Mechanical, Electrical, and Environmental Evaluation of Nano-Miniature Connectors

Federal Manufacturing & Technologies

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MECHANICAL, ELECTRICAL, AND ENVIRONMENTAL EVALUATION OF NANO-MINIATURE CONNECTORS

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Published July 2001

Final Report

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Abstract

Because of their small size (0.025-inch spacing), nano-miniature connectors have been chosen for JTA telemetry applications. At the time they were chosen, extensive testing had not been done to determine the mechanical, electrical, and environmental characteristics of these connectors at the levels required for use by weapon systems. Since nano-miniature connectors use some unique plating and wire crimping processes not used in most design agency connectors, it was decided that these properties should be tested thoroughly. This report describes the results of that testing.

Summary

Sandia National Laboratory personnel reviewed various connector specifications including MIL-PRF-83513, DESC 94031 and Nanonics specification N10138 to determine appropriate mechanical, electrical, and environmental requirements for nano-connectors in weapon systems. Actual testing was performed by Honeywell Federal Manufacturing & Technologies (FM&T). Additional fretting corrosion testing was performed by Sandia National Laboratory in conjunction with New Mexico State University.

Testing was performed on both rectangular and circular style nano-miniature connectors. Several of the tests performed in this evaluation were performed at higher levels than used during the original commercial qualification done by Nanonics Corporation who manufactured the connectors tested. On tests where the levels were about the same, this evaluation confirmed Nanonic's results. However, on tests with higher standards, some failures were encountered.

Failures were observed in four main areas. They were chatter during vibration and shock, contact retention/crimp strength, uneven thickness and porosity in gold plating, and high contact resistance due to fretting corrosion. Chatter exceeding one microsecond duration was observed in all axes during shock

testing. A total of six wires pulled out of the connectors with a five-pound axial pull.

Nickel plating was found to be in the 10 – 20 microinch thickness range while gold was in the 35 – 50 microinch thickness range. However, gold thickness was found to be uneven and porous. This condition may have caused poor fretting corrosion results that sometimes caused contact resistance to go into the kilohm range after a few million fretting cycles.

Additional testing on fretting included the effect of commercial lubricants on fretting corrosion. This study showed that fretting corrosion on nano-miniature connectors could be eliminated with the use of some commercial lubricants.

Discussion

Scope and Purpose

Since electronic packaging is becoming increasingly smaller, there is a definite need for electrical connectors to also be reduced in size to be more proportional to the size of advanced electronic components. Nano-miniature connectors with a pitch spacing of 0.025 inch are an attractive potential solution to this problem for interconnections. However, only a few companies make this size of connector line, and currently none are qualified to deliver this type of connector for weapon use.

A survey of nano-miniature connectors was performed for Sandia National Laboratories in 1997. As a result of this survey, connectors manufactured by Nanonics in Phoenix, Arizona, were selected for use in JTA telemetry applications. The project group requested that additional evaluation be done on this line of connectors to see if they could be qualified for weapon use.

Nanonics specification (N10138) was compared at Sandia against other miniature connector specifications including DESC 94031, MIL-PRF-83513, and SA3565 (MDM connector) product specification PS411426. From this, proposed testing was based on MIL-PRF-83513 with modifications to cover Sandia's requirements for JTA applications. It was determined that visual, mechanical, electrical, and environmental testing of the connectors would be performed by Honeywell Federal Manufacturing & Technologies (FM&T). Fretting studies of the connectors were assigned to Sandia and New Mexico State University.

Two types of nano-miniature connectors were selected for evaluation at Honeywell FM&T to be representative of the connectors that might be used in future applications. The first was a two-row rectangular Dualobe connector with 51 pins in the plug and 51 sockets in the receptacle. The second was a circular connector with 44 pins in the plug and 44 sockets in the receptacle. Six mating pairs of each type were used for the majority of testing. Additional samples of each type were used for plating samples and fretting studies. (A third type of connector was initially selected for evaluation. It was the same as the rectangular connectors that were tested, except that the 51-socket connector had PC terminations instead of wire terminations. Testing on this configuration was abandoned based on similarity with the other 51-pin connectors and cost and time considerations.)

Prior Work

Results of fretting studies on nano-miniature connectors (Group V testing in this report) have been completed and are reported in a paper by Dr. James T. Hanlon and Dr. Neil R. Aukland entitled *MIL-L-87177 and a Commercial Lubricant Improve Electrical Connector Fretting Corrosion Behavior*.¹

Activity

Description of Testing Performed

Table 1 shows tests performed and the order in which they were performed for each group. Six mated pairs of each of the two types of nano-connectors were subjected to Group I testing summarized below. These mated pairs were subdivided into two smaller groups for Groups II and III testing. Groups IV and V tests used separate samples. In the Group I testing description below, two columns indicates that parts were unmated for that test, while one column indicates that they were mated during testing.

Table 1. Tests Performed

Group I Testing

Sockets Pins

Visual & Mechanical Visual & Mechanical

Contact Engage/Separate

Mount connectors on boards

Mate Parts

DWV Sea level

DWV 70K feet

Insulation Resistance

Contact Resistance (Low signal)

Temperature cycle

Humidity

Unmate connectors

Remove moisture

Mate connectors

DWV Sea level (within 2 hours)

IR (Within 2 hours)

IR after 24 hours

Contact Resistance (post humidity)

Vibration

Shock (2 pairs only)

DWV Sea level

Insulation Resistance

Contact Resistance (post vibration & shock)

Unmate Parts

Visual and Mechanical Visual and Mechanical

Durability Durability

Mate Parts

Contact Resistance

Unmate Parts

Parts may be removed from boards for remainder of testing

Remove Jackposts or coupling ring

Mating/Unmating Mating/Unmating

Visual and Mechanical Visual and Mechanical

Group II Group III

Mated Pair 1 – 3 Mated Pair 4 – 6

Contact Retention /Crimp Strength Insert Retention

Visual & Mechanical Visual & Mechanical

Other samples used for the following tests

Group IV Group V

Plating Thickness Fretting

Detailed descriptions of the testing instructions for each of the tests performed are provided in Table 2 below:

Table 2. Definition of Test Conditions

GROUP I (6 MATED
PAIRS)

TEST	INSTRUCTIONS FOR TESTING
Visual and Mechanical	Inspect connectors for damage and for conformance to vendor drawings
Contact engage/separation	Measure engagement/withdrawal forces per MIL-STD-1344, method 2014, with 0.0128 +/- 0.0001 diameter pin on 20% of contacts but not less than 7 socket contacts in each connector. Insert and withdrawal test pin 3 times. On third cycle, measure engage and withdrawal force. Mount the connector half containing socket contact in a fixture to secure body and insert gage pin using device to gradually apply axial force. Measure force with push-pull type force gage. Do not bottom out gage pin in socket.
DWV (Sea level and 70K ft)	Mated connectors tested per MIL-STD-1344, method 3001. The test voltage shall be applied between each individual contact and all other contacts tied in common to the shell. The voltage shall be applied at approximately 500 V/s and held for a minimum of 5 seconds. Test voltage: 400 Vrms (sea level) 80 Vrms (70K ft) 200 Vrms (post humidity).
Insulation Resistance (IR)	Mated connectors tested per Mil-STD-1344, method 3003. The test voltage shall be applied between each individual contact and all other contacts tied in common to the shell. Test Voltage: 500 +/- Vdc normal condition and 100 +/- Vdc post humidity.
Contact Resistance (CR) low signal	On mated connector pairs, measure resistance across all contacts using a 4-wire contact resistance setup (100mA short circuit, 20mV open circuit). Measurements shall be made at contact termination points or at the ends of pigtail wires and have the wire resistance subtracted and the data recorded.
Temperature Cycling	Expose mated pairs to temperature cycles of -65C to +125C per MIL-STD-1344, method 1003, condition A (5 cycles w/1 hour soak

and 5 min transition).

Humidity Fully wired and mated connectors shall be tested per MIL-STD-1344, method 1002, type II with the following exceptions:

A: Upon completion of step 6 of the final cycle, connectors shall be removed from the chamber, unmated, and surface moisture removed from the inserts. Immediately following removal of surface moisture, DWV test (sea level) and IR test shall be performed within 2 hours.
B: After the 24 hour conditioning period, the IR shall again be measured as specified in the IR test normal condition.

Vibration Mount mated connector pairs to specified fixture and secure pigtail wires to prevent whipping and resonance. Final fixturing shall be approved by the DA prior to testing. The receptacle shall be mounted to the fixture as intended in normal use (e.g., mounting screws for rectangular connectors and locking nut with bulkhead connectors.) Plugs shall be engaged with the receptacles and held by normal means. All contacts shall be wired to monitor discontinuity of signal (chatter) with equipment capable of detecting a 1 microsecond discontinuity. The connectors shall be subjected to random vibration as specified in Appendix A in each of 3 axes.

Shock Mount mated connector pairs to specified fixture and secure pigtail wires to prevent whipping and resonance. Final fixturing shall be approved by the DA prior to testing. The receptacle shall be mounted to the fixture as intended in normal use (e.g., mounting screws for rectangular connectors and locking nut with bulkhead connectors.) Plugs shall be engaged with the receptacles and held by normal means. All contacts shall be wired to monitor discontinuity of signal (chatter) with equipment capable of detecting a 1 microsecond discontinuity. The connectors shall be subjected to shocks as specified Appendix A in each of 3 axes.

Mating/Unmating Measure the maximum forces required to mate and unmate paired connectors per MIL-STD-1344, method 2013. Connectors shall be rigidly fixtured to permit mating and unmating of the counterpart connectors and to measure the axial force in both directions. Axial load shall be gradually applied until plug and receptacle are fully mated. Then force shall be applied to completely separate the connectors.

Durability Counterpart connectors shall be mated and unmated 500 times at a rate of 200 +/- 100 cycles per hour in a manner to simulate actual service.

GROUP II (half of samples)

TEST

INSTRUCTIONS FOR TESTING

Contact Retention

Apply axial load to pigtail at the rate of 1 lb/sec and maintain max load of 5 lbs for 5 seconds minimum per method 2007 of MIL-STD-1344. Wire breakage outside of connector is not a failure. Test 50% of contacts per connector.

Crimp Strength

Testing per Contact Retention test is sufficient for installed contacts.

Visual and Mechanical

See Group I testing.

GROUP III (half of samples)

TEST

INSTRUCTIONS FOR TESTING

Insert Retention

Apply 50 psig air pressure or equivalent load to front face of connector at the rate of 10 psig/sec and hold for 5 seconds minimum.

Visual and Mechanical

See Group I testing.

GROUP IV (1 untested pair)

TEST

INSTRUCTIONS FOR TESTING

Plating Thickness

Determine thickness of gold and nickel plating on pin contacts and inner surface of socket contacts along mating surfaces using optical metallography.

GROUP V (4 untested pairs)

TEST

INSTRUCTIONS FOR TESTING

Fretting

Perform evaluation of fretting characteristics as noted in statement of work with NMSU, Advanced Interconnection Lab. (This work is summarized in the document, "MIL-L-87177 AND A COMMERCIAL LUBRICANT IMPROVE ELECTRICAL CONNECTOR FRETTING CORROSION BEHAVIOR" by Dr. James T. Hanlon and Dr. Neil R. Aukland.)

Nanonics Qualification Test Requirements

Several of the qualification tests used during this evaluation are more stringent than the qualification tests that were used by Nanonics Corporation to qualify their connectors. For the purposes of comparison, Table 3 lists the qualification standards that were used and have been published by Nanonics. Only tests that were similar to ones being conducted in this evaluation are listed.

