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Failure Modes and Effects Analysis of Magneto-Rheological Brake

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Abstract— In this work, an effort has been made to study the reliability analysis of the system using the Failure Modes and Effects Analysis (FMEA) technique. FMEA is a development tool used to identify failures and effects on system, products or services. In addition to identifying failure modes and failure mode effects, FMEA provides for quantification and categorisation of failure information in order to allocate and prioritize the risk. The greatest impact of FMEA is in pre-production phases of new product or system development in order to provide failure free systems and products during implementation. FMEA is a versatile tool that has many expressions and that can be integrated with the statistical and software tools to provide for a comprehensive view of risk. Thus, the various possible causes of failure and their effects of a magneto-rheological (MR) brake along with the ways of prevention are discussed in this work.

Index Terms— MR Brake, FMEA, Probability, Risk Priority Number (RPN), Recommendations.
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1 INTRODUCTION

Magneto rheological (MR) brake is type of brake, which works on the principle of properties of MR fluid. A magneto-rheological fluid is smart fluid which changes its phase from liquid to the solid on the application of lagnetic field and vice versa only within few mili seconds [1].

In the case of all fluids the variation of viscosity with temperature is reversible but this does not allow the viscosity to be controlled easily. In the case of MR the fluid viscosity becomes intelligently controllable using the magnetic field. This change of viscosity up to the solid condition is reversible and is the basic feature of MRF technology [2], [3].

MR brake actuates in following manner; when magnetic field is applied, viscosity of fluid suddenly increases due to a chain like structures. This chain-like structure restricts the motion of the fluid and therefore changes the rheological behavior of the fluid. The MR-effect is produced because of this resistance to flow caused by the chain-like structure. Since there is no mechanical linkage in this brake so the stopping distance & stopping time to stop the vehicle is less [4].

Reliability is the probability of a device performing its purpose adequately for the period intended under the given operating conditions [5], [6].

Reliability is carried out by two ways [7],

(a) Qualitative Analysis:
  1. Failure mode effective analysis (FMEA)
  2. Fault tree Analysis (FTA)

(b) Quantitative Analysis:
  1. Probabilistic Risk Assessment (PRA)
  2. Statistical Process Control (SPC)

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2 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

2.1 Introduction to FMEA

Failure mode and effect analysis (FMEA) is primarily a quality planning tool. It is useful in developing features and goals for both products and processes, in identifying critical product/process factors and designing counter measures to potential problems, in establishing controls to prevent process errors, and in prioritizing process subunits to ensure reliability.

Failure mode and effect analysis is a tool that examines potential product or process [8].

The FMEA process is typically utilized in three areas of product realization and use, namely **design, manufacturing and service**. A design FMEA examines potential product failures and the effects of these failures to the end user, while a manufacturing or process FMEA examines the variables that can affect the quality of a process. The aim of a service FMEA is to prevent the misuse or misrepresentation of the tools and materials used in servicing a product [8].

There is not a single, correct method for conducting an FMEA; however the automotive industry and the U.S. Department of Defense (Mil-Std-1629A) have standardized procedures/ processes within their respective realms. Companies who have adopted the FMEA process will typically adapt and apply the process to meet their specific needs [8].

The FMEA process supports the design process by

- Objectively evaluating the design through a knowledgeable team,
- Improving the design before the first prototype is built,
- Identifying specific failure modes and their causes,
- Assigning risk-reducing actions that are tracked to closure.

Successful implementation of FMEA will

- Improve the reliability and quality of product while identifying safety issues,
- Increase customer satisfaction,
- Reduce product development time,
- Track corrective action documentation,
- Improve product and company competitiveness,
- Improve product image.

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2.2 Process to conduct FMEA

Following steps are consider for processing the Failure Mode Effect Analysis (FMEA) [8].

- Identify all components or systems at given level of the design hierarchy.
- List the function of each identified component or system.
- Identify failure modes for each component/system. Typically there will be several ways in which a component can fail.
- Determine the effect (both locally and globally) on the system.
- Classify the failure by its effects on the system operation.
- Determine the failure's probability of occurrence.
- Identify how the failure mode can be detected (may point out what needs to be inspected on a regular basis).
- Identify any compensating provisions or design changes to mitigate the failure effects.

A group of experts goes through the design of a system, considers all possible faults of all involved components and attempts to identify their impact on the fulfillment of the functionality and safety of system. When potential failure modes are identified, corrective action can be taken to eliminate them or to continually reduce a potential occurrence. The FMEA also documents the rationale for the chosen manufacturing process. It provides for an organized critical analysis of potential failure modes and the associated causes for the system being defined. The technique uses occurrence and detection probabilities in conjunction with severity criteria to develop a risk priority number (RPN) for ranking corrective action considerations [9].

Performing the task is costly, because precious expert working hours are spent, and it is error prone, because human analysis tends to be incomplete. It is also repetitive, because, at least in theory, it should be applied after major design modifications. The procedure described in is summarized in Figure 1 [9].

2.3 Elements of FMEA

1. **Failure -**the way in which a design fails to perform as intended or according to specification.
2. **Effect-** the customer resulting from the failure mode.
3. **Cause** -which an element of the design resulted in a failure Mode.

