Reliability Demonstration Test (RDT) Report

for

High Temperature Operational Life (MTBF)

and

Temperature Cycling (MTBF)

for the MaxSonar™, Product Lines

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Reliability Demonstration Test Executive Summary

This test was conducted to verify and document the reliability of the Maxbotix MaxSonar™ product lines. Test parameters were selected that, if met, would establish and verify a mean time between failure (MTBF) of at least 200,000 hours. Additionally, industry practice states that product performance at temperature extremes (-40°C, +65°C), during and after a significant number of temperature cycles, is required to validate the MTBF.

High Temperature Operational Life Test Conditions for an MTBF of 232,896 hours with a 90% Confidence Level

Our product lifetime test was setup in an industry standard way. To facilitate reasonable test duration, the test temperature of 85°C allowed an acceleration factor. For the purposes of this test, the Arrenhius model was used. The equations used in the calculation of the acceleration factor can be found in the Appendix.

The test was conducted on 25 of the WR products (both the LV and the XL in the WR product lines) and 25 of the XL products. The product lifetime (MTBF) test started on January 18, 2010, and the test was stopped March 15, 2010, for an actual test duration of 67,025 cumulative test hours. During the course of the product life test there were no failures. As a result, the MTBF value was calculated using an acceleration factor and a standard Chi-squared distribution.

The MTBF of the MaxSonar product line is **232,896 hours** for products operated at 45°C or less. Because no failures were observed during our testing, MaxBotix Inc., believes that the values in this report can be taken as a conservative estimate of product lifetime.

Temperature Cycling Test Conditions for 229,139 hours with a 90% Confidence Level

The goal for this temperature test was to demonstrate product performance when subjected to a large number of temperature cycles. The test was completed on twenty of the Maxbotix MaxSonar™ products consisting of ten WR products (both the LV and the XL in the WR product lines) and ten XL products. These products were subjected to 177 temperature cycles from –40°C to +65°C. For each cycle the product soaked at the temperature extreme product for 30 minutes. Product operation was daily verified during the first 101 temperature cycles. At 101 cycles the products received a full test. Then an additional 76 temperature cycles were ran and the product was again tested and verified to operate properly. The cumulative total of 3540 temperature cycles was completed. No products failed during this temperature cycle testing. The mathematical relationship of temperature cycling to product lifetime showed a product lifetime of MTBF value of **229,139 hours**. The equations used in the calculation can be found in the Appendix.

Extending the Test Results to the LV-MaxSonar-EZ Products

The LV-MaxSonar-EZ (LV-EZ) line of sensors was not subjected to this test, but MaxBotix Inc., believes that these test results can be extended to the LV-EZ products because the LV-EZ products use very similar circuits (expect with fewer components) and the LV-EZ product lines actually subject the transducer and circuitry to less stress than the products we tested.

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2 High Temperature Operational Life Test (MTBF)

2.1 Test scope

The purpose of this test was to use High Temperature Operational Life Testing to demonstrate the long-term operation of our Maxbotix Inc., MaxSonar™ sensor line. The test started on January 18, 2010 and ended on March 15, 2010.

2.2 Test Samples

The test was carried out on 50 units. Of these, a sample of 25 units was issued from our production stock to represent the XL product line and a sample of 25 was issued to represent the WR product line. All units were prescreened on the assembly floor to ensure correct operation before the test using the same method as our regular production parts.

2.3 Test Conditions

During this burn-in time the units under test were powered at 5.0 Volts, and the product was commanded to range continuously. All units were installed in a test chamber that maintained a temperature of 85°C +/- 3°C. All units were monitored once daily for the following parameters: Mean Voltage, Peak to Peak Output Voltage, Maximum Output Voltage, Minimum Output Voltage, Analog Output Voltage, Average Current Draw, & Voltage of Operation (Input Voltage). During this time temperature data was monitored to ensure the correct operation of our temperature chamber.

All parts were subjected to test conditions for a 1340.5-hour duration. After the test was completed all units were removed from the test assembly and inspected to verify the integrity of the components and the overall operation of the units under test.