Table 3. Nanonic's Qualification Test Summary

TEST	REQUIREMENT	MIL-C-83513 TEST METHOD/CRITERIA
Dielectric Withstanding Voltage	No dielectric breakdown; 1 minute duration at high potential	Para. 4.7.5; MIL-STD-1344, Method 3001, Sea level: 400 VAC; 70K ft: 80 VAC
Insulation Resistance	1,000 megohms minimum	Para. 4.7.6; MIL-STD-1344, Method 3003, Voltage: 500 VDC
Contact Resistance	70 milliohms max.	Para. 4.7.7; MIL-STD-1344, Method 3004. Current 1.0A: Wire: 30 AWG, stranded (7/38)
Contact Engagement/ Separation Force	Engagement: 4.0 Oz. Max. Separation: 0.2 Oz. Min.	Para. 4.7.8 0.0128 dia. Pin
Connector Mate/Unmate Force	19.125 Lbs. Max.	Para. 4.7.3 6 Oz. Max times qty of contacts/connector (51)
Temperature Cycling	No Physical Damage	Para. 4.7.9; MIL-STD-1344, Method 1003, 5 cycles, -55C to +125C.
Humidity	No dielectric breakdown at 200 VAC; Insulation Resistance: 100 megohms minimum.	Para. 4.7.10, MIL-STD-1344, Method 1002, type II, 240 hours, omit step 7a.
Vibration	No physical damage or electrical discontinuity greater than 1 sec.	Para. 4.7.13; MIL-STD-1344, Method 2005, condition IV. 20 G's, 10 - 2000 Hz, 12 hrs.
Shock	No physical damage or electrical discontinuity greater than 1 sec.	Para. 4.7.14; MIL-STD-1344, Method 2004, Condition E. 50G's, 3 Axes, 11 msec duration (6 shocks, total)
Durability	No physical damage; no mechanical/electrical degradation	Para. 4.7.15; 500 mate/unmate cycles
Low Signal level Contact Resistance	70 milliohms max.	Para. 4.7.20; MIL-STD-1344, Method 3002. Voltage: 20 mV, Current: 100 mA.
Contact Retention	No contact displacement	Para. 4.7.4; MIL-STD-1344, Method 2007. Axial Load: 3 Lbs Min.
Insert Retention	No Insert displacement	Para. 4.7.18; MIL-STD-1344, Axial Load: 50 psig

Crimp Tensile
Strength

No wire breakage in crimp area
or wire pullout.

Para. 4.7.19; Load: 1.94 Lbs, min. Wire:
MIL-W-22759/33, 30 AWG, Stranded
(7/38)

Summary of Connectors Tested and Overview of Results

Six mating parts of the 51-pin Duallobe rectangular connectors and six of the 44-pin circular connectors were used for Groups I, II, and III testing. Examples of the 51-pin rectangular nano-miniature connectors are shown in Figure 1.

Figure 1. 51-Pin Duallobe Rectangular Connectors

Examples of the 44-pin Nanonics circular nano-miniature connectors are shown in Figure 2.

Figure 2. 44-Pin Circular Connectors

A picture of a cross-sectioned 51-pin mated pair of connectors is shown in Figure 3 to better show how the contacts of these connectors mate. Sockets are cylindrical metal tubes that have a large indentation in the middle to separate the receptacle end of the contact from the end in which wire terminations are crimped. These features are clearly visible in the photograph. There is also a smaller indentation in the socket contact near the mouth of the socket contacts. This provides friction between the pin and socket to make electrical contact. This feature is not clearly visible in the photograph because it forms a very shallow dimple on only one side of the contact. The pins are also hollow tubes which have been formed to look like hemispherically tipped pins on one end. A couple of the pins in the photograph have been cut to show that they are hollow.

Figure 3. Cross Section of 51-Pin Mated Pair of Connectors

A tabulation of all of the tests that were performed is shown in Table 4. In this table, all tests that passed are color-coded green. Anything that had results that were significantly different from other results but were not considered failures is color-coded yellow. Anything that was considered a failure is color-coded red. A detailed description of these results follows in the next section.

Table 4. Overview of Results

NANONICS CONNECTOR TESTING OVERVIEW OF RESULTS			
TEST DESCRIPTION	51 DUALOBE	44 CIRCULAR	51 DUALOBE PC
<hr/>			

Visual & Mechanical (Sockets)	PASSED	PASSED	PASSED
Visual & Mechanical (Pins)	PASSED	PASSED	PASSED
Engage/Separate Forces (Sockets)	LOW FORCES	PASSED	PASSED
Mate connectors	PERFORMED	PERFORMED	STOPPED
DWV Sea Level	PASSED	PASSED	
DWV High Altitude	PASSED	PASSED	
Insulation Resistance	PASSED	PASSED	
Contact Resistance	PASSED	PASSED	
Temperature Cycling	PERFORMED	PERFORMED	
10 day Humidity testing	PERFORMED	PERFORMED	
DWV immediately after Humidity	PASSED	PASSED	
IR immediately after Humidity	PASSED	PASSED	
IR after 24 hour drying cycle	2 PINS FAIL	PASSED	
Post humidity contact resistance	PASSED	PASSED	
Vibration	2 of 6 FAIL	PASSED	
Shock	2 TESTED, 2 FAIL	2 TESTED, 2 FAIL	
Post Shock DWV at Sea Level	2 PINS FAIL	PASSED	
Post Shock Insulation Resistance	2 PINS FAIL	PASSED	
Post Shock contact resistance	PASSED	PASSED	
Unmate Parts	PERFORMED	PERFORMED	
Visual & Mechanical (Sockets)	PASSED	PASSED	
Visual & Mechanical (Pins)	PASSED	PASSED	
Durability	PERFORMED	PERFORMED	
Mate connectors	PERFORMED	PERFORMED	
Post durability contact resistance	PASSED	PASSED	
Remove jackposts/coupling nut	PERFORMED	PERFORMED	
Post durability mating/unmating	PASSED	PASSED	
Visual & Mechanical (Sockets)	PASSED	PASSED	
Visual & Mechanical (Pins)	PASSED	PASSED	
Group II			
Contact Retention/Crimp Strength	FAILED	PASSED	
Visual & Mechanical	PASSED	PASSED	
Group III			
Insert Retention	PASSED	PASSED	
Visual & Mechanical	PASSED	PASSED	
Group IV			
Plating Thickness	FAILED	FAILED	FAILED

