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DEVELOPMENT OF ULTRASONIC WRENCH FOR FLARED TUBING CONNECTIONS, VOLUME I

by HERMAN T. BLAISE and NICHOLAS MAROPIS
Manufacturing Engineering Laboratory

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By

Herman T. Blaise
George C. Marshall Space Flight Center
Huntsville, Alabama

and

Nicholas Maropis
Technidyne Incorporated
West Chester, Pennsylvania

ABSTRACT

This interim report summarizes the initial development of an ultrasonic torque system of wrench-tightening aluminum and stainless steel flared tubing connections. A prototype ultrasonic wrenching system, now undergoing review at Marshall Space Flight Center, was produced during the first three phases of this four-phase development program. The first three phases were: (1) feasibility, (2) tool design, fabrication and testing and (3) evaluation. Work on the fourth phase, design of a semi-automated system, is under way at Technidyne Incorporated. The use of an ultrasonic energized torquing tool, under controlled conditions, increases the probability of a leaktight connection between missile components.

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MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND TECHNOLOGY DIVISION

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DEVELOPMENT OF ULTRASONIC WRENCH FOR FLARED TUBING CONNECTIONS

SUMMARY

The effectiveness of various ultrasonic vibratory modes, frequencies, power levels and pulse times was investigated in connection with wrench-tightening 0.00635-meter (0.25-inch) aluminum and 0.0127-meter (0.5-inch) stainless steel flared tubing connections, representative of the size range from 0.003175 meter (0.125 inch) to 0.0254 meter (1 inch). An ultrasonic torque wrench for flared tubing connections in this size range was designed, built, evaluated and delivered to the Marshall Space Flight Center. Clear evidence of a significant and useful effect was shown by a higher percentage of leaktight connections and by increased breakaway torque on disassembly. The relative hardness of the flare, union and sleeve was found critical for leaktightness to result from the increase in wrench rotation that occurs during ultrasonic activation.

INTRODUCTION

For many years much effort has been expended at Marshall Space Flight Center to provide flared tube connection assemblies in a no leak condition. Although considerable advances have been made in processing methods and equipment used in the production of precise flared tube connectors, the problem of flared connection leaks in space vehicle fluid systems still exists. With near perfection achieved in the production of flared tube connection hardware, the Manufacturing Research and Technology Division of the Manufacturing Engineering Laboratory at Marshall Space Flight Center (MSFC), National Aeronautics and Space Administration (NASA) made further investigations into the probable causes of leaks in tube connections.

In the fall of 1964, a program was started to provide a tool to assist in further elimination of leaks in tube connections. Various reports and data reviewed indicated that the application of ultrasonics to tube assemblies being torqued might have two advantageous effects: (1) reduction of interfacial friction and (2) transit improvement in the deformation properties of the material sealing surfaces. With the goal of providing a practical tool permitting consistent leak-tightness through the application of ultrasonic energy to the connection during tightening, Marshall Space Flight Center has entered into a contractual agreement with Technidyne Incorporated of West Chester, Pennsylvania under Contract No. NAS8-11965. The contract covers a four-phase development program.

This interim report describes the work accomplished during Phase I (Feasibility), Phase II (Tool Design, Fabrication and Testing), and Part 1 of Phase III (Evaluation). These phases have produced a prototype ultrasonic wrenching system which is being evaluated and tested at MSFC for support in the development of a semi-automated system in Phase IV of the program. Work is in progress at the Technidyne Corporation on the design of the semi-automated system. Technidyne is conducting tests and evaluating the actual mechanical forces engaged between mating surfaces and on coupling components, as the result of being torque wrenched at various ultrasonic power levels.

The MSFC program is now scheduled to be completed by June 1967 with the final report to be published in July 1967.

HERMETIC-QUALITY FLARED TUBING CONNECTIONS

The achievement of consistent hermetic-quality flared tubing connections has been less than satisfactory because a substantial percentage of such assemblies leak, causing costly disassembly and lost time. The purpose of this work has been to develop a practical tool permitting consistent leaktightness through the application of ultrasonic energy to the connection during tightening.

Variable Compression

The flared tube connection is sealed by rotating the nut to compress the tube flare against the union bevel (Fig. 1). A major portion of the applied torque overcomes friction in the threads between the back shoulder of the nut and the face of the compression sleeve and between the sleeve and the tube flare. These forces vary from assembly to assembly and result in uncontrollable compression in the seal area. Laboratory experience has shown that ultrasonic vibration reduces friction so it was theorized that an ultrasonic tool suitable for flared tube connections would effect greater compression between the tube flare and the union at the specification level of applied torque, resulting in leaktight connections of improved reproducibility.

