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US Army - TARDEC

Evaluation of 90 Degree Gearbox Design

GVR-BOT Technical Report

Tyrus Valascho, Robert Sosin
8-15-2013



Executive Summary: Motor and 90 degree gearbox prototype units were tested. Temperature chamber and load testing was performed on 3 different type gearboxes. Each of the 3 tests ended in a failed gearbox.

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Introduction

An evaluation of a potential replacement motor for the iRobot PackBot Main Driver Motors was made. This evaluation consisted of baseline testing of the iRobot gearboxes and motors, then testing of 3 different prototype designs for a Maxon replacement gearbox.

Background

There have been numerous failures in the field of the PackBot Main Driver Motors. The part that consistently fails is the gearbox when under conditions of high load, high heat, or both high load and high heat.

In the beginning of the PackBot Standardization project, the drive motors were identified as a component that could be replaced to improve the reliability of the system. The difficulty was finding a 90 degree gearbox that would fit inside the space of the PackBot Main Electrical Housing, which is only 55 mm in height.

A market survey for motor¹ / gearbox combinations that would fit within the size envelope of the existing PackBot product only yielded one result:

Maxon Right Angle Gearhead Ø32 mm, 1.8 - 2.4 Nm, PN 435098

Maxon EC motor EC40 BL D 170W KL 2 WE A, PN 393023

The intent was to purchase 2 of the chosen motor / gearbox combinations and install them in a Standardized PackBot. A performance and durability test would be performed on the original PackBot, then again with the Standardized PackBot utilizing the proposed motor / gearboxes.

Baseline PackBot Testing

Baseline Test Plan

For this test, the UUT (Unit Under Test) will be powered up and running during the test. The UUT will be attached to a robot dynamometer and will be driven in a consistent direction (forward or backward, it doesn't matter which) during the duration of the test.

All tested components are inside the main electrical enclosure of the robot, and the robot is operated while maintaining communications with the OCU (Operator Control Unit). Thermocouples are attached to the subcomponents being measured inside the UUT and attached to a datalogger. The UUT and dynamometer are placed inside the thermal chamber and an additional "ambient" thermocouple is placed in open air near the center of the chamber.

The chamber is brought to the desired test temperature with the UUT inside – unpowered - and soaked for at least 1 hour before the test is started. Once the soak time has elapsed, the UUT is powered on and the test begins. During the test, the datalogger is monitored to see what temperature the measured subcomponents stabilize at. Stabilization occurs when all measured subcomponent

¹ Note that the motor was not an exact replacement. The original PackBot design uses a brushed DC motor and the PackBot Standardization project was intending to use a brushless DC motor.

temperatures remain within a constant temperature +/- 1 C for at least 30 minutes. Once stabilization occurs, the test can stop.

Test Results

For testing, a PackBot was disassembled and thermocouples were placed at several locations within the main electrical housing, as shown in Table 1.

Table 1 - Location of PackBot Thermocouples

Name	Description	Location
AMBIENT	Ambient temperature of chamber	Not attached to the robot
L HOUSING	Housing of Left Drive Motor	Inside stack, attached to motor housing
R HOUSING	Housing of Right Drive Motor	Inside stack, attached to motor housing
CENTER STACK	Center of Electronics Stack	Near top heat sink, inside electrical housing
CASE BOTTOM	Main Electrical Housing, bottom side	External to electrical housing, bottom side
FLIPPER MOTOR	Housing of Flipper Motor	Inside stack, attached to motor housing

The PackBot motor / gearboxes were tested at -20 C ambient three times and at +50 C ambient eight times. There were 3 gearbox failures during this testing.

In Table 2, the results of the testing are provided for the +50 C ambient case.

Table 2 - PackBot Temperature Testing Results at +50 C Ambient, Full Load

Trial #	Stable Max Temp (C)	Time to Stabilize (min)	Max Temp (C)	Notes	Simulated Slope (degrees)
1	n/a	n/a	59.7	Invalid test - comm loss	30
2	n/a	n/a	75.3	Invalid test - batteries ran out	30
3	n/a	n/a	76.7	Invalid test - batteries ran out	30
4	n/a	n/a	78.9	Invalid test - batteries ran out	30
5	n/a	n/a	78.5	Invalid test - batteries ran out	30
6	n/a	n/a	91.5	Invalid test - left and right gearboxes failed	30
7	75	70	75.7	Swapped batteries twice during test	30
8	n/a	n/a	82	Invalid test - right gearbox failed	30

This testing was performed with a load rig (dynamometer) setting of a simulated 30 degree incline. Many of the tests conducted were unable to complete and a stable final temperature couldn't be determined until the seventh trial.