Group V

Fretting

FAILED

FAILED

N/A

Group I Testing

The details of each test are discussed in the following narrative. Since most of the tests passed and were very similar for both rectangular and circular connectors, they will be discussed only once. If discrepancies occurred on only one type of connector, that will be noted.

Visual and Mechanical

All dimensions shown on the vendor drawings for each connector were measured. Connectors were also inspected for workmanship. In all cases, connectors were found to be in tolerance and exhibit superior workmanship. This inspection was repeated after shock and again after durability testing. There was no visible degradation after shock. After durability, the threads on the circular connectors and the jackscrew threads on the rectangular connectors showed considerable wear. In some cases, the jackscrews broke during the 500 mating cycles. However, the pins and sockets showed no signs of degradation and all dimensions were still within tolerance.

Contact Engage/Separate

A 0.0128 +/- 0.0001-inch diameter steel pin was mounted on a digital force gage designed by Honeywell specifically for measuring engagement/withdrawal forces on connector sockets. A minimum of 20% of the sockets on each connector was randomly selected for measurement. Engagement force on the 51-socket connectors (PC mount) averaged 2.23 Oz. Separation force on these connectors averaged 1.78 Oz. Engagement force on the 44-socket connectors averaged 2.15 Oz and separation force averaged 1.67 Oz. These figures were almost identical to the results that were obtained by Trace Laboratories for Nanonic's own evaluation of the sockets.

However, the 51-socket connectors that had wire terminations had significantly lower results. The engagement force averaged 1.08 Oz and the separation force averaged 0.70 Oz. Some of the contacts in these connectors appeared to be from a different batch of slightly larger socket contacts than were on the other two sets. A minimum engagement/withdrawal force had not been specified, so these results were not considered to be failures. These average values do meet the qualification limits used by Nanonics as shown in Table 3.

DWV (Dielectric Withstanding Voltage) Sea Level

In order to do electrical testing on nano-miniature connectors, it was necessary to solder them to specially designed printed circuit boards to minimize the amount of handling of the 36 AWG wire that is used on the connectors. This allowed the use of larger diameter wire to be used to make connections to the electrical test equipment with less chance of breakage. Circular connectors were attached to identical boards. See Figure 4.

Figure 4. 51-Pin Mated Pair Attached to Printed Wiring Board

To perform DWV, the wires leading to the PC board were inserted into push pins inside a Honeywell safety switch box. The box was then hooked to an AC hipot tester. The switch box was designed so that it allowed 400 Vrms (sea level test) to be applied to each contact one at a time with all other contacts and the shell held in common. This allowed quick, accurate testing once all the wires were connected to the push pins.

The DWV sea level test was conducted three times on both the rectangular and circular connectors. It was performed as an initial test, then immediately after humidity, and finally after shock testing. Both types of connectors passed this test each time with one exception. After shock, S/N 6 of the rectangular connectors had two pins (49 and 50) fail DWV testing. This same failure had occurred previously during insulation resistance testing following humidity testing. This failure is discussed in more detail in the humidity test section and in Appendix B.

DWV (Dielectric Withstanding Voltage) High Altitude

This test is the same as the DWV sea level test except that the PC board with connector is placed inside a vacuum chamber. The wires hooked to the PC board were then run out through the wall of the chamber to the electrical test equipment. Pressure was reduced inside the chamber to an equivalent pressure of 70,000 feet altitude. Each contact was then tested against all other contacts and the shell at 80 Vrms. This test was performed only once on each connector. All connectors of both type passed this test.

Insulation Resistance

Insulation resistance is performed similarly to DWV testing. The wires on each PC board were connected to push pins on a Honeywell safety switch box. The box was then connected to a General Radio GR1864 megohmmeter. This arrangement allowed 500 VDC to be applied to each contact one at a time with all other contacts and the shell held in common. The insulation resistance measurement was taken and recorded after the voltage had been applied for 15 seconds.

This test was performed four times on each type of connector. It was performed as an initial test, then immediately after humidity testing (100 VDC), one day later after a 24-hour drying period, and finally after shock. Both types of connectors passed this test successfully each time with one exception. After the 24-hour drying period and again after shock, S/N 6 of the rectangular connectors had two pins (49 and 50) fail insulation resistance. This failure is discussed in more detail in the humidity test section and in Appendix B.

Except for the two pins that failed, insulation resistance on these connectors was very good. In most cases, they measured in the teraohm and gigaohm range, which is quite remarkable considering the spacing of the contacts. Figures 5 and 6 summarize the average insulation resistance measurements for the rectangular and circular connectors. The manufacturer advertises that the insulation resistance is 1000 megohms minimum (1 gigaohm minimum).

Figure 5. 51-Pin Insulation Resistance Averages

Figure 6. 44-Pin Insulation Resistance Averages

Contact Resistance

Contact resistance was performed using Honeywell's low signal contact resistance tester. This is a four-wire contact resistance tester which allows two wires to make contact with the wires on each side of a connector contact. The resistance of the 36 AWG wire was measured separately, then the length determined. This value was subtracted from the measured value to get the contact resistance.