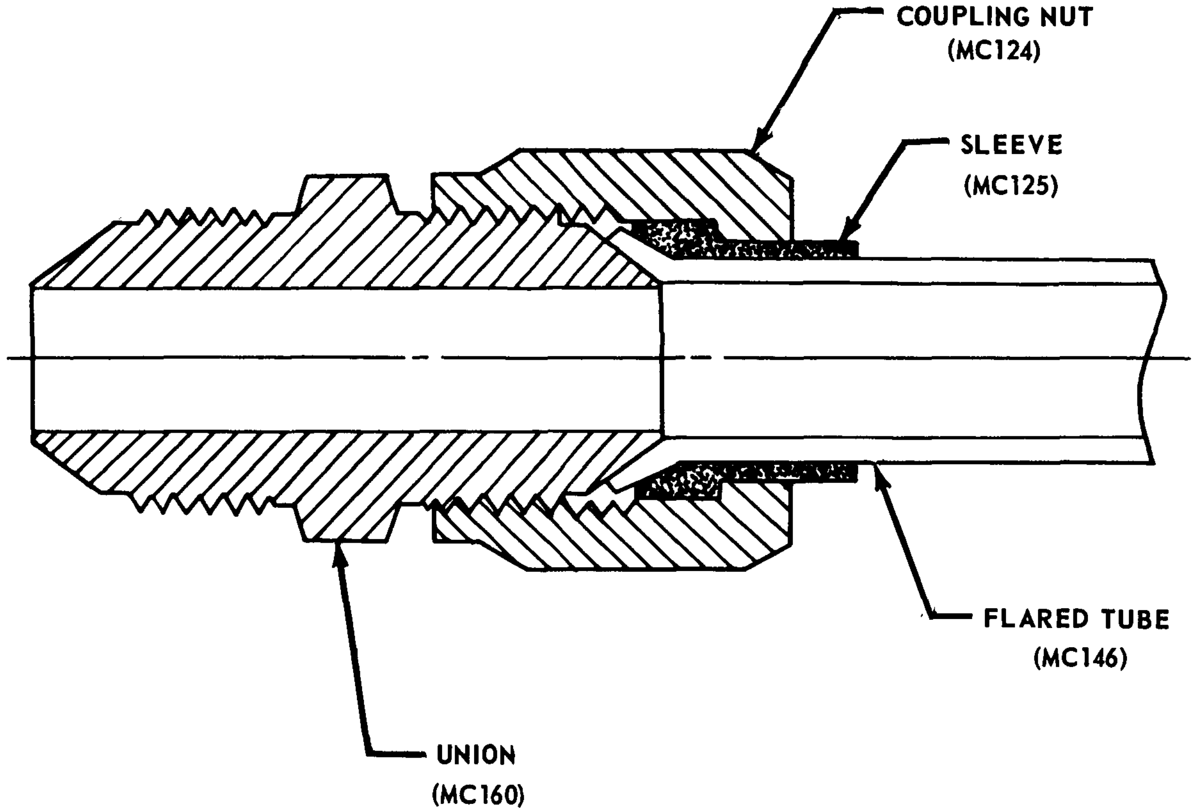


FIGURE 1. FLARED TUBING CONNECTION

Specifications

Specifications for certain flared tube connection components of interest are presented in NASA's MC124, MC125, MC146 and MC160 which cover the coupling nut, the sleeve, the flared tubing end and the union, respectively. It was decided by personnel of the Manufacturing Engineering Laboratory at MSFC that the flared tube sizes of greatest interest and urgency were in the range of 0.003145 meter (0.125 inch) to 0.0254 meter (1 inch) (outside diameter of the tube). Discussions with Technidyne personnel indicated that it would probably not be unreasonable to evolve an ultrasonic wrench design for 0.00635-meter (0.25-inch) aluminum tubing and for 0.0127-meter (0.5-inch) stainless steel tubing as representative of the 0.003145 meter (0.125 inch) to 0.0254 meter (1 inch) tubing size range.

Evaluation

Exploratory evaluation of ultrasonic wrenching of flared tubing connections was carried out utilizing commercial components to affirm the feasibility of this method. The commercial tubes were of the same material as the MC components: 6061-T6 aluminum alloy and CRES 304 stainless steel. Because commercial fittings of these materials were not readily available, standard commercial aircraft-quality fittings of 2024-T6 aluminum alloy and AISI 316 stainless steel were used.

DEVELOPMENT OF ULTRASONIC DESIGN CRITERIA

To develop design criteria for an ultrasonic wrench, an investigation of vibratory mode, frequency, ultrasonic power level and pulse time was carried out to determine the conditions under which ultrasonic wrenching leads to improved leaktightness of flared tubing connections.

Vibratory Mode

The effectiveness of any ultrasonic tool depends on the efficient transmission and delivery of acoustic energy to the work. Development of an ultrasonic wrench required consideration of the relationship of vibratory mode (direction) to the geometry of the flared tubing connection and an investigation of the effectiveness of the several possible modes.

Three vibratory modes were considered because of their possible efficacy in delivering acoustic energy to the mating surfaces of the connection. These modes were flexural (or bell), axial (or longitudinal) and torsional. The axial and flexural modes provide dynamic forces acting more or less perpendicular to the thread surfaces, but differing in the distribution of the component force vectors. The torsional mode provides dynamic forces which operate "cookie-cutter-like" in the plane of the tightening torque at the thread surfaces.

Ultrasonic systems were assembled to transmit vibration in each mode to the connection. Each system incorporated nickel transducers designed to operate at a nominal frequency of 15 kilohertz (15 kilocycles per second).

For the axial and torsional mode studies, the fitting was attached to an adapter coupler, and vibration was transmitted from the primary coupler through the adapter coupler to the fitting (Fig. 2). In the axial system, longitudinal vibration was transmitted directly from the transducer-coupling to the union which was tightly screwed into the end of the adapter coupler. Torque was applied to the nut. In the torsional system, longitudinally vibrating transducer-couplings attached tangentially to a tapered coupler drove it in torsion. An adapter coupler transmitted the torsional vibration to a tip into which the nut was inserted. Torque was applied through the union.

In the flexural mode, a longitudinally excited coupler induces flexural vibration in an acoustically designed wrench head which delivers both vibration and torque. The "closed" flexural mode or bell mode was used in this investigation because it presents fewer variables than the open flexural mode (Fig. 2), although end-use requirements dictate an open-end wrench head design for flared tube coupling geometries. Vibration was applied through the box wrench to the nut, and torque was applied through the union.

The mode survey was carried out with commercial components. Tubes were flared by the contractor; the flares were satisfactory for this investigation but did not meet strict MC specifications.

Partly because of the limited number of commercial flared tubes available, a number of repeat assemblies were made. Reverse torque was applied (without ultrasonics) to the assembly until the components were separated, then they were tightened again.

Effectiveness of the different modes of ultrasonic vibration was evaluated generally in terms of the magnitude of additional relative rotation between the union and the coupling nut. This rotation resulted from activation of the ultrasonic system because leaktightness was assumed to be associated with relative rotation and the resulting compression between the union and the tube flare. In addition, values of breakaway torque required to separate the assemblies were compared.

The resulting measurements with the three modes are summarized in Table I for 0.00635-meter (0.25-inch) aluminum and in Table II for 0.0127-meter (0.5-inch) stainless steel, without regard to number of repeat assembly operations. Because additional rotation is less on repeat assembly, the data do not show the correlation that exists between the magnitude of additional rotation

