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"FAILURE MODE EFFECT AND CRITICALITY ANALYSIS PERFORMANCE TEST ON DC BRUSH MOTORS USED IN SPACECRAFT APPLICATIONS"

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ABSTRACT

Spacecraft components are expected to withstand intensive launch loads and withstand adverse environmental conditions that are encountered during the space mission. These components are tested rigorously and performance test procedures are used to evaluate the components for qualification and acceptance decisions. The work reported in this paper demonstrates the development of FMECA analysis for the stringent performance standards that is expected of the DC brush motors, which are used to power the deployment mechanism of the unfurlable antenna in a spacecraft. The DC Brush motors are one of the critical components in the space module.

The rigorous testing of the DC brush motors yield a large number of failures occurring during the test. This paper highlights the analysis of failure events observed in DC brush motors using the FMECA Technique. This work adds value to the decision making process in the organisation by analysing the performance failures using the FMECA methodology. The corrective measures suggested through the analysis, helps the decision makers in qualifying the Components based on the performance tests.

KEYWORDS: DC Brush Motor, Unfurlable Antenna, FMECA, Performance Test

INTRODUCTION

DC brush motors must withstand vibration and extreme temperatures during launch and on orbit. DC brush motor undergoes various types of testing to find out the components which are malfunctioning and in turn causes the system failure. The motor undergoes testing like thermovaccum, thermal cycling, electrical, vibration test etc. Through the scrutiny of the results of the component testing, failures have been identified and correction measures have been suggested. Since the brush motor is used for the space application during the deployment of unfurlable antenna and solar array, even a single component failure event in the DC brush motor cannot be tolerated , which is a stringent performance standard. This is since failure of DC Brush motors, will result in failure of antenna deployment mission activity and cause delay of the launch of the spacecraft mission.

The brush motors has been tested for launch loads occurring during the spacecraft mission. Since the type of component failure are not able to be observed on all the motors. Detection of the failure is diagnosed and detected by the operator using Built in Test equipments (BITES) and is recorded. Objective of these tests are to check the performance of the motors against the launch loads and harsh simulated environments.

Literature Review

The open literature reports a number of publications highlighting the FMECA analysis. A few of the relevant literature has been briefly reviewed herein.

S. Satisha et. al outlines the quality management for space systems. This paper is useful in understanding process of inculcating good practises in spacecraft. This paper also outlines the activities of the reliability programme as part of qualification and acceptance for space modules. This paper also dwells on components derating method are critical tools reported in the work [1].

MA Cunbao et. al presented safety analysis of airborne weather radar based on Failure Mode, Effects and Criticality Analysis. This work assures importance of safety of the Airborne Weather Radar (WXR) that directly affects the safety of the whole aircraft and the flight. The Failure Modes, the Effect and the Criticality Analysis (FMECA) methods in the safety analysis of system are firstly investigated and then the criticality matrix is generated. Secondly, the criticality matrix is applied to classify the failure modes [2].

Noordwijk explains The failure modes, effects analysis or failure modes effects and criticality analysis (FMEA/FMECA) process provided is a timely, iterative activity, is an effective tool in the decision making process. Initiation of the FMEA/FMECA is actioned as preliminary information is available at high level and extended to lower levels are available [3].

Li Jun et al explains the reliability of aircraft equipment. Adopting the FMECA Analysis to aircraft during the flight operation will result in flight safe. In order to make the equipment work normally, FMECA is applied in an aircraft equipment to analyze its reliability and improve operational reliability of the product. According to the process of reliability theory in enlisting all kinds of the failure mode, reasons, effects and criticality of the products to be determined [4].

W.Century Blvd.Suite et al explains the Failure Modes, Effects and Criticality for the Battery Charger. The FMECA analysis consists of outlining all possible Failure Modes of elements and then determination of the Effects and Criticality of the failure modes. The analysis concluded that the battery charger board was designed to prevent single point failure. The analysis suggests there were several single point failure modes that can inhibit or restrain operation of the board. There are no failures that are classified as severe or catastrophic [5].