2.4 Test Results

No failures were observed during the course of this test. In addition, all product passed production tests after this life testing was completed.

By testing 50 units for 1340.5 hours data was accumulated for 67,025 hours of combined product usage hours. During the course of this test no failures were observed, with an calculated mean time between failure (MTBF) of 232,896 hours with a 90% confidence factor. Reference the Appendix for calculations related to the MTBF value.

2.5 PVC Housing Flow

During the course of this test the PVC housing on the MaxSonar™ WR product line was observed to cold flow. Because this test was conducted for an extended period of time in excess of 80°C this is an expected result. Despite moderate deformation of the housing all units continued to function normally. This is still in line with our -40°C to +65°C (+85°C limited operation) values. It is recommended for units that will be subjected to temperatures in excess of +80°C that these temperatures be maintained no longer than 30-minutes for non-recurring operation and 5-minutes for recurring operation.

For more information on the effects of temperature on the stiffness of PVC reference the Appendix.

3 Temperature Cycling Life Test

3.1 Test scope

The purpose of this test was to use Thermal Cycling Testing to demonstrate the long-term operation of our Maxbotix Inc., MaxSonar™ sensor line. (This temperature cycling test was designed to work in tandem with the mean-life test to establish the ability of the MaxSonar™ sensor to operate in temperature conditions ranging between -40°C and +65°C.) The test was conducted at Maxbotix Inc. starting on February 24, 2010 and concluding on April 05, 2010.

3.2 Test Samples

Temperature Cycling was carried out on a total of 20 units. Of these 10 were issued from production to represent the XL product line and 10 were issued to represent the WR product line. All units were prescreened using the method as regular production parts.

3.3 Test Conditions

To achieve this goal a test was designed to expose the parts to the specified –40°C to +65°C temperature range for 177 temperature cycles with 30 minutes dwell at each cycle extreme. The temperature chamber used was a Tenney JR.

The temperature chamber was monitored for proper operation. In addition, one of the WR unit's analog voltage envelope was also connected to the data logger and the analog offset voltage for this unit was recorded. Because the analog envelope offset voltage is a function of temperature, this voltage can verify that the product under test matches the chamber temperature. Please reference the Appendix for a detailed plot of time verses temperature showing this output in relation to the chamber temperature.

For the first 100 temperature cycles the product operation was verified twice daily (once during a cold cycle and once during a hot cycle) in order to verify the following: Minimum waveform voltage, maximum waveform voltage, verified correct transmit burst, and verified the analog envelope output signal.

At cycle 101 full product testing was completed at each temperature extreme. In addition product was removed from the temperature chamber and the product received the full production test. This removable process required unsoldering of lead wires from the products. No failures occurred.

An additional 75 temperature cycles were carried out with the product non-powered. Product operation was again verified. No failures occurred.

3.2 Test Results

By testing 20 units for 177 cycles with a test duration 317 hours, the product recieved 3540 cumulative cycles over 6340 cumulative hours. During the course of this test no failures were observed, with a calculated mean time between failure (MTBF) of 229,139 hours. Reference the Appendix for calculations related to the MTBF value.