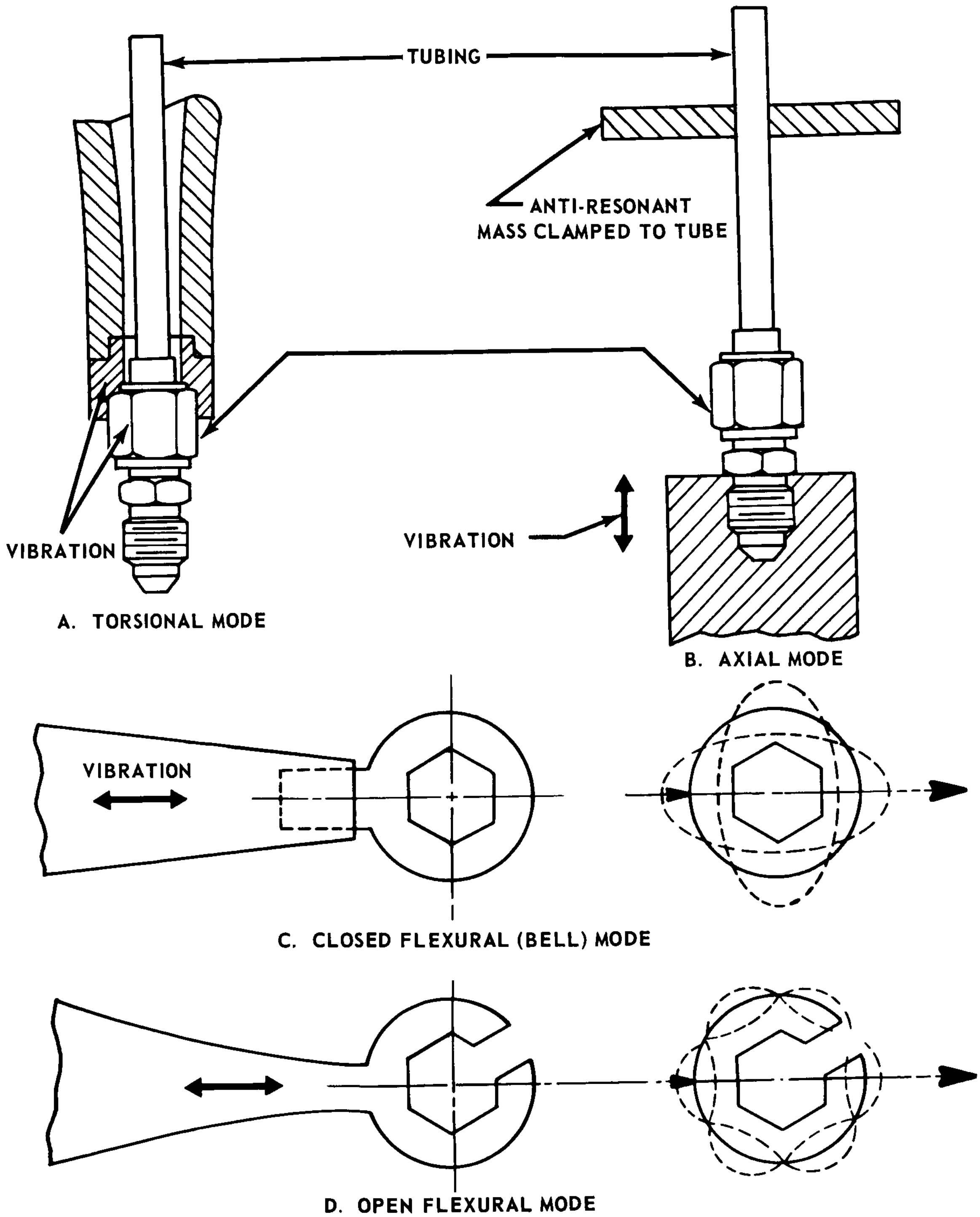


FIGURE 2. VIBRATORY MODES

TABLE I

EFFECT OF VIBRATORY MODE ON 0.00635-METER (0.25-INCH) ALUMINUM CONNECTIONS*

Torque Level joules (in.-lb)	Mode	Ultrasonic Power watts	Range of Additional Rotation, degrees	Range of Breakaway Torque, joules (in.-lb)
7.91 (70)	Non-Ultrasonic	0		4.75 - 5.88 (42-52)
	Bell	100	6	7.68 (68)
		200	4-7	7.23 - 8.13 (64-72)
		300	10	7.68 (68)
		400	5-9	7.91 - 8.59 (70-76)
	Axial	50	2	5.88 (52)
		200	5-26	6.78 - 9.49 (60-84)
		300	8-14	8.13 - 10.85 (72-96)
		400	9-12	9.49 - 10.85 (84-96)
	Torsional	50	0	6.78 (60)
		100	0	6.78 (60)
		200	0	7.23 (64)
		300	0	7.23 (64)
		400	2	7.68 (68)
13.56 (120)	Non-Ultrasonic	0		9.49 - 10.85 (84-96)
	Bell	200	5	10.39 (92)
		400	8-10	10.85 (96)
	Axial	50	6-37	12.20 - 14.46 (108-128)
		100	5	12.43 (110)
		200	3-5	12.65 (112)
		300	14-17	15.82 (140)
		400	8-9	14.46 - 17.17 (128-152)

* A frequency of 15 kilohertz (15 kilocycles per second) was used.

TABLE I (Concluded)

Torque Level joules (in. -lb)	Mode	Ultrasonic Power watts	Range of Additional Rotation, degrees	Range of Breakaway Torque, joules (in. -lb)
13.56 (120)	Torsional	50	0	10.85 (96)
		100	0	10.85 (96)
		200	0.5	10.85 (96)
		300	0	10.85 (96)
		400	0	10.85 (96)
		500	0	10.85 (96)

TABLE II

EFFECT OF VIBRATORY MODE ON 0.0127-METER (0.5-INCH) STAINLESS STEEL CONNECTIONS*

Torque Level joules (in.-lb)	Mode	Ultrasonic Power watts	Range of Additional Rotation, degrees	Range of Breakaway Torque, joules (in.-lb)
53.67 (475)	Non-Ultrasonic	0		40.67 - 45.76 (360-405)
	Bell	175	7	42.37 (375)
		250	6	42.37 (375)
		450	6-7	42.93 (380)
		550	5	42.37 (375)
		650	4-5	49.71 - 52.20 (440-462)
	Axial	200	0-2.5	44.06 - 51.97 (390-460)
		400	0-4.5	48.58 - 51.97 (430-460)
		600	1-2	48.58 - 51.97 (430-460)
		800	1-6.5	50.84 - 51.97 (450-460)
	Torsional	50	1	51.97 (460)
		100	1	51.97 (460)
		200	0	45.19 - 49.71 (400-440)
		400	0-1	47.45 (420)
		800	1.25-20	47.45 - 51.97 (420-460)
		1600	2	47.45 (420)

* A frequency of 15 kilohertz (15 kilocycles) was used.

and the ultrasonic power level. The ranges of additional rotation and breakaway torque presented in Tables I and II represent from one to four assemblies for each set of conditions.

The torsional mode, which did not yield significant additional rotation during tightening, appeared ineffective for ultrasonic wrenching of flared tubing connections.