Contact resistance was performed four times on each type of connector. It was performed as an initial test, post humidity, post shock, and post durability. There was no significant fluctuation in contact resistance from test to test. Figures 7 and 8 summarize the average contact resistance measurements for these connectors for each test.

Figure 7. 51-Pin Contact Resistance Averages

Figure 8. 44-Pin Contact Resistance Averages

Temperature Cycling

Mated pairs of connectors were subjected to 5 cycles of temperature cycling from -65°C to $+125^{\circ}\text{C}$ with a one-hour soak at each temperature and a five-minute transition time between temperatures. Temperature cycling was followed by the ten-day humidity test. Electrical end points for both of these tests were performed after that.

Ten-Day Humidity Testing

Mated pairs of connectors were put into a Blue M Electric automatic humidity chamber. The cycle was set in accordance with MIL-STD-1344, method 1002, type II. This caused the temperature in the chamber to cycle between $+25^{\circ}\text{C}$ and $+65^{\circ}\text{C}$ while the relative humidity ranged from 80% to 98%. Ten 24-hour cycles were performed.

At the conclusion of the humidity testing, connectors were removed one at a time so that they could be electrically tested within 2 hours of removal from the chamber. Excess moisture was wiped off of the connectors before they were subjected to DWV and IR testing. All connectors passed DWV and IR testing immediately following humidity testing.

Connectors were then allowed to dry in open air for a period of 24 hours. At the end of the drying period, all connectors were again tested for insulation resistance. All connectors passed this test with one exception. S/N 6 of the rectangular connectors on pins 49 and 50 appeared to be shorted when tested for insulation resistance. Additional evaluation with an ohmmeter indicated that a resistance of approximately 10.5 K ohms had developed between pins 49 and 50 of the mated pair. Later investigation

found that it was actually only on the socket side connector of S/N 6, pins 49 to 50. Since these pins had passed IR 24 hours earlier, it was concluded that the low resistance path developed between these two pins during the drying process.

S/N 6 mated pair was taken to a vacuum oven and baked out for two hours at 60°C. The resistance between pins 49 and 50 remained at 10.5 K ohm after this procedure. This condition remained in place for the remainder of the testing, causing additional electrical failures for these pins during post shock DWV and post shock insulation resistance. Over the next few months, the resistance value crept upwards from 10.5 K ohms to about 56 K ohms, but would not go away. After all prescribed testing was complete, S/N 6 was sent to failure analysis to try to determine what caused the low resistance path between pins 49 and 50. Results of the failure analysis are in Appendix B.

Vibration Testing

Six mated pairs of both rectangular and circular connectors were subjected to short, medium, and long duration random vibration in each of three axes. In order to be able to monitor contact chatter during the vibration tests, the PC boards were jumper-wired to create several individual circuits on each board. This allowed 6 to 9 contacts to be put into series for each chatter monitor channel rather than trying to monitor all contacts on one channel. The equipment did not have enough channels to monitor each contact individually. A discontinuity of more than one microsecond would cause the chatter monitor to alarm.

All connectors passed the random vibration testing with two exceptions. S/N 1 of the rectangular connectors failed chatter on pins 31 – 36 during short duration (26.6 Grms) testing in the Z axis. S/N 3 of the rectangular connectors failed chatter on pins 25 – 30 during short duration (26.6 Grms) testing in the X axis. Figure 9 shows two of the PC boards with 51-pin connectors attached as they were mounted in the vibration fixture on top of the vibration machine. The black wires go to the chatter monitor equipment. The same connector mounting scheme was also used for shock testing.

Figure 9. Two Mated Pairs Mounted on Vibration Equipment

Shock Testing

Shock testing proved to be the most difficult and most costly test to run. It was very difficult to get all wires secured tightly enough so that there would be no wire breakage during testing. Because of the time and money that this test took, the test was limited to two mating pairs of rectangular connectors and two mating pairs of circular connectors. S/N 1 and S/N 4 rectangular mated pairs were tested while S/N 2 and S/N 5 circular mated pairs were tested.

Shock testing consisted of three different shock pulses simulating low frequency, medium frequency, and high frequency shocks. Each shock was applied in each of three axes on both types of connectors. The shocks were haversine shocks with amplitudes of 3000 to 4000 g and different durations. Actual values are listed in Appendix A of this report. As in the vibration testing, groups of 6 to 9 contacts were wired in series and connected to a chatter monitor to detect discontinuities of one microsecond or more during the shock pulses.

Numerous chatter failures occurred on both types of connectors during shock testing. It was even discovered that side pressure on the back end of the circular connectors while they were sitting in their holding fixture was enough to trip the alarm on some chatter circuits. Table 5 shows a summary of the

chatter failures during shock testing.

Table 5. Shock Test Failures

SHOCK TEST CHATTER FAILURES

51 PIN CONNECTORS

S/N	SHOCK TEST	DIRECTION	CHATTER ON PIN NUMBERS:
1	4000 G	+Y	31 – 42
		+X	43 – 51
		+Z	37 – 51
	3800 G	+Y	37 – 51
		+Z	37 – 42
	3000 G	+X	37 – 42
		+Y	13 - 18, 25 - 51
		+Z	25 - 30, 37 - 51
		+X (REPEATED)	1 - 12, 37 - 51
4	4000 G	+Y	1 – 12, 13 – 18
	3000 G	+X	13 - 24, 43 - 51
		+Y	19 - 24, 37 - 42
		+X (REPEATED)	1 - 18, 25 - 30, 37 - 42

44 PIN CONNECTORS

S/N	SHOCK TEST	DIRECTION	CHATTER ON PIN NUMBERS:
2	4000 G	+X	13 - 18, 25 - 30, 37 - 44
		+Z	31 - 36
	3800 G	+X	13 - 18
		+Z	13 - 24, 31 - 36
	3000 G	+X	1 - 24, 31 - 36
		+Z	13 - 24, 31 - 36
5	4000 G	+X	1 – 44
		+Y	1 - 6, 19 – 44
		+Z	1 - 24, 37 - 44
	3800 G	+X	13 – 44
		+Y	1 - 6, 13 - 24, 31 - 44

3000 G	+Z	13 - 18, 25 - 30
	+X	7 - 44
	+Y	13 - 44
	+Z	1 - 44

Durability Testing

Since a contact resistance test was required after durability and because mating/unmating was required to be as close to actual mating conditions as possible, it was decided that durability would be performed by hand while parts were still connected to the PC boards. Each of the six mating parts of each type of connector was required to be mated and unmated 500 times.

