effect on the torque-tension relationship. For a given torque application, the introduction of ultrasonics increases the tension.

However, the amount of the increase is not sufficient enough to handle the fasteners corroded by the shipyard environment.

The breakaway torque measured with an ultrasonically powered wrench is less than the breakaway torque measured with a conventional wrench.

It is recommended that the positive results obtained with the ultrasonic tightening of fasteners be explored with an emphasis on the effect that ultrasonics has on the torque-tension relationship.

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