The axial and bell modes, superimposed on the torque load, yielded significant additional relative rotation between the nut and the union for both the 0.00635-meter (0.25-inch) aluminum and the 0.0127-meter (0.5-inch) stainless steel. Although additional rotation obtained with both modes was roughly equivalent, breakaway torques for aluminum assemblies tightened at 13.56 joules (120 inch-pounds) and for stainless steel assemblies were higher for the axial mode than for the bell mode.*

Because both the axial and flexural (bell) modes were effective, the flexural mode (open) was selected for the ultrasonic wrench because it permitted a practical wrench head configuration not dissimilar to that found on standard torque wrenches. This arrangement provides reasonable access to flared tubing connections in more or less space-limited situations. Moreover, theoretical considerations indicate that flexural vibration will probably be localized in the connection; whereas axial vibration will be conducted away from the tube connection by the tubes, as by an acoustic waveguide.

Frequency

On the basis of other work, no frequency effect for the range from 15 to 60 kilohertz was anticipated. The frequency of 15 kilohertz was used for the mode survey because components for systems to operate in the various modes at this frequency were available. To verify the presence or absence of a frequency effect, an axial-mode system was assembled to operate at 28 kilohertz for comparison with the 15 kilohertz axial-mode system.

The frequency investigation, carried out in conjunction with the mode survey, used commercial components and repeat torquing. Table III summarizes the results. Significant additional rotation and increase in breakaway torque occurred at both 15 and 28 kilohertz. (The ranges each represent from one to four assemblies.) Somewhat greater ultrasonic effects (at the same power level) were observed at 15 kilohertz, almost certainly because of the smaller

* Breakaway torque values obtained with the completed ultrasonic wrench (open flexural mode) were significantly higher than those obtained with the bell-mode (closed flexural) experimental system.

TABLE III

EFFECT OF FREQUENCY - AXIAL MODE

Tubing	Torque Level joules (in. -lb)	Frequency (Kilohertz)	Ultrasonic Power, watts	Range of Additional Rotation, degrees	Range of Breakaway Torque joules (in. -lb)
0. 00635-Meter (0. 25-Inch) Aluminum	7. 91 (70)	Non-Ultrasonic	0		4. 75 - 5. 88 (42-52)
		15	50	2	5. 88 (52)
			200	5-26	6. 78 - 9. 49 (60-84)
			300	8-14	8. 13 - 10. 88 (72-96)
			400	9-12	9. 49 - 10,85 (84-96)
		28	50	1-2	6. 33 - 7. 68 (56-68)
			100	2. 5-4	6. 78 - 7. 23 (60-64)
			200	3. 5-4	8. 13 (72)
			300	2. 5-13	7. 68 - 8. 13 (68-72)
			400	3	7. 23 - 8. 59 (64-76)
	13. 56 (120)	Non-Ultrasonic	0		9. 49 - 10. 85 (84-96)
		15	50	6-37	12. 20 - 14. 46 (108-128)
			100	5	12. 43 (110)
			200	3-5	12. 65 - 16. 27 (112-144)
			300	14-17	15. 82 (140)
			400	8-9	14. 46 - 17. 17 (128-152)
		28	50	0-3	11. 75 - 12. 65 (104-112)
			100	0-2. 5	11. 75 (104)
			200	2-5. 5	11. 75 - 13, 56 (104-120)
			300	1. 5-2. 5	10. 85 - 13. 56 (96-120)
			400	3	12. 65 (112)
0. 0127-Meter (0. 5-Inch) Stainless Steel	53. 67 (475)	Non-Ultrasonic	0		40. 67 - 45. 76 (360-405)
		15	200	0-2. 5	44. 06 - 51. 97 (390-460)
			400	0-4. 5	48. 58 - 51. 97 (430-460)
			600	1-2	48. 58 - 51. 97 (430-460)
			800	1-6. 5	50. 84 - 51. 97 (450-460)
		28	200	0-3. 5	45. 19 - 50. 84 (400-450)
			300	2	45. 19 (400)
			400	0-5	42. 93 - 51. 97 (380-460)

mass of the wrench head and coupling nut in proportion to the mass of the ultrasonic coupler of the larger system. Both systems, however, effected the minimum additional rotation associated with leaktight connections.

Because no substantial effect of frequency was observed, selection was based on the practical requirements of physical size and power-handling capacity of the wrench design projection. Increasing the frequency of any ultrasonic tool decreases both its size and its ultrasonic power-handling capability. The frequency of 28 kilohertz was selected to provide a small practical wrench while permitting adequate power for tightening the largest fittings (0.0254-meter, 1-inch diameter).

Power Capacity

The power-handling capability required for an ultrasonic wrench to provide leaktight flared tubing connections was investigated. Experiments were carried out with NASA MC tubes, nuts and sleeves and with commercial unions (MC unions were not available). Aluminum and steel connections were tightened at several levels of ultrasonic power input through the bell and axial (15 kilohertz) systems. The assemblies were leaktested at 24.1×10^5 newtons per square meter (350 pounds per square inch gage) internal helium pressure (as described in the section PERFORMANCE OF ULTRASONIC WRENCH). This relatively low pressure provided an indication only of helium leaktightness at high pressure. After leak test, selected assemblies were disassembled and retorqued up to fourteen times; these were leaktested after the fifth, tenth and fifteenth assembly.

Tables IV and V summarize the additional rotation caused by ultrasonics and the leaktest results for various power levels to the two systems (data for all torque levels are combined). Additional rotation was greater than obtained with commercial components, probably because of the solid film MoS_2 lubricant on the MC components. These experiments confirmed the effectiveness of the bell and axial modes.

In general, more ultrasonic than non-ultrasonic assemblies were leaktight. The most consistent tendency toward leaktightness on initial assembly seemed to occur with minimum additional rotation - 2 to 5 degrees - upon application of ultrasonic power. The minimum power to yield this rotation for 0.00635-meter (0.25-inch) aluminum was about 75 watts to the nickel transducers.