FMECA ANALYSIS ON DC BRUSH MOTOR

The procedures to carry out FMECA are as follows:

Description of the Product / Process of the System

Failure mode effect and criticality analysis is carried out to identify the failure mode, effect and causes for the failures. The entity analysed is the DC Brush motor, FMECA is carried to know which the elements of the DC Brush motors are causing failure of the component in turn causing the system failure. A systematic analysis of the systems to the level of detail is required is required to demonstrate that no single failure will cause an undesired event. DC Brush motor is used for the deployment of Unfurlable Antenna, and the various components which are connected to the antenna for deployment are items like Kevlar cable spool, bevel gear etc.

Construction of Functional Block Diagram

A block diagram of the deployment of DC brush motor is initially created, Figure 2: Shows the main components of the product, as also the process steps as blocks connected according to relations between them. The FMEA Table worksheet is prepared from the relationship of block diagram. Around these relations the FMEA can be developed. Figure 1 shows the Hierarchical representation of the DC brush motor. The components assembled and used for deployment of Unfurlable Antenna are represented in this diagram.

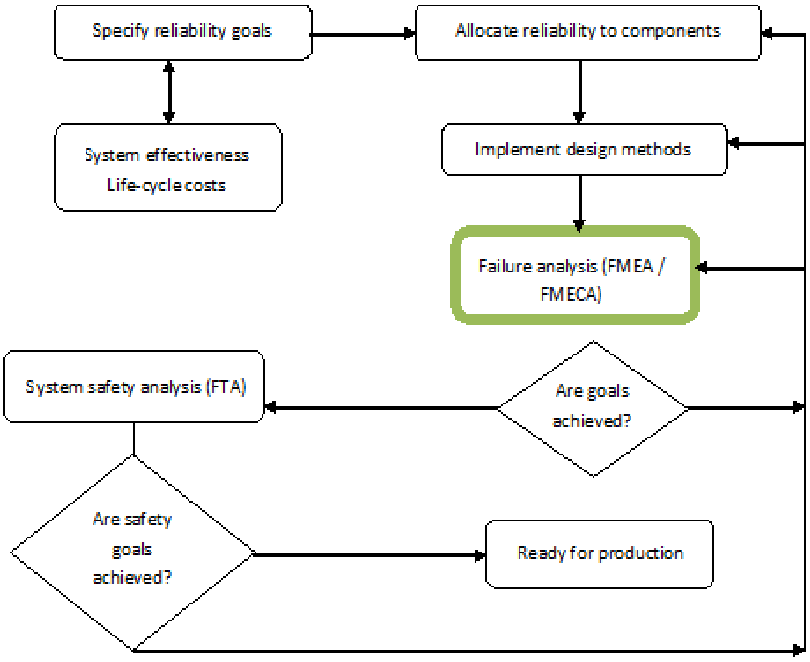

Figure 1: Reliability Design Process

Listing of Components and Functions

The Components are listed with their functions in Table 1 Below.

Table 1: Components and Functions of the DC Brush Motor Assembly

Components	Functions
Metal Housing	A metal case to house the magnets and bearings and fix the endcap. It is also responsible for producing a magnetic field using the magnets to chart the flow of magnetic force.
Bearing	This component supports the shaft that is part of the armature assembly and also provides lubrication for the shaft to turn with less friction.
Magnet	The permanent magnet is the key component in producing a magnetic field which in turn produces torque or the turning force of the motor.
Spring Holder	This component fixes the magnet to the housing
Commutator	The commutator commonly uses copper segments and more recently, graphite. This component comes in contact with the brush to allow current to flow through the armature and is responsible for the direction of the current to shift as it spins and slides in contact with the brushes.
Lamination Stack	Composed of stamped sheet metal called laminations, the lamination stack has slots for the magnet wire windings where current can flow.
Magnet Wire	Magnet wires are used as windings for the armature.
Shaft	The shaft is where the mechanical output characteristics of the motor are measured such as speed and torque. The whole idea of the motor is to provide rotational motion to the shaft.
Brush Holder	This component holds the brush in place and provides electrical insulation from the metal housing.
End cap	The end cap is a stamped metal part that holds the bearing in place and strengthens the plastic brush holder. The terminals protrude through the end cap.
Terminals	Usually in pairs, the terminals are the electrical input contacts of the motor.
Brush	The brush, usually composed of carbon material, enables electrical current to flow from the terminal to the armature as it slides in contact with the commutator while the armature assembly is rotating.
Brush Leaf	This component holds the brush and enables the brush to slide and come in contact with the commutator at just the right amount pressure.