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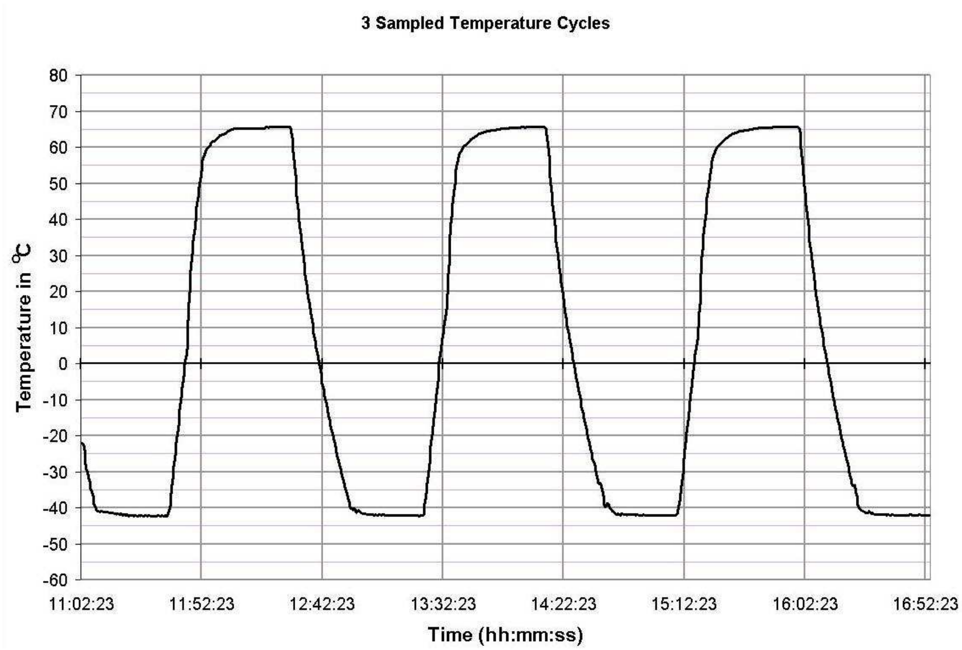
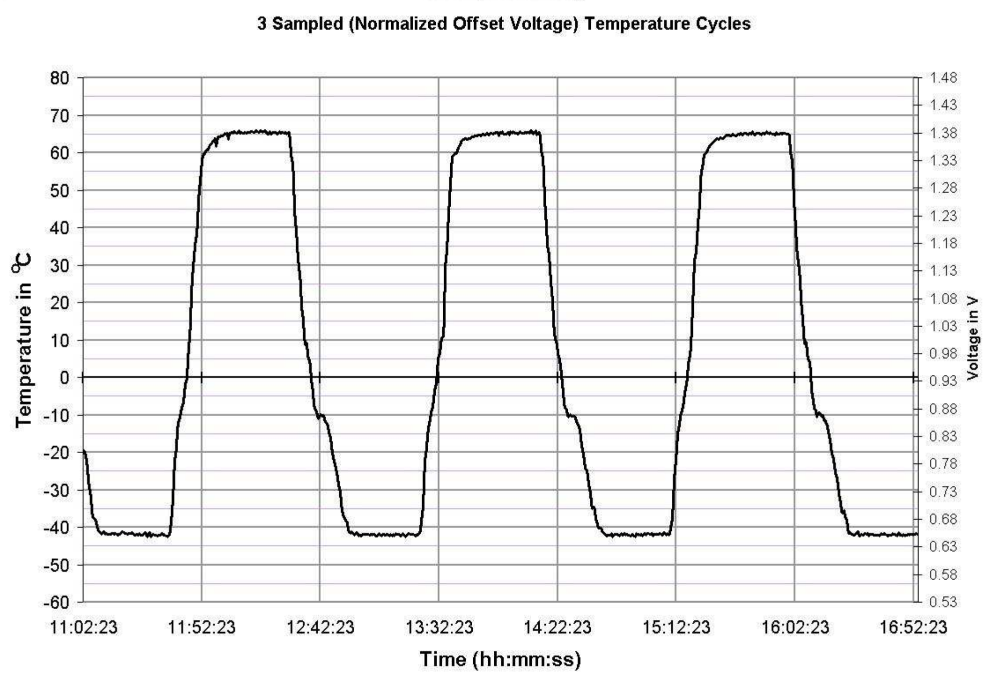
4 Appendix