TABLE IV

ULTRASONIC WRENCHING OF 0.00635-METER (0.25-INCH) ALUMINUM CONNECTIONS*

Frequency and Mode	Ultrasonic Power, watts	No. of Times Assembled	Range** of Additional Rotation, degrees	No. of Samples	No. of Leakers***
Non-Ultrasonic	0	1		4	0
		5		4	1
		10		4	1
		15		4	1
15-Hz Bell	75	1	2-3	4	0
		5	2-3	2	0
		10	2-4	2	0
		15	2-9	2	0
	150	1	3-4	4	0
		5	3-4	2	0
		10	3-4	2	0
		15	3-5	2	0
	200	1	14-15	4	0
		5	4-6	2	0
		10	5	2	1
		15	5-6	2	1
	400	1	25-90	4	0
		****			
15-Hz Axial	200	1	8-28	4	0
		5	10-14	2	1
		10	7-9	2	0
		15	2-3	2	0
	400	1	17-47	4	0
		5	10-13	2	0
		10	13-15	2	0
		*****			

* Torque level of 7.91 to 13.56 joules (70-120 inch-pounds)
** All torque levels
*** 350 psig internal pressure with gaseous helium
**** Repeat tightenings not possible because of damage to flares and sleeves
***** Nuts cracked prior to 15th assembly

TABLE V

ULTRASONIC WRENCHING OF 0.0127-METER (0.5-INCH) STAINLESS STEEL CONNECTIONS*

Frequency and Mode	Ultrasonic Power, watts	No. of Times Assembled	Range** of Additional Rotation, degrees	No. of Samples	No. of Leakers***
Non-Ultrasonic	0	1		4	1
		5		2	0
		10		2	1
		15		2	1
15-Hz Bell (15 kc)	400	1	5-22	4	2
		5	0-4	2	0
		10	3-4	2	0
		15	6-10	2	0
	800	1	18-45	4	1
		5	2-5	2	0
		10	2-4	2	0
		15	3-4	2	0
15-Hz Axial (15 kc)	400	1	8-25	3	0
		5	2-5	2	0
		10	2-7	2	2
		15	2-9	2	0
	800	1	12-35	4	0
		5	7-10	2	0
		10	2-6	2	0
		15	4-6	2	0

* Torque level of 50.84-56.49 joules (450-500 inch-pounds)

** All torque levels

*** 350 psig internal pressure with gaseous helium

Previous work with commercial components had shown that the minimum power to yield this rotation for 0. 0127-meter (0. 5-inch) stainless steel was about 200 watts. Thus, approximately the same power density (watts per square inch) appeared to be associated with both materials because the flare surface area of the former is about one-third that of the latter.

Ultrasonic power required for each tube size from 0. 003175 meter (0.125 inch) to 0. 0254 meter (1 inch) was estimated on the basis of flare surface area and the power density shown effective for both 0. 00635-meter (0. 25-inch) and 0. 0127-meter (0. 5-inch) tubing. Power requirements were estimated for a ceramic transducer, which was to be used for the ultrasonic wrench, rather than for a nickel transducer of the type used in the experimental systems. Ceramic transducers of the type used here have overall electromechanical conversion efficiencies more than twice that of the "A" nickel transducers that were used in the scouting work and are therefore designed for about half the input power capacity. It was estimated that the largest tube (0. 0254-meter, 1-inch outside diameter, either aluminum or stainless steel) would require about 400 electrical watts to a ceramic transducer. The wrench was designed to accept a maximum of 500 watts to the transducer on a pulse basis.

Pulse Time

An ultrasonic pulse time of about three seconds was found necessary to permit the operator to maintain the specified torque level during additional relative rotation between the nut and union. Pulse times much longer than this caused excessive thickness deformation of the components. A fixed pulse time of three seconds was therefore selected for the ultrasonic wrench.

ULTRASONIC WRENCH SPECIFICATIONS

With the foregoing information as a base, specifications for an ultrasonic wrench for tightening flared tubing connections in the size range from 0. 003175-meter (0. 125-inch) to 0. 0254-meter (1-inch) diameter were agreed upon in conferences between NASA and Technidyne personnel.

Design

The complete ultrasonic wrench (Fig. 3) consists of a frequency converter, junction box and wrench assembly.

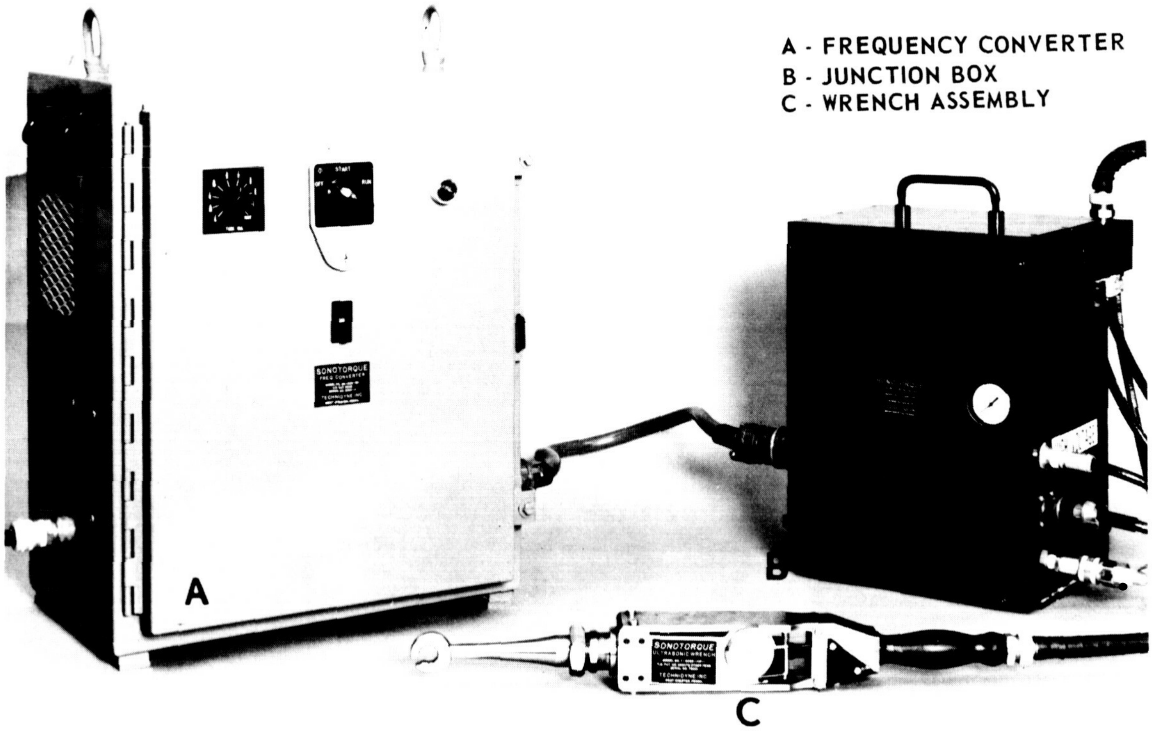


FIGURE 3. ULTRASONIC WRENCH

Frequency Converter. - Line power is converted to the design frequency of the system [in this case, 28 kilohertz (28 kc)] by a solid-state frequency converter in a standard NEMA-type switch box. This device incorporates a power selector, calibrated in terms of tubing diameter, and a solid-state timer to provide a three-second (fixed time) power pulse.

Two interchangeable cables, 0.6096 meter (2 feet) and 16.76 meters (55 feet) long, transmit power and control signals from the frequency converter to the junction box. The cables are encased in lightweight rubber-covered metallic flexible tubing, which also carries cooling air to the transducer.