For the rectangular connectors, the process involved using a 0.9-mm hex driver and alternating back and forth between the two jackscrews to slowly mate and unmate the connectors. The two samples (S/N 1 and S/N 4) that had undergone shock testing did not get tested for durability because the solder contacts on the board had been covered with RTV to keep the wires from breaking during shock. This would have made it impossible to do the post durability contact resistance test. Of the remaining four, all but one had at least one jackscrew head break off during the 500 cycles. The 500 cycles were then completed by mating the socket connector on the board with a new mating part with fresh jackscrews.

For the circular connectors, the process involved rotating the knurled nut with finger pressure to mate and unmate the connectors. As testing progressed, the friction in the external threads increased significantly. By the end of the 500 cycles, the friction was so bad that it was impossible to tell with certainty that parts were being fully mated. Unlike the rectangular parts, the circular parts do not have any reference point that indicates when full mating has occurred. On the rectangular parts, full mating is ensured if the front surfaces of the two connectors touch.

Because of ES&H (Environment, Safety and Health) concerns about repetitive motion injuries for inspectors, only one group of 100 cycles per day was permitted. To keep the testing going, several different inspectors did 100 cycles of the testing on the same day.

The threads on the circular connectors and the jackscrews on the rectangular connectors suffered most of the wear. They are not really designed to withstand more than about 100 mating cycles. Both the pin and socket contacts showed very little sign of wear after durability. The dimple inside the socket contacts was slightly discolored, but plating was still present. No wear could be detected on the pins. There was no significant change in contact resistance after durability testing. See Figures 7 and 8.

Group II Testing

Contact Retention/Crimp Strength

Three of the six mated pairs from Group I testing for each type of connector were selected for Group II testing. Connectors with as much remaining wire as possible were removed from the printed wiring boards and unmated. Individual wires from each of the connectors were clamped to a force gage and the connector was pulled in an axial direction with five pounds of force. The force was maintained for five

seconds minimum. Fifty percent of the wires on each connector were randomly selected to be pull tested.

Circular connectors were tested first. All wires tested on both the pin and socket connectors passed the test. Rectangular connectors were tested next. All wires tested on the socket contact connector passed the test with no problem. However, six wires pulled out of the pin contact rectangular connectors. On five of them, the wire pulled out with the contact still attached while the sixth pulled loose from the crimp. See Figure 10. At least one wire pulled out from each of the three pin contact connectors tested.

There were some cracks in the epoxy around the wires after this testing. Other than the wires that pulled out, there were no other signs of damage.

Figure 10. 51-Pin Nano-connector Contact Retention/Crimp Strength Failures

Group III Testing

Insert Retention Testing

Three of the six mated pairs of both rectangular and circular connectors from Group I testing were selected for Group III testing. Connectors were removed from the printed wiring boards with as much wire attached as possible. Connectors were clamped in place and the entire bundle of wires was pulled with a force of 50 pounds and held for 5 seconds minimum. No inserts were pulled out during this test on any of the connectors. Also, no individual wires were pulled out of the connectors while performing this test.

Group IV Testing

Plating Thickness

Nanonics Corporation has both pin and socket contacts made out of beryllium copper material. They are

extruded from flat stock that has already been plated with gold over nickel. This is a proprietary process. This process allows plating to be on both inside and outside surfaces since plating inside surfaces on these tiny contacts would be practically impossible if done after forming. The extrusion process will cause the original plating to be stretched as the contacts are formed. They advertise that the plating thickness of the gold and nickel on the finished contacts is 30 microinches.

Since contacts are identical in rectangular and circular connectors, five pins from a new rectangular connector and five sockets from a new circular connector were used for plating thickness measurements. Contacts were overplated with nickel and cross-sectioned. The nickel layer could not be detected visually as is common with cross-sectioning on contacts that were not extruded after plating. A nickel layer was detected and measured by X-ray.

A gold plating layer was detected visually. However, it varied in thickness and had breaks where no gold was visible. Measurements that were made were taken at the thickest points. A summary of these results is shown in Table 6. In general, nickel thickness was 10 – 16 microinches and gold was 35 – 48 microinches. Breaks in the plating may have been caused by the extrusion process. They may also account for the poor fretting performance discovered in Group V testing.

Table 6. Gold and Nickel Plating Thickness Data

SUMMARY OF NICKEL AND GOLD PLATING THICKNESS DATA

NANONICS PINS	(MICROINCHES)					
PLATING	#1	#2	#3	#4	#5	AVERAGE
NICKEL	12.6	14.3	9.7	4.9	12.4	10.78
GOLD	39	70.1	39.3	20.5	33.3	40.44

(GOLD MEASUREMENTS WERE TAKEN IN THICKEST AREAS OF EACH PIN)

(NICKEL WAS NOT VISIBLE EXCEPT WITH X-RAY)

NANONICS SOCKETS (MICROINCHES)

INSIDE

SURFACE

PLATING	#1	#2	#3	#4	#5	AVERAGE
NICKEL	9.7	19.8	17.1	15.5	19.5	16.32
GOLD	48.8	47.6	55.1	48.4	38.2	47.62

OUTSIDE SURFACE

PLATING	#1	#2	#3	#4	#5	AVERAGE
NICKEL	15.5	11.9	13.3	14.2	16.6	14.3
GOLD	44.9	24.3	50.1	17.4	39.98	35.34

(GOLD MEASUREMENTS WERE TAKEN IN THICKEST AREAS OF EACH PIN)