4.1 Typical Temperature Cycle Timeline





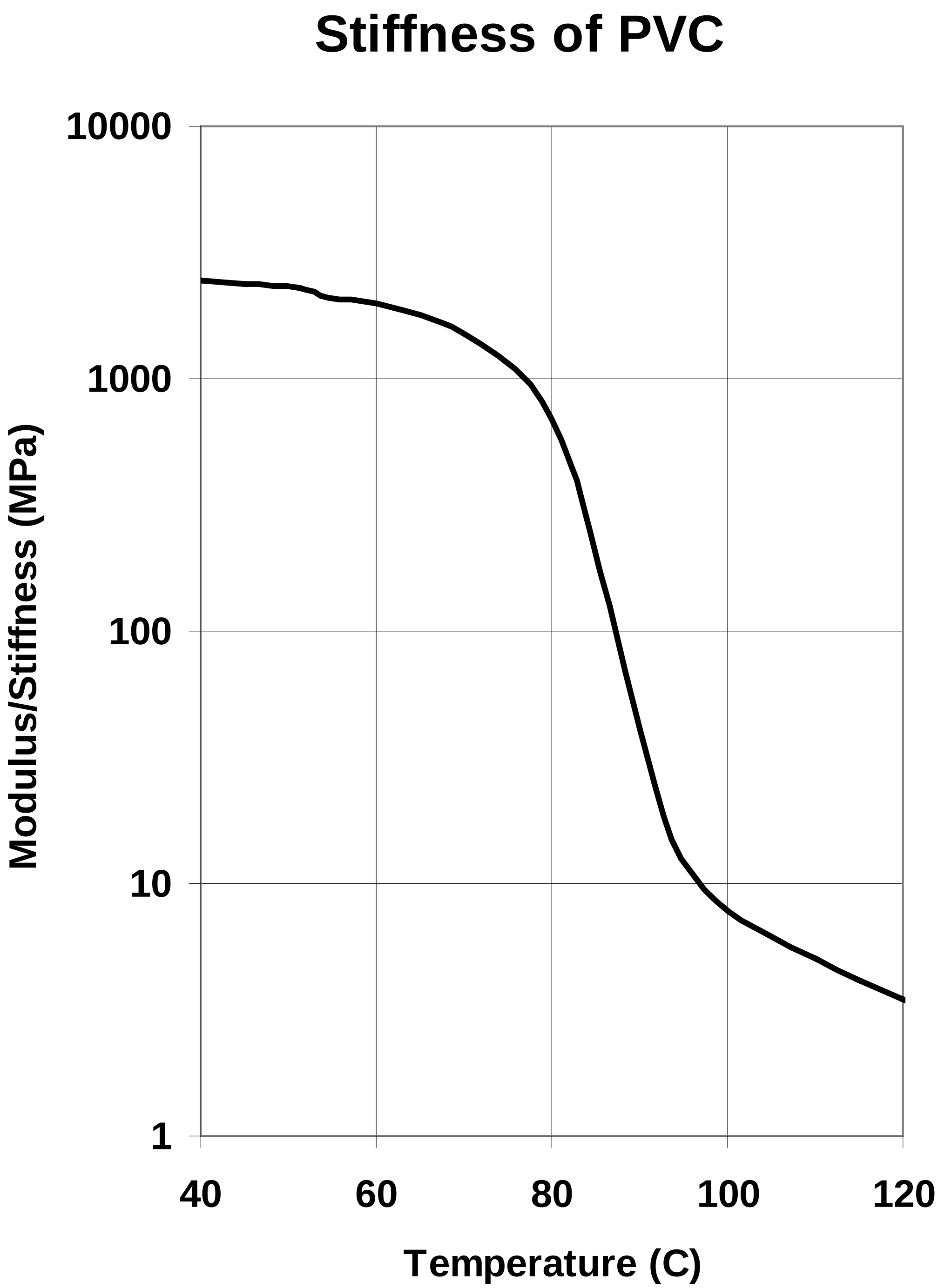
*The above chart includes the analog offset voltage of one test unit to confirm that units in the test chamber reached the desired temperatures at the same time as the chamber. Offset voltage is normalized using the equation below.

$$T = m \times V + b$$

T = Temperature
V = Offset Voltage Measured
m = 146.4 Kelvin/Volt
b = -138.05288 Kelvin

4.2 PVC Temperature Considerations

For the WR-MaxSonar products the PVC housing is subject to the physical limitations of the plastic exterior. In order to prevent cold flow the sensors should only see limited operation at temperatures of 85°C for limited periods of time (30 minutes or less). At 65°C PVC will have a modulus (or stiffness) of 1800 Mpa (maintains rugged, sturdy, PVC properties), but at 85°C PVC will have a modulus (or stiffness) of 560 Mpa (might allow for cold flow movement).