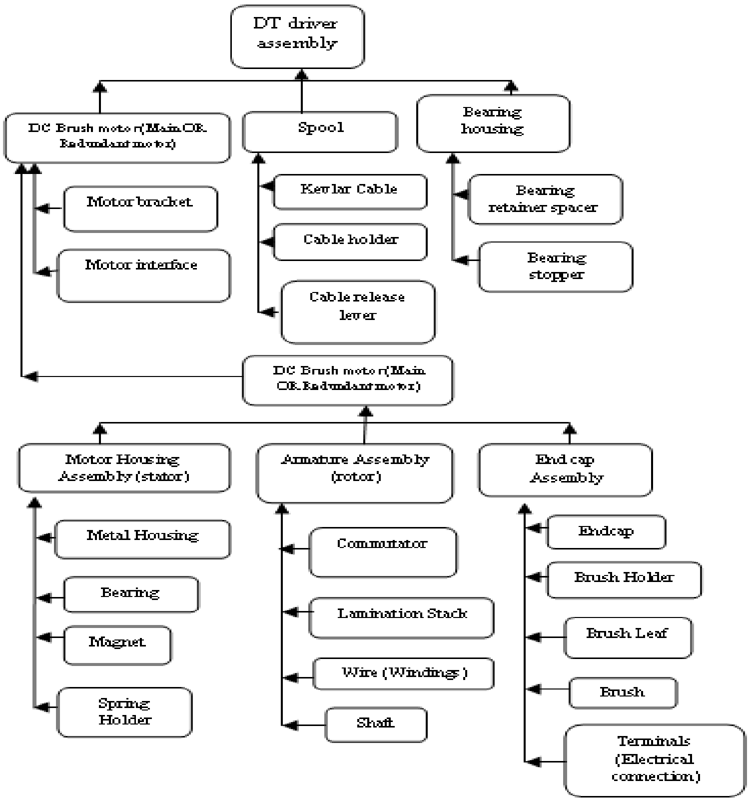

Figure 2: Hierarchical Representation of DC Brush Motor

Identification of Potential Failure Modes

The failure modes on DC brush motor are identified as follows:

Failure Modes

The predictable failure modes at each systems level is analysed and identified. Potential failure modes will be determined by the examination of components outputs and functional outputs identified in applicable block diagrams and schematics.

Failure modes found in DC Brush motor are shown in Table 2.

Table 2: Failure Modes on DC Brush Motor

Electrical Failure Mode	Mechanical Failure Mode
Winding Failure in short mode	Breaking, Yielding, Bending
Winding Failure in open mode	Shear
Insulation failure	Jamming of gears, improper backlash, Non-coplanar hinge line
	Bond failure in shear due to thermal fatigue

Failures are listed in technical terms for each component as also the process step, as a failure mode in one component or process step may become a cause of failure mode in another.

Determination of Failure Effects and Causes

Failure Effects

The consequences of failure mode on component operation, function or status identified, evaluated, and recorded. The Failure Effects are shown in Table 3. The failure under consideration may affect several systems levels in addition to the systems level under analysis.

Table 3: Failure Effects on DC Brush Motor

Electrical Failure Mode Effects	Mechanical Failure Effects
Reduction in torque	No drive force
No Current, no torque	High friction force Structural instability
Increase in current	No spring kick off torque/ less torque

Identification of Failure Causes

A failure cause is a design weakness that results in a failure, the Failure Causes shown in Table 4. Criticality is the measure of effect of a malfunction of an item on the performance of a system. This assessment requires tracing the causes. A Cause is the means by which a particular element of the design or process results in a Failure Mode.