(NICKEL WAS NOT VISIBLE EXCEPT WITH X-RAY)

Group V Testing

Fretting Study

The fretting portion of this evaluation was performed by Dr. James T. Hanlon of Sandia National Laboratory and Dr. Neil R. Aukland of New Mexico State University. They have presented their results in a paper entitled *MIL-L-87177 and a Commercial Lubricant Improve Electrical Connector Fretting Corrosion Behavior*.¹

In summary, this portion of the evaluation was performed on a different set of samples from those used in Group I through Group IV testing using equipment developed at New Mexico State University. After conducting the fretting experiment, they also investigated the effect of commercial lubricants on the fretting conditions that were discovered.

Fretting corrosion is due to micro-motion at a connector's contact surface where it interfaces with the other contact and is a primary mechanism that causes connectors to fail under vibration. The equipment used was capable of generating millions of fretting cycles in a relatively short time. However, they found that unlubricated contacts began exceeding 0.5-ohm contact resistance with as few as 2,341 cycles. Over the course of ten million cycles, many of these contacts developed contact resistance in the kilohm range. This result was considerably worse than fretting results on Sandia-designed connectors that typically have 50 - 100 microinches of nickel plating overcoated with 50 microinches of gold plating.

Additional studies using several different types of commercial lubricant found that some of them were capable of eliminating fretting corrosion until several million fretting cycles had occurred. In fact, some lubricants were found to be able to recover contacts that had developed kilohm range contact resistance

when cycled with no lubrication. When lubricated, these contacts immediately reverted to low contact resistance (less than 12 ohms) and remained stable at that level for millions of additional cycles.

Accomplishments

Two types of nano-miniature connectors have been evaluated extensively for visual, mechanical, electrical, and environmental defects. Six pairs of 51-pin/socket rectangular connectors and six pairs of 44-pin/socket circular connectors were evaluated. Additional samples of each type were used for plating thickness and fretting studies.

Nano-miniature connectors were found to have insulation resistance that was much better than many MC, SA, and commercial connectors that have been tested at Honeywell FM&T. Insulation resistance measurements ran in the high gigaohm or teraohm range. This is remarkable when the extremely close spacing of the contacts is considered.

At the vibration and shock levels used in this evaluation, nano-connectors had a problem with contact chatter. This evaluation did not allow discontinuities of more than one microsecond and there were both vibration and shock failures at this level. Based on this, nano-connectors could have problems with high volume data transmission in high vibration or shock environments. They would be better suited for applications where longer duration discontinuities could be allowed.

Contacts and bodies of the nano-connectors showed little sign of wear through extensive testing. Mating features such as the jackscrews on the rectangular parts and the external threads on the circular parts did wear out when parts were mated more than about 100 times. It was also noted that it was much easier to determine when the rectangular parts were fully mated than it was with the circular parts.

Gold plating was found not to be a continuous layer. Breaks in the plating were observed and nickel plating could only be detected by X-ray analysis. It was not detected visually. Where gold was observed, it averaged in the 35 – 48 microinch thickness range. Nickel was detected to be in the 10 – 17 microinch thickness range. Breaks in the plating are probably the biggest concern because, when coupled with the thin nickel barrier, contacts could be subject to corrosion problems in the long term. This is also the probable reason that the contacts had poor fretting corrosion results.

Fretting studies conducted at New Mexico State University found that nano-connectors were highly susceptible to fretting corrosion. Contact resistance started to increase with just a few thousand fretting cycles and in several cases reached the kilohm range by the time 10 million fretting cycles had occurred. This would make the use of these connectors highly risky in an environment with a lot of vibration.

The fretting study also found that fretting corrosion could be reduced dramatically and even recovered after it had developed with the use of some commercial lubricants. With lubrication, fretting corrosion can be held within acceptable limits for several million fretting cycles. Lubrication is highly recommended for applications with these connectors.

Two of 570 contacts tested developed a low resistance path between themselves 24 hours after humidity testing. Although it was a very real condition that could not be corrected, it appeared to be an anomaly since none of the other contacts had any indication of lowered resistance between them. Because it occurred as a result of 10-day humidity testing, it should be considered a low-risk phenomenon under normal operating and storage conditions.

Reference

1Dr. James T. Hanlon and Dr. Neil R. Aukland, *MIL-L-87177 and a Commercial Lubricant Improve Electrical Connector Fretting Corrosion Behavior*.

APPENDIX A

SHOCK AND VIBRATION SPECIFICATION

Shock and Vibration Test Specifications

The shock and vibration specifications presented below were generated by A. Dennis, SNL9135 and published in Summary of Mechanical Environments For Selected Weapons Systems Components, Issue A, 5/12/99. The information presented below represents selected environments taken from this document. Modifications, noted by strikethrough, were made to the specifications in order to meet testing capabilities.

2.1. Shock

The haversine shocks specified in Table 2.1 envelop the shock requirements for the weapons systems addressed by this study. The shock specifications in Table 2.1 shall be applied along ~~both directions~~ positive direction of the connector's/component's three orthogonal axes.

Table 2.1, Summary Shock Specifications for Connectors and Components

Category	Amplitude (g)	Duration for 10% Amplitude Pulse Width (msec)	Velocity (ft/sec)
High Frequency	4000	0.5	4.0
Medium Frequency	3800	0.9	68.4
Low Frequency	3300 –3000	2.4*	158.4 –140

* A 2.8 ms base-line pulse width 3200-g haversine shock for the B83 was included in the development of the specification for low frequency shocks. This shock was placed in the low frequency group rather than the medium frequency group because of its large velocity change.