4.3 Activation Energies of Integrated Circuit Components

Failure Mode	Activation energy in eV
Oxide Breakdown	0.3 - 0.5 eV
Corrosion	0.3 - 0.5 eV
Electo-migration	0.45 - 1.0 eV
Ionic Migration	0.6 - 1.4 eV
Assembly Defects	0.5 - 0.7 eV

For the purposes of our calculations an activation value of 0.53 eV was used. This aggrees with the rule of thumb of doubling the equivalent product usage hours for every 10°C above the normal operational temperature. For additional information on the reliability of electroninc components reference MIL-HDBK-217.

4.4 Acceleration Factor Calculation (Operational Life)

The Arrhenius equation below is used to model the relation between increased temperature and the acceleration of the aging of a product as compared to its normal operational temperature.

$$A_f = e\wedge\left(\frac{Ea}{k}\left\{\frac{1}{T_s} - \frac{1}{T_t}\right\}\right)$$

A_f = acceleration factor
Ea = activation energy in electon-volts (eV) = 0.53 eV
k = Boltzmann's constant = 8.617×10^{-5} eV/T_k
T_s = Temperature of normal operation, in degrees Kelvin = 318°K (45°C)
T_t = Temperature of operation during test, in degrees Kelvin = 358°K (85°C)
T_k = Kelvin Temperature
e = 2.71828 (mathematical constant)

This equation yeilds an acceleration factor of 8.00.

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4.5 High Temperature Operational Life (MTBF)

Because we observed no failures during our test we computed MTBF using a Chi-squared distribution. For the purposes of this test a level of confidence of 90% was considered acceptable. The MTBF formula using a Chi-squared distribution is:

$$MTBF = \frac{2 \cdot (N \cdot T) \cdot A_f}{X^2[\alpha, (2(n+1))]}$$

where:
MTBF = Mean time between failures
2 is the
N is the Number of elements = 50 sensors
T = Total test time = 1340.5 hours
A_f = Acceleration factor from Arrenhius equation = 8.00 (reference Appendix 4.6)
α = 0.1 (Confidence level of 90%)
n = number of failures (used to calculate degrees of freedom) Our test did not have any failures so, n = 0
$X^2[\alpha,(2(n+1))]$ = Chi-squared distribution function = 4.605

Using this equation and substituting the above values yields a MTBF of 232,896 hours at a confidence level of 90%. This is to say that the "mean life" for our product is more than 90% likely to meet or exceed **232,896 hours** based upon the data we collected with no failures.

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4.6 Temperature Cycling (MTBF)

The equation below is used to model the relation between increased temperature and the acceleration of the aging of a product as compared to its normal operational temperature.

$$A_f = \left(\frac{\Delta T_t}{\Delta T_s}\right)^{1.9} \left(\frac{H_s}{H_t}\right)^{0.333} e \times \left(\frac{Ea}{k}\left\{\frac{1}{T_{MaxS}} - \frac{1}{T_{MaxT}}\right\}\right)$$

A_f = acceleration factor
Ea = activation energy in electon-volts (eV) = 0.53 eV
k = Boltzmann's constant = 8.617×10^{-5} eV/T_k
ΔT_s = Difference in Temperature during normal operation* = 20°C
ΔT_t = Difference in Temperature during test operation = (+65°C – (-40°C)) = 105°C
H_s = Cycle frequency in the field (Cycles/24hours) = 1
H_t = Cycle frequency in the lab = 13.4
e = 2.71828 (mathematical constant)
T_{MaxS} = Temperature during normal operation* in Kelvin= 304°K (21°C+273°K)
T_{MaxT} = Maximum Temperature during test operation in Kelvin= 338°K (65°C+273°K)

*Temperature of normal operation assumed to be 21°C +/- 10°C for these calculations.

This equation yeilds an acceleration factor of 47.405. With 20 units tested for 317 hours with no failures being observed this calculatea an MTBF value of **229,139 hours**.

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