Table 4: Failure Causes on DC Brush Motor

Electrical Failure Cause	Mechanical Failure Cause
Excessive Current	Excessive shear load
No Current	Excessive load, wear
Failure of insulating material, grounding failure	Less backlash, misalignment of gears, temperature excursion

Ranking the Components According to Criticality and Calculation of RPN

The items are ranked from possibility of failure occurring based on the probability of the Occurrence, probability of Detection, Severity. It is measured on a scale.

The Probability of the Occurrence

The probability of the Occurrence of the causes should be ranked, again in some chosen scale. Probability that the mode of failure will happen by considering the redundancies and safety margins

Scale: 1 to 5, with 5 being the highest possibility and 1 being the lowest possibility of occurrence.

The Probability of Detection

The probability of Detection should be determined and ranked. This should reflect the likelihood that the Current Controls is designed for detecting the Failure Cause or the Failure Mode itself.

Probability that the probable mode of failure, will be detected during testing/ inspection on ground.

Scale: 1 to 5, with 5 being the least possibility of detection whereas 1 being the highest possibility of detection.

Severity

Severity is an assessment of how serious the Effect of the potential Failure Mode on the overall system or process. The Scale for severity is defined as follows:-

- 5: Mission failure
- 4: Major impact on mission performance
- 3: Deterioration in mission performance
- 2: Minor impact on mission performance
- 1: No effect on mission performance

Risk Priority Number (RPN)

Risk Priority Number is an alternate evaluation approach to Criticality Analysis. The risk priority number provides a qualitative numerical estimate of design risk. RPN is defined as the product of three independently assessed factors: Severity(S), Occurrence (O) and Detection (D).

RPN = (S) * (O) * (D)

RPN= (severity)*(occurrence)*(detection)

Recommended Actions

To improve the system and its design should be compiled addressing the most important potential problems according to the failures caused. These include inspection, testing, redesigning of the product/process, replacing individual components, adding redundancy to the system or its components, scheduling preventive maintenance etc.

RESULTS

FMECA analysis is demonstrated as an useful method for ranking the failures based on the system for detection, frequency of occurrence of failures and the severity of failures. FMECA is carried out on the elements and the components of the DC brush motor. The criticality has been assessed for reducing the risk of failures.

The following major risk assessments were derived from FMECA analysis:-

- Failure component leading to high failure based on the frequency of occurrence is identified in this study. The possibility to perpetuate the mission failures of system in these cases is high. Since one or two failures often occur leading to system failure this must be prevented.
- The detection in some cases is ranked as 1 and 2 these leads to high failures. These failures affect the spacecraft mission.
- The severity with respect to some failure events was ranked as 4 and 5.
- The severity and detection ratings for some failure events are listed as follows:-

  Motor interface bracket detection as 1, observation as 1 and severity as 5. Kevlar drive cable detection as 1, observation as 2 and severity as 5. Spool interface detection as 1, observation as 3 and severity as 5. Bevel gears detection as 1, observation as 2 and severity as 5. Kick off springs detection as 1, observation as 1 and severity as 4. Spring anchor pins detection as 1, observation as 1 and severity as 4. Bonded joints detection as 2, observation as 2 and severity as 5.
- Based on the risk priority number. Spring anchor pins has RPN of 4, Motor interface bracket has RPN of 5, and Kevlar drive cable and Bevel gears has RPN of 10. Spool interface 15, Kick off springs and bonded joints has RPN of 20. These elements have high risk of failures leading to the failure of DC brush motor while on-orbit. Hence corrective measure has been suggested so as to reduce risk of failures.

CONCLUSIONS

FMECA on DC Brush Motor

The dominant failure modes identified from the performance test data and FMECA analysis on DC brush motor are:

Electrical Failures

The Dominant failure modes in the Electrical side of the DC Brush motors are:-

Winding Failure in short mode, Winding Failure in open mode, Insulation failure, Reduction in torque/ Increase in current, No Current, Failure of insulating material, grounding failure.

Mechanical Failures

The Dominant Failure modes on the Mechanical side are:-

Breaking, yielding, bending, shear, jamming of gears, improper backlash, non-coplanar hinge line, bond failure in shear due to thermal fatigue, no drive force, high friction force, no spring kick off torque/ less torque, less backlash, misalignment of gears, temperature excursion, excessive shear load, excessive load and wear.