For the cold testing, the load rig was removed and the robot was run with the tracks just moving in air. This was because the hot testing resulted in a high rate of failures of the gearboxes, so it was decided to not damage any more for purposes of this baseline.

The results of the cold testing are provided in Table 3.

Table 3 - PackBot Temperature Testing Results at -20 C Ambient, No Load

Trial #	Stable Max Temp (C)	Time to Stabilize (min)	Max Temp (C)	Notes	Simulated Slope (degrees)
1	-5.5	45.3	-5.3		N/A
2	-5.2	39.6	-5.1		N/A
3	-5.4	48.9	-5.4		N/A

The purpose of the testing was to determine the stable end temperature of various components in known ambient temperature environments. These values are listed in the columns “Stable Max Temp” in Table 2 and Table 3.

New Design Testing

For the testing, two prototype gearboxes were produced and PackBot 500 gearheads attached for mounting inside a Standardized PackBot / GVR-BOT. An image of the two completed parts – separated from the motors – is provided in Figure 1.



Figure 1 - Two Prototype 90 Degree Gearboxes

The serial numbers of the two parts used in testing are 12-0028 and 12-0025.

For testing of the Standardized PackBot, the motors, gearboxes, and motor controllers were instrumented with thermocouples. An image of the instrumented vehicle, including power and thermocouple wiring, is provided in Figure 2.



Figure 2 - Standardized PackBot with Instrumentation Installed

The location and description of the thermocouples is recorded in Table 4.

Table 4 - Location of Standardized PackBot Thermocouples

Name	Description	Location
AMBIENT	Ambient temperature of chamber	Not attached to the robot
L MTR CNTRL	Left Motor Controller	Attached to motor controller
R MTR CNTRL	Right Motor Controller	Attached to motor controller
L MTR	Left Drive Motor	Attached to drive motor housing
R MTR	Right Drive Motor	Attached to drive motor housing
L GEAR BX	Left Gear Box	Attached to gear box housing
R GEAR BX	Right Gear Box	Attached to gear box housing

The Baseline Test Plan was run using multiple prototype designs from the manufacturer. After each test run, any failures and observations were fed back to the manufacturer and design modifications were made to the gearbox. When complete, they would send the revised parts back to TARDEC-GVR for testing.

Test 1: 29APR2013 - 03MAY2013

Configuration

The test was run with all components installed in a prototype Standardized PackBot chassis and installed in the small robot dynamometer and the complete assembly placed in the temperature chamber. Figure 3 provides an image of the pre-test configuration, before the robot was placed in the dynamometer.