Figure 2.3.1. PSD Plot of Summary Short Duration Random Vibration Specifications for Connectors and Components

Table 2.3.1. Breakpoints for Short Duration Random Vibration Specifications

Frequency (Hz)	PSD g ² /Hz
10	6.2e-02
21	1.6e-01
100	1.6e-01

Figure 2.3.2. PSD Plot of Summary Medium Duration Random Vibration Specifications for Connectors and Components

Table 2.3.2. Breakpoints for Medium Duration Random Specification

Frequency (Hz)	PSD g^2/Hz
10	$2.0\text{e-}02$
17	$2.0\text{e-}01$
25	$2.0\text{e-}01$
30	$1.0\text{e-}01$
60	$1.0\text{e-}01$
80	$2.0\text{e-}02$
200	$2.0\text{e-}02$

Figure 2.3.3. PSD Plot of Summary Long Duration Random Vibration Specifications for Connectors and Components

Table 2.3.3. Breakpoints for Long Duration Random Specification

Frequency (Hz)	PSD g^2/Hz
5	1.0e-01
10	1.0e-01
25	3.00e-01
50	3.00e-01
134	1.00e-02
590	1.00e-02
700	5.0e-02
860	5.0e-02
1000	2.0e-02
2300	2.0e-02

APPENDIX B

FAILURE ANALYSIS OF POST HUMIDITY

DWV/IR FAILURE

51 SOCKET CONNECTOR

S/N 6, PINS 49 AND 50

RESISTANCE PATH

FAILURE ANALYSIS OF POST HUMIDITY DWV/IR FAILURE

51 SOCKET CONNECTOR S/N 6, PINS 49 TO 50

Twenty-four hours after the 10-day humidity test was performed, a resistance path formed between pins 49 and 50 of the 51-socket connector labeled S/N 6. Immediately after humidity testing both of these sockets had passed insulation resistance testing with values of 70 megohms or higher. Twenty-four hours later the resistance between the two pins measured 10.5 kilohms. Once this resistance path developed, it remained fairly stable throughout the remainder of the testing. It did gradually increase in value over the next few months to approximately 56 kilohms.

At the conclusion of all testing, S/N 6 was sent to the Honeywell FM&T Failure Analysis department to see if it could be determined what caused this resistance path. The lab was requested to perform a

vacuum bake to see if the resistance could be altered. Then, they were to take X-rays to look for metallic material between pins 49 and 50. Finally, they were to check surfaces for other foreign material using a scanning electron microscope (SEM).

Figure B-1 shows the rear of S/N 6 as it was received in the lab. Pin 49 is the white wire while pin 50 is the black wire. The photo shows where the wires enter the black insulation material.

Figure B-1. Rear of S/N 6 Connector - Wires 49 and 50 Shown

Figure B-2 shows the contact side of the connector. Sockets 49 and 50 are marked with arrows. There is no visible sign of contamination on the surface of the insulator.

Figure B-2. Front of S/N 6 Connector - Sockets 49 and 50 Shown

The connector was vacuum baked at 212 degrees F for 24 hours. Immediately upon removal from the oven, the resistance between pins 49 and 50 measured 22.6 kilohms. Five hours later, it measured 47.6 kilohms. Twenty-four hours later, it measured 55.2 kilohms. Vacuum baking did not permanently change the resistance characteristics.

The next step was to take X-ray photographs of the connector to look for metallics. No metallics were found. Figure B-3 shows the X-ray view.

Figure B-3. X-ray Photograph of Sockets 48 Through 51

The connector was prepared for SEM inspection by attaching an ohmmeter to pins 49 and 50 wires to monitor resistance. The top black insulation material around the wires was scored between pins 47 and 48 so that a small section of it could be removed. Below this top layer of insulation was another layer of insulation made of a different material. After scoring, a scalpel was used to pop off the top layer of insulation from pins 48 to 51. Immediately upon removal of this layer, the low resistance path between pins 49 and 50 went open.

Figure B-4 shows the connector with the top layer of insulation removed around pins 48 through 51. Some bare wire is visible on pin 50. Since the resistance path disappeared in this operation, the cause of the resistance path must be present in this area of the connector. All surfaces in this area were analyzed by SEM.

Figure B-4. Rear of S/N 6 Connector - Top Insulation Layer Removed

SEM inspection showed that metallic particles (copper, gold, and silver) were present and embedded between pins 49 and 50 in the insulation material that was removed. Also, a large void was found in the insulation next to the white lead between it and the black lead.

Next, the area on top of the connector where the top layer of insulation had been removed was inspected. A "disturbed" area ran between pins 49 and 50. X-ray analysis of the "disturbed" area showed copper and chlorine present in addition to the expected background elements. The sockets were gold plated over copper with the wires crimped in. Inspection of the sockets found the gold plating cracked and flaking with base copper exposed and appearing corroded. Figure B-5 shows an X-ray area scan of the surface between sockets 49 and 50 in the "disturbed" area.

For comparison, ten wires and pins from the opposite end of the connector were inspected. The samples were prepared with the same technique. SEM inspection and X-ray analysis showed no evidence of corrosion on the sockets or wires and the surface of the lower layer insulation was not "disturbed." X-ray analysis showed some chlorine present in the top layer of insulation, but no chlorine present on the surface of the sockets.

Figure B-5. X-ray Analysis of "Disturbed" Area Elements

Conclusion

Analysis shows that chlorine is present on the surfaces between the two types of insulating material in the areas of pins 49 and 50 and is not present in other areas. The presence of chlorine may be evidence of a chlorinated contaminant being there. Since the resistance path did not materialize until after the humidity testing, the humidity test may have hydrated the contaminant, creating a corrosive agent. The agent then attacked the exposed copper on both pins and provided a conductive, low resistance path between them. The failure of this connector is probably due to the presence of a chlorinated contaminant between pins 49 and 50.