The Corrective Actions Suggested for Reducing the Risk DC Brush Motor Failures are

- Motor has to be separately qualified for all the environments and loads.
- A separate document should exist for qualification and acceptance.
- Performance test in IST mode to be added, a current limit circuit to be introduced in the circuit. Redundant motor or redundant winding to be introduced.
- Insulation check at high voltage under extreme temperature in vacuum to be carried out. Grounding of motor body to be carried out.
- Methods must be explored for having sufficient margin of safety for all components.
- Sufficient design margin of 2.54 available and Brinell hardness is 500 BHN for the bevel gear.
- Sufficient clearance to be ensured in temperature extremes to avoid jamming of gears.

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APPENDICES

Table 5: FMECA Worksheets

Sl No	Part Description	Part Function	Failure Mode	Failure Causes	Immediate Effect	System Level Effect	D	O	S	RPN	Prevention/Correction Action
1.	DC Brush Motor for DRT Deployment	Provides Drive Torque For deployment	Winding Failure In short Mode	Excessive Current	Reduction In torque/ Increase in Current	Reduction In torque Margin	2	1	5	10	Motor has to be Separately qualified for all the environments and loads. A separate document should exist for qualification and acceptance. Performance test in IST mode to be added, current limit circuit to be introduced. Redundant motor or redundant winding to be introduced.
			Winding Failure In open mode	No Current	No Current, no torque	No Deployment	2	1	5	10	Motor has to be separately qualified for all the environments and loads. A separate document should exist for qualification and acceptance. Performance test in IST mode to be added, current limit circuit to be introduced. Redundant motor is there.
		Full deployment may not take place	Insulation failure	Failure of insulating material, grounding failure	Reduction in torque/No torque	Full deployment may not take place	2	1	5	10	Insulation check at high voltage under extreme temperature in vacuum will be carried out. Grounding of motor body will be carried out. No redundancy, life test required.
2.	Motor interface bracket	Provides support for motor mounting	Bending	Excessive load	No drive force	No deployment	1	1	5	5	Available margin of safety to be checked and to be qualified through tests.
3.	Kelvar drive cable	Transfer drive force from motor to deploying member	Breaking	Excessive load	No drive force	No deployment	1	2	5	10	Having sufficient margin of safety.
4.	Spool interface	Provide support for spool	Shear	Excessive shear load	No drive force	No deployment	1	3	5	15	Available margin of safety to be checked and to be qualified through tests.
5.	Bevel gears-1&2	It converts multi-degree of freedom to single-degree of freedom and provide a co-ordinated deployment	Failure due to excessive stress or wear	Excessive load, wear	High friction force	May slow down/prevent the full deployment of the antenna and latch up	1	2	5	10	Sufficient design margin of 2.54 available and Brinell Hardness is 500 BHN.
			Jamming of gears, improper backlash, Non-coplanar hinge line	Less backlash, misalignment of gears, temperature excursion	High friction force	May slow down/prevent the full deployment of the antenna and latch up	2	2	5	20	Sufficient clearance to be ensured in temperature extremes to avoid jamming of gears.
6.	Kick off springs (torsion springs LH & RH)	To provide initial stating torque for kick-off	Yielding	Excessive load, temperature excursion	No spring kick off torque	No kick off force	1	1	4	4	Adequate safety margin of 0.317 exists.
7.	Spring anchor pins	Anchor the ends of the spring	Shear, bending (Yielding)	Excessive load, temperature excursion	No spring kick off torque/ less torque	No kick off force / reduction in force	1	1	4	4	Sufficient margin of safety to be ensured.
8.	Bonded joints	Join the CFRP tubes to the hinge tube location	Bond failure in shear due to thermal fatigue	Bond material failure due to excessive load or temperature excursion	Structural instability	Due to structural instability, stiffness and required aperture dia. May not be achieved	2	2	5	20	Bonds need to be qualified in temperature extremes and provision of riveting along with adhesive bonding should be studied.