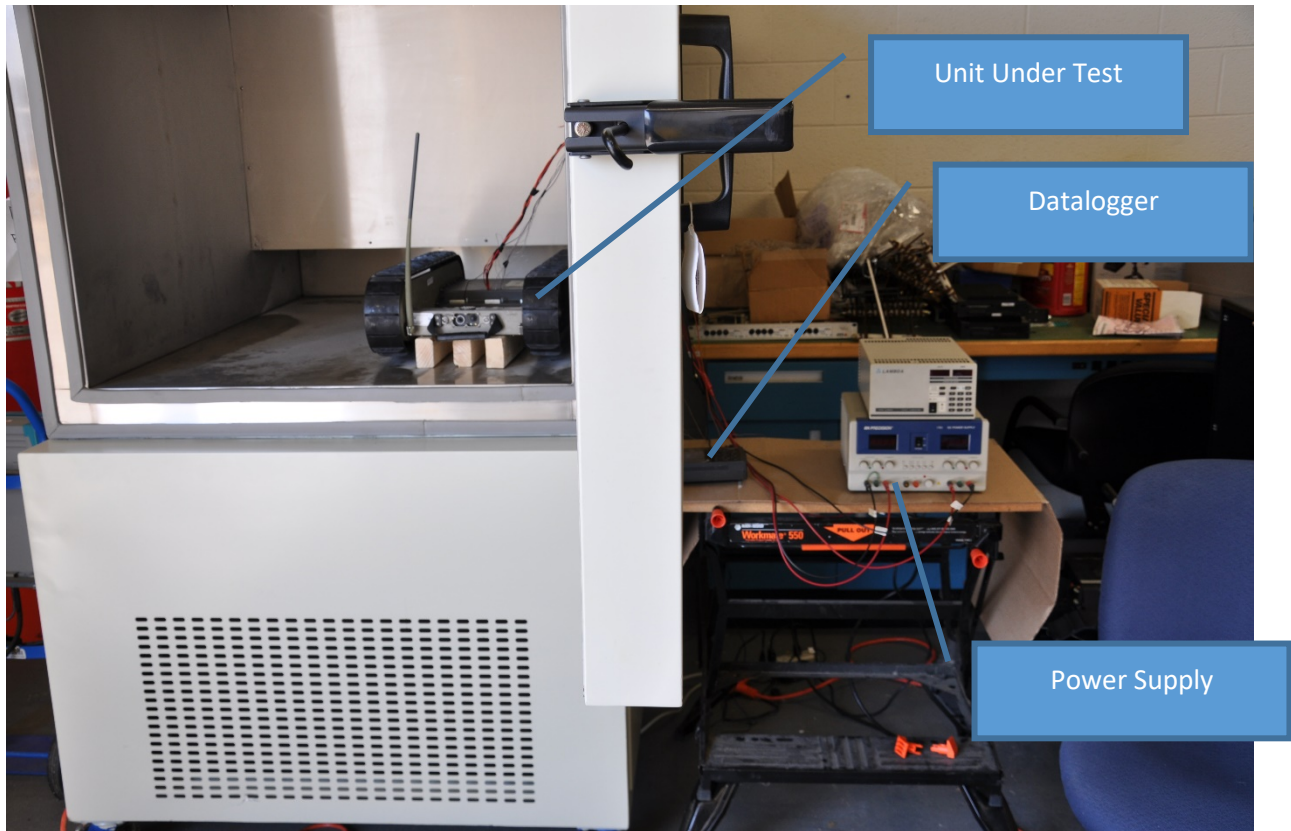


Figure 3 - Test1 Configuration without Dynamometer

Power was provided externally by a power supply - not the robot batteries - so the tests could continue without stopping the test, opening the temperature chamber, and replacing batteries. Thermocouples were installed as indicated in Table 4.

Results

Twelve test runs were completed at several different ambient temperatures between -19.1 C and +50.5 C. The results of the testing are provided in Table 5, which show the maximum temperatures reached by the components during testing.

Table 5 - Maximum Temperatures Recorded during Test 1

Test #	Date	Ambient Temp (C) ²	Total Test Time (hours)	Simulated Slope (degrees)	L MTR CNTRL	R MTR CNTRL	L MTR	R MTR	L GEAR BX	R GEAR BX
1	4/29/2013	31.8	0:51:01	-15	43.8	40.9	47.3	49.3	66.5	72.8
2	4/30/2013	48.8	0:52:01	-15	62.2	60.2	64.8	66.9	79.4	87.3
3	4/30/2013	-18.8	0:53:34	-15	2.3	-1.4	7.0	9.1	31.4	41.5
4	5/1/2013	25.5	1:48:19	-15	49.7	51.4	53.0	54.1	70.6	72.6
5	5/1/2013	50.5	1:00:44	-15	63.0	64.1	67.0	65.7	83.0	82.5
6	5/1/2013	-19.1	1:01:53	-15	4.1	6.6	10.6	8.8	36.5	37.9
7	5/2/2013	18.5	2:51:23	0	54.3	56.2	58.5	57.1	75.3	73.2
8	5/2/2013	25.4	1:01:04	20	49.7	51.6	53.5	53.6	68.6	70.8
9	5/2/2013	26.2	0:57:04	25	49.8	52.2	54.0	54.0	68.7	70.3
10	5/2/2013	28.2	1:25:20	30	57.3	60.6	61.0	61.2	74.4	76.3
11	5/3/2013	50.5	1:21:07	30	69.3	72.0	73.0	71.5	86.4	86.0
12	5/3/2013	-17.4	0:49:07	30	11.5	13.3	23.5	19.7	48.1	44.0

Most of this testing was exploratory, intended to gather data about the prototype hardware at different test conditions.