Junction Box. - The junction box contains an impedance-matching network, transformer, inductance coil, overvoltage spark gap, cooling air regulator and air pressure gage. A safety interlock assures that high voltage cannot be applied to the transducer if the front panel is removed.

Wrench Assembly. - The wrench assembly incorporates a ceramic transducer (lead zirconate titanate), which delivers from 70 to 85 percent of the high-frequency input electrical power as vibratory power into an acoustical calorimeter ("resistive load"). The 28 kilohertz transducer is nominally rated at 300 watts (input) continuous duty and 500 watts (input) pulse duty (3 seconds on, 3 seconds off). A force-insensitive mount brazed to the transducer-coupling system minimizes loss of vibratory energy to the torque wrench beams and indicating mechanism.

The wrench assembly is provided with a standard dial indicator, calibrated in inch-pounds of torque. Acoustically designed 12-point, open-end wrench heads for each size fitting are mechanically interchangeable by means of a precision acoustical junction.

The complete wrench assembly with a wrench head in place weighs approximately 5 kilograms (11 pounds).

Operation

Use of the wrench assembly to tighten a flared tubing connection is illustrated in Figure 4. The operator tightens the nut to the indicated specification

FIGURE 4. TIGHTENING FLARED TUBING CONNECTION WITH ULTRASONIC WRENCH

torque level; he then depresses the thumb switch, exciting the ultrasonic system to the preset power level. During the fixed three-second pulse time, the operator maintains the desired torque level as the ultrasonically induced additional rotation occurs.

PERFORMANCE OF ULTRASONIC WRENCH

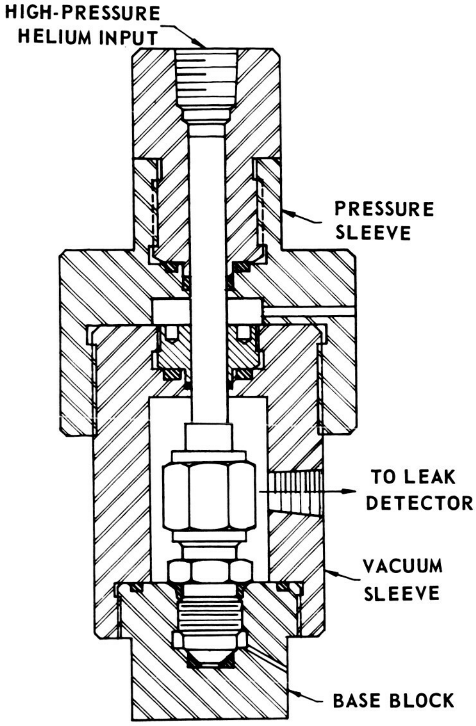
The effectiveness of the ultrasonic wrench in producing leaktight flared tubing connections between MC components was evaluated by comparing leak test results of assemblies tightened with the ultrasonic wrench and control assemblies tightened without ultrasonics. Breakaway torques were also compared.

The same representative connections, 0.00635-meter (0.25-inch) aluminum and 0.0127-meter (0.5-inch) stainless steel, used in this evaluation were used in the development of design criteria. However, components in this evaluation included MC unions as well as MC flared tubes, coupling nuts and sleeves, whereas in the earlier work commercial unions were used with MC tubes, coupling nuts and sleeves. Aluminum assemblies, both ultrasonic and control, were tightened at torque levels from 7.91 to 15.82 joules (70 to 140 inch-pounds); stainless steel assemblies were tightened at torque levels of 50.84 and 56.49 joules (450 and 500 inch-pounds). Ultrasonic pulse time was the fixed interval (3 seconds) provided by the ultrasonic wrench; ultrasonic power was set at 50 watts for 0.00635-meter (0.25-inch) aluminum tubing and 150 watts for 0.0127-meter (0.5-inch) stainless steel.

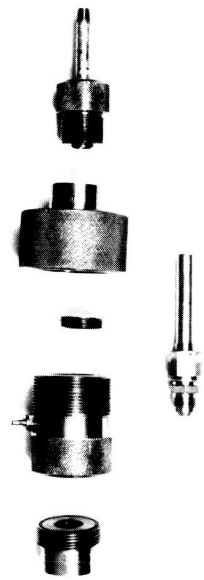
After leak test, most assemblies were disassembled (non-ultrasonically) for comparison of breakaway torque values.

Helium Leak Test

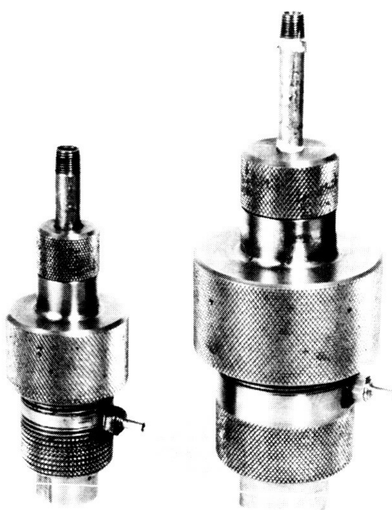
Assemblies made under the various conditions were helium leak-tested at pressures of zero, 68×10^5 newtons per square meter (1000 pounds per square inch), and 20×10^6 newtons per square meter (3000 pounds per square inch). Leak rate was measured with a mass spectrometer having a calibrated test sensitivity of 10^{-8} cubic centimeters of helium per second. Adapter fixtures were designed to permit application of controlled internal pressure up to 24×10^6 newtons per square meter (3500 pounds per square inch) to the assemblies, together with vacuum leak detection on the exposed surfaces. Figure 5 shows a



A. PRESSURE FIXTURE DESIGN



B. PRESSURE FIXTURE DISASSEMBLED



C. PRESSURE FIXTURES FOR 0.006635 METER (1/4-INCH)
AND 0.0127 METER (1/2-INCH) TUBING

FIGURE 5. PRESSURE FIXTURE FOR HELIUM LEAK TEST

cross-sectional sketch of the pressure fixture design and photographs of the fixtures for 0.00635-meter (0.25-inch) and 0.0127-meter (0.5-inch) tubing.

Table VI summarizes leak test results without reference to torque level. All assemblies were helium leaktight without pressure. An increasing number of both ultrasonic and control assemblies leaked at increasing pressure. However, a significantly greater precentage of ultrasonic assemblies were leaktight at both 68×10^5 newtons per square meter (1000 pounds per square inch) and 20×10^6 newtons per square meter (3000 pounds per square inch).