The results of this testing identified 3 test conditions where the gearboxes exceeded their designed maximum temperature of 85 C.

In addition, one of the gearboxes was observed to leak oil during the 50 C ambient testing. The leaking is documented in Figure 4.

² The ambient temp sensor was very near the outside access port of the chamber, and was probably reading somewhere between chamber ambient temp and outside air temp (~30 C)

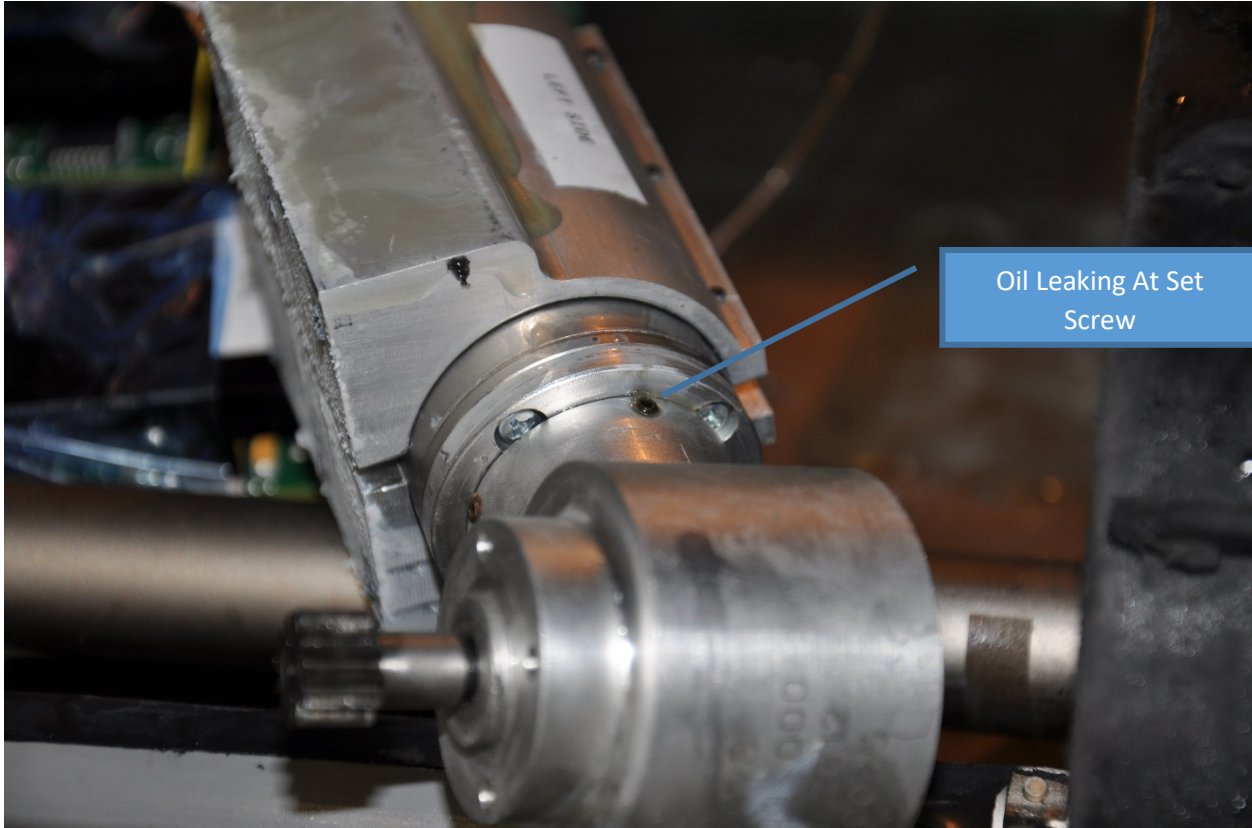


Figure 4 - Oil Leak Observed in Left Side Gearbox

Based on these results, the manufacturer requested that the gearboxes be returned so they could investigate the issues observed by the TARDEC testing team.

Test 2: 21MAY2013 - 23MAY2013

The gearboxes were returned to TARDEC-GVR for further testing after modifications by the manufacturer intended to improve the heat flow and reduce internal heating of the components.

Configuration

The test was run with all components placed directly in the test chamber, as can be seen in Figure 5.

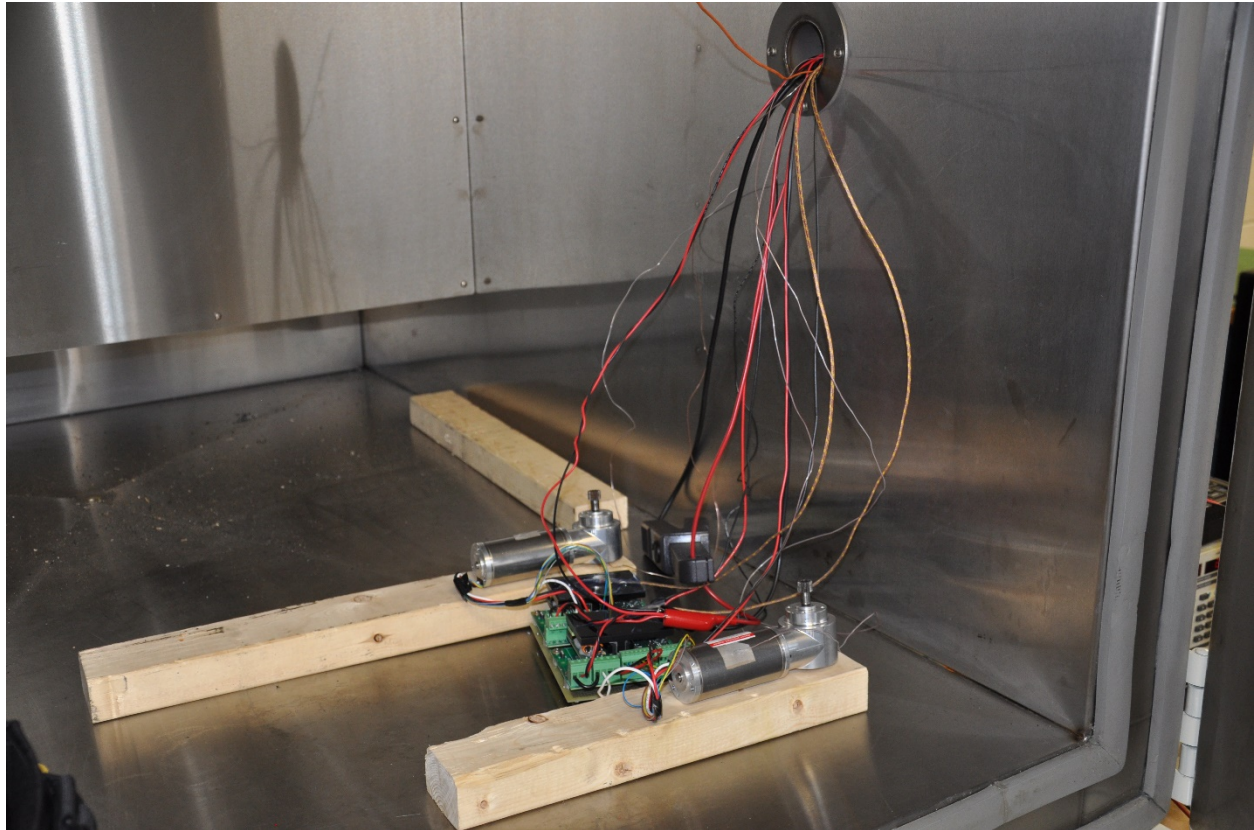


Figure 5 - Test with Components in Chamber

Power was provided externally by a power supply. Thermocouples were again installed as indicated in Table 4 - Location of Standardized PackBot Thermocouples, even though the components were now removed from the electrical housing of the robot.

Results

Table 6 contains the temperatures that were observed during testing.

Table 6 - Maximum Temperatures Recorded during Test 2

Test #	Date	Ambient Temp (C)	Total Test Time (hours)	Simulated Slope (degrees)	L MTR CNTRL	R MTR CNTRL	L MTR	R MTR	L GEAR BX	R GEAR BX
1	5/21/2013	50.9	3:42:11	N/A	54.5	51.8	62.3	61.5	69.8	69.6
2	5/22/2013	80.7	4:19:54	N/A	82.3	81.7	88.2	88.0	93.9	94.6
3	5/22/2013	70.1	1:40:37	N/A	73.2	73.1	78.8	79.5	83.3	86.5
4	5/23/2013	-16.2	3:00:15	N/A	-11.4	-11.5	4.0	1.4	18.0	15.1

In addition, another oil leak was found. This time the leak occurred at the back of the gearbox, as can be seen in Figure 6.