Average additional rotation by ultrasonics (Table VII) was a few degrees above the 2 to 5 degrees associated with leaktight assemblies made with commercial unions in the earlier work.

Because more of these assemblies leaked than was expected on the basis of previous leak test results at the lower test pressure of 24×10^5 newtons per square meter (350 pounds per square inch) helium, six aluminum assemblies were made with commercial unions remaining from the preliminary work (Table VIII). These six assemblies were leaktight up to 20×10^6 newtons per square meter (3000 pounds per square inch).

Breakaway Torque

To evaluate any possible effect of ultrasonic wrenching on long-term sealing characteristics, most assemblies were disassembled (without ultrasonics) and breakaway torques measured. Table IX presents average breakaway torques for ultrasonic and control assemblies. The breakaway torque for one stainless steel assembly tightened at 56.49 joules (500 inch-pounds) was 11.30 joules (100 inch-pounds) above the next value and thus pulled up the average. If this value is discounted, ultrasonically assembled units show generally higher breakaway torque values. Thus, less relief should occur with ultrasonically tightened flared tubing connections.

METALLOGRAPHIC EXAMINATION*

Joint Mechanics

Because almost all assemblies made during preliminary work with commercial unions (other components, MC) were leaktight, although at relatively

* Metallographic examinations were carried out at MSFC and at Technidyne.

TABLE VI

SUMMARY OF LEAK TEST RESULTS - MC COMPONENTS*

Tubing	Method of Tightening	Test Pressure, n/m^2 (psi)	No. of Assemblies Tested	No. of Assemblies Leaktight**	Percent Leaktight
0.00635-meter (0.25-Inch) Aluminum	Non-Ultrasonic	0	30	30	100
		68×10^5 (1000)	20	3	15
		20×10^6 (3000)	30	2	6.7
	Ultrasonic (50 w, 3 sec)	0	18	18	100
		68×10^5 (1000)	18	9	50
		20×10^6 (3000)	18	8	44.5
0.0127-meter (0.5-Inch) Stainless Steel	Non-Ultrasonic	0	21	21	100
		68×10^5 (1000)	21	7	33
		20×10^6 (3000)	21	5	24
	Ultrasonic (150 w, 3 sec)	0	23	23	100
		68×10^5 (1000)	23	13	57
		20×10^6 (3000)	23	7	30

* Torque levels were 7.91-15.82 joules (70-140 inch-pounds) for 0.00635-meter (0.25-inch) aluminum and 50.84-56.49 joules (450-500 inch-pounds) (0.5-inch) stainless steel.

** Test sensitivity: 10^{-8} cubic centimeters helium per second

low pressure, metallographic examinations were made to observe possible reasons for the different leak test results obtained with MC unions. This work, carried out at MSFC, involved nine aluminum assemblies made in evaluation of the ultrasonic wrench, four with commercial unions and five with MC unions. The assemblies were mounted in plastic and sectioned. TUKON microhardness measurements showed that the MC sleeve and MC union were harder than the flare of the MC tube, but the commercial union was softer than the flare.

Figure 6 shows a comparison of a leaktight assembly made with a commercial union and a leaking assembly made with an MC union. Both assemblies

TABLE VII

ADDITIONAL ROTATION FOR LEAKTIGHT CONNECTIONS - MC COMPONENTS

Tubing	Torque, joules (in. -lb)	Test Pressure n/m^2 (psi)	No. of Assemblies Tested	No. of Assemblies Leaktight*	Avg Additional Rotation of Leaktight Assemblies, degrees
0.00635-Meter (0.25-Inch) Aluminum	7.91 (70)	0	1	1	15.0
		68×10^5 (1000)		0	
		20×10^6 (3000)		0	
	13.56 (120)	0	13	13	7.1
		68×10^5 (1000)		7	3.7
		20×10^6 (3000)		7	3.7
	15.82 (140)	0	4	4	6.2
		68×10^5 (1000)		2	6.0
		20×10^6 (3000)		1	3.0
0.0127-Meter (0.5-Inch) Stainless Steel	50.84 (450)	0	9	9	9.6
		68×10^5 (1000)		6	8.5
		20×10^6 (3000)		3	14.0
	56.49 (500)	0	14	14	6.3
		68×10^5 (1000)		7	4.7
		20×10^6 (3000)		4	4.6

* Test sensitivity: 10^{-8} cubic centimeters helium per second

TABLE VIII

LEAK TEST RESULTS FOR 0.00635-METER (0.25-INCH) ALUMINUM CONNECTIONS MADE WITH COMMERCIAL UNIONS

MC Flared Tubes, Nuts and Sleeves

Method of Tightening	Torque, joules (in. -lb)	Leak Rate (10^{-8} cc/sec) at Test Pressure of 0	68×10^5 n/m^2 (1000 psi)	20×10^6 n/m^2 (3000 psi)
Non-Ultrasonic	7.91 (70)	None	None	None
Ultrasonic (50 w, 3 sec)	7.91 (70)	None	None	None
	7.91 (70)	None	None	None
	13.56 (120)	None	None	None
	13.56 (120)	None	None	None