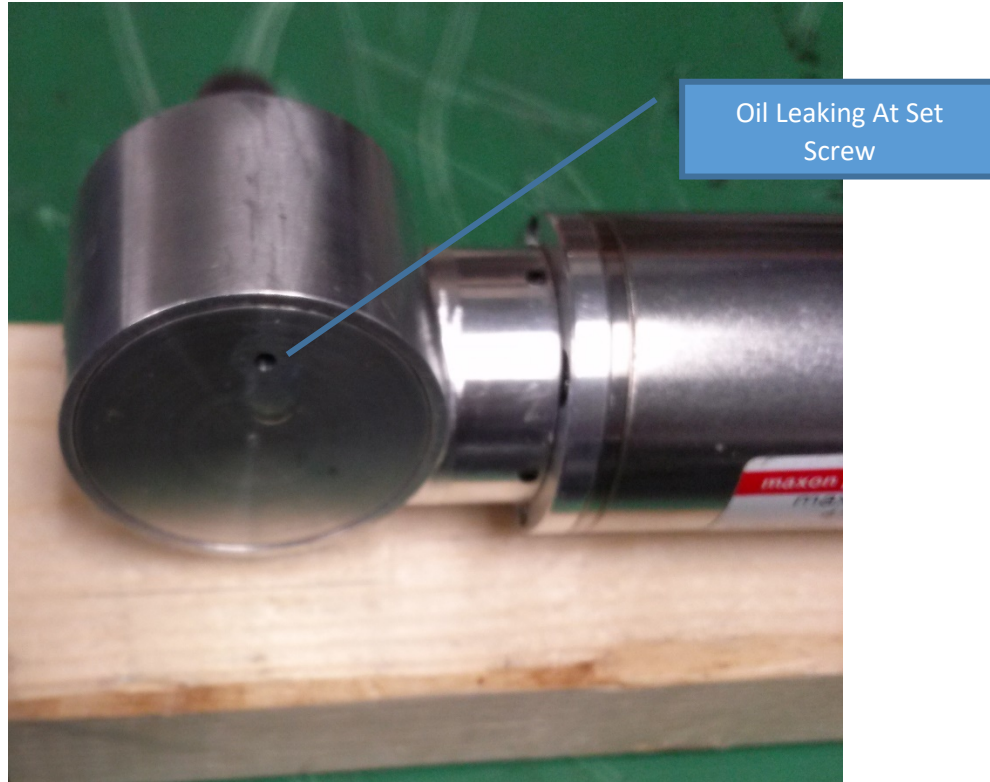


Figure 6 - Oil Leak Observed at Back of Gearbox

After receiving the results, the manufacturer again requested that both units be returned for analysis and repair.

Test 3: 15AUG2013

The gearboxes were returned to TARDEC after modifications to correct the leaking. Once received, another test was initiated to verify operations.

Configuration

The configuration for this test was identical to the one used in Test 2. The motors and motor drivers were mounted in the test chamber and thermocouples were placed in the same locations.

Results

A single test was run with the updated gearboxes. This test was only run once, as can be seen in Table 7, due to one of the motors quickly exceeding its maximum temperature limit (100 C).

Table 7 - Test 3 Results

Test #	Date	Ambient Temp (C)	Total Test Time (hours)	Simulated Slope (degrees)	L MTR CNTRL	R MTR CNTRL	L MTR	R MTR	L GEAR BX	R GEAR BX
1	8/15/2013	23.8	1:16:12	N/A	29.3	30	84.7	105.7	87.1	77.2

The manufacturer was again contacted, but it was decided to stop testing updated versions of the gearboxes until the manufacturer was confident a robust design had been achieved.

Conclusions and Recommendations

Attempts to baseline the original PackBot gearboxes and motors resulted in multiple failed parts. A replacement to these failures was the purpose of this testing, but the replacement gearboxes also experienced multiple failures during the course of testing.

It appears that after this testing, the gearbox is no longer offered as a product by Maxon.

Appendices

Abbreviations and Acronyms

OCU: Operator Control Unit

UUT: Unit Under Test