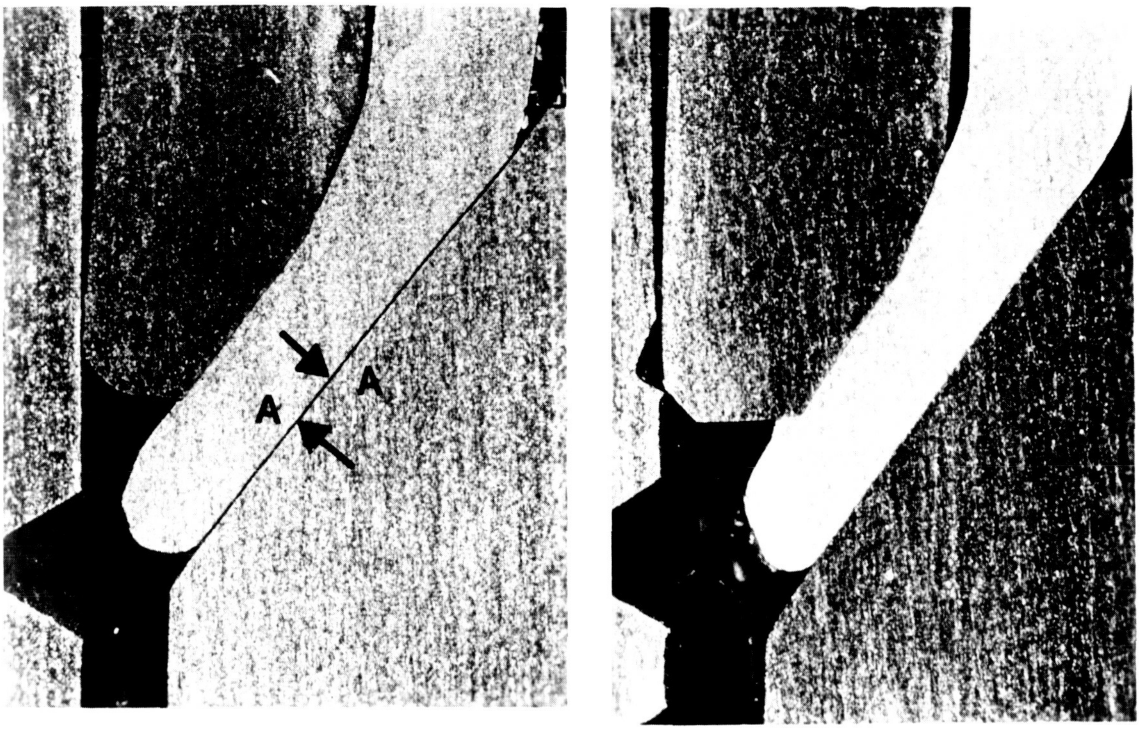
TABLE IX

BREAKAWAY TORQUES

MC Components

Tubing	Method of Tightening	Torque, joule (in. -lb)	No. of Assemblies Tested	Avg Breakaway Torque, joule (in. -lb)
0. 00635-Meter (0. 25-Inch) Aluminum	Non-Ultrasonic	7. 91 (70)	1	4. 51 (40)
		11. 29 (100)	9	7. 23 (64)
		13. 56 (120)	4	
		15. 82 (140)	16	9. 94 (88)
	Ultrasonic (50 w, 3 sec)	7. 91 (70)	1	4. 51 (40)
		13. 56 (120)	13	12. 08 (107)
		15. 82 (140)	5	14. 01 (124)
0. 0127-Meter (0. 5-Inch) Stainless Steel	Non-Ultrasonic	50. 84 (450)	11	45. 41 (402)
		56. 49 (500)	10	53. 55 (474)
	Ultrasonic (150 w, 3 sec)	50. 84 (450)	9	52. 65 (466)
		56. 49 (500)	14	52. 76 (467)

had been tightened at the same torque level 13. 56 joules (120 inch-pounds) with the ultrasonic wrench (at 50 watts, 3 seconds). The commercial union, being the softest component in the assembly, is slightly deformed at the inside tip, while the inside wall of the MC union is not disturbed. In the assembly made with the MC union, the sleeve has penetrated into the back of the flare. This condition is typical of the other assemblies made with MC unions observed at MSFC (and may account for the greater additional rotation associated with leak-tight assemblies made with commercial unions). It was concluded that when the union is softer than the flare, the union yields and permits a greater contact area between the sealing surfaces of the flare and union. When the union is harder than the flare, line contact is made between the flare and union opposite the point of penetration of the sleeve, and extended intimate contact between the sealing surfaces does not occur.



A. COMMERCIAL UNION
LEAKTIGHT CONNECTION
SAMPLE 223

B. MC106 UNION
LEAKING CONNECTION
SAMPLE 116

FIGURE 6. PHOTOMICROGRAPHS OF 0.00635-METER (0.25-INCH) ALUMINUM FLARED TUBING CONNECTIONS
(Torque Level: 13.56 Joules, 120 Inch-Pounds; Ultrasonic Power: 50 watts)

The dark line between the union and tube flare (A-A) in the photograph at the left in Figure 6 may be caused by the separation that occurred on relief of compressive stress. Such relief is likely to occur when flared tubing connections are sectioned unless the plastic mounting is braced with a metal band. Separation cannot have existed before sectioning because the connection did not leak. The dark line could also represent the relatively thick annodized coating typical of the commercial unions. This coating was measured microscopically with a calibrated eyepiece and found to be approximately 0.0000127-meter (0.0005-inch) thick.

Effect of Ultrasonics on Material Properties

Metallographic studies were carried out at Technidyne to observe any decrease in the thickness of the flare or increase in its hardness. Measurements of thickness and microhardness were made on flares of selected assemblies from the preliminary work. These assemblies had been made with MC flared tubing and commercial unions under varying conditions of ultrasonic power level and repeat assembly. The data indicated a slight thickness deformation of the steel and a slight hardness increase for both materials with repeat ultrasonic assembly at higher power levels. Although measurements were insufficient to permit reliable conclusions, no adverse effect on performance was expected. Moreover, the helium leak test at 24×10^5 newtons per square meter (350 pounds per square inch) showed equal performance of repeat assemblies except at excessive power levels (Tables IV and V). Greater thickness deformation of the flare would obviously occur in assemblies made with MC unions because of penetration of the sleeve into the back of the flare.

CONCLUSIONS

The application of high intensity vibratory energy to flared tubing connections during tightening at constant torque provides additional relative rotation of the nut with respect to the union, almost certainly increasing compressive stresses between the union bevel and tube flare, as evidenced by the slight work-hardening observed in the metallurgical study. Evaluation of the ultrasonic wrench designed for this purpose showed that the application of ultrasonic energy under properly controlled conditions at a satisfactory power level and pulse time increased the probability of a leaktight connection between MC components.

Where ultrasonic wrenching caused close contact between the sealing surfaces of the flare and union, as in assemblies made with commercial unions, some of the ultrasonic energy apparently acted to provide local deformation, probably of the softer union. Repeat ultrasonic wrenching (at the same power and torque levels) of assemblies made with commercial unions resulted in less additional rotation than occurred on initial assembly, suggesting that local yielding associated with ultrasonic metal-working had resulted in a better "fit" between the components.

Most of the ultrasonic energy probably produced friction reduction, as may be inferred from the fact that about the same power density per square inch of tube flare was required to provide a leaktight connection for the 0.00635-meter (0.25-inch) aluminum and 0.0127-meter (0.5-inch) steel, which have very different yield strengths.

NASA TM X-53550 APPROVAL

DEVELOPMENT OF ULTRASONIC WRENCH
FOR FLARED TUBING CONNECTIONS, VOLUME I

By Herman T. Blaise and Nicholas Maropis

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

W. A. Wilson

W. A. WILSON
Chief, Methods Development Branch

J. P. ORR
Chief, Manufacturing Research and
Technology Division

for

W. R. KUERS
Director, Manufacturing Engineering Laboratory

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Technidyne Incorporated (25)
West Chester, Pennsylvania 19380
Attn: Mr. N. Maropis

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