It is important to note that the relationship between and within failure modes, effects and causes can be complex. For example, a single cause may have multiple effects or a combination of causes could result in a single effect. To add further complexity, causes can result from other causes, and effects can propagate other effects [10].

An effective FMEA identifies corrective actions required to prevent failures from reaching the customer; and to assure the highest possible yield, quality, and reliability Designers often focus on the safety element of a product, erroneously assuming that this directly translates into a reliable product. If a high safety factor is used in product design, the result may be over-designed, unreliable product that may not necessarily be able to function as intended.

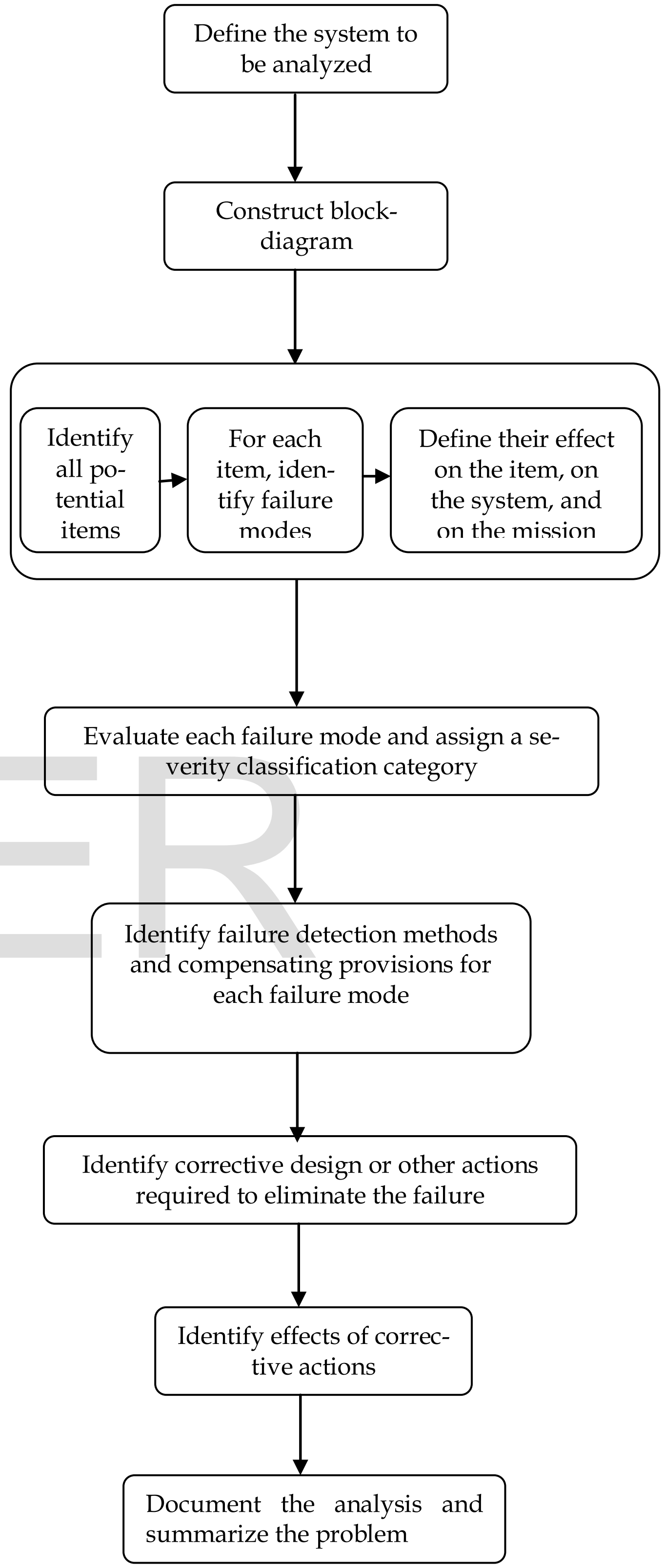

Fig.1 FMEA Process flow chart [9]

2.4 Scope of FMEA

The FMEA is comprised of two sections: a Functional Block Diagram (FBD), and the Failure Modes and Effects Analysis (FMEA) spreadsheet [11].

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FMEA utilizes a team generally composed of the following sections:

- Design Engineering,
- Manufacturing Engineering,
- Field Service [7].

2.5 Functional Block Diagram (FBD)

The functional block diagram is a step-by-step diagram that details the functionality of a development process. The process is broken down in to three parts-input, process and output. The FBD is high level diagram detailing the high level processes that take place for each input, process and output. The FBD cannot begin until there is technical understanding of the design or process by all the FMEA team members. Here team leader provides the necessary detailed information, i.e. schematics mechanical drawings theory of operation and so on. The team must be sure that they agree that they understand the device or system described by the team leader and his documentation.

The following steps are considered for drawing the FBD:

- Identify the high-level processes that take place in the design.
- Identify the inputs and outputs.
- Write three FBD labels (Input, Process, Output).
- Place the labels on the wall beneath each FBD titles.
- Identify the necessary inputs for high-level process and align them under the high INPUT label.
- Finally, write down the outputs that results from the process, placing them under the OUTPUT label.

2.5.1 Functional Block Diagram (FBD) of MR brake

We have done the functional block diagram of MR brake. Following Figure 2 shows the FBD of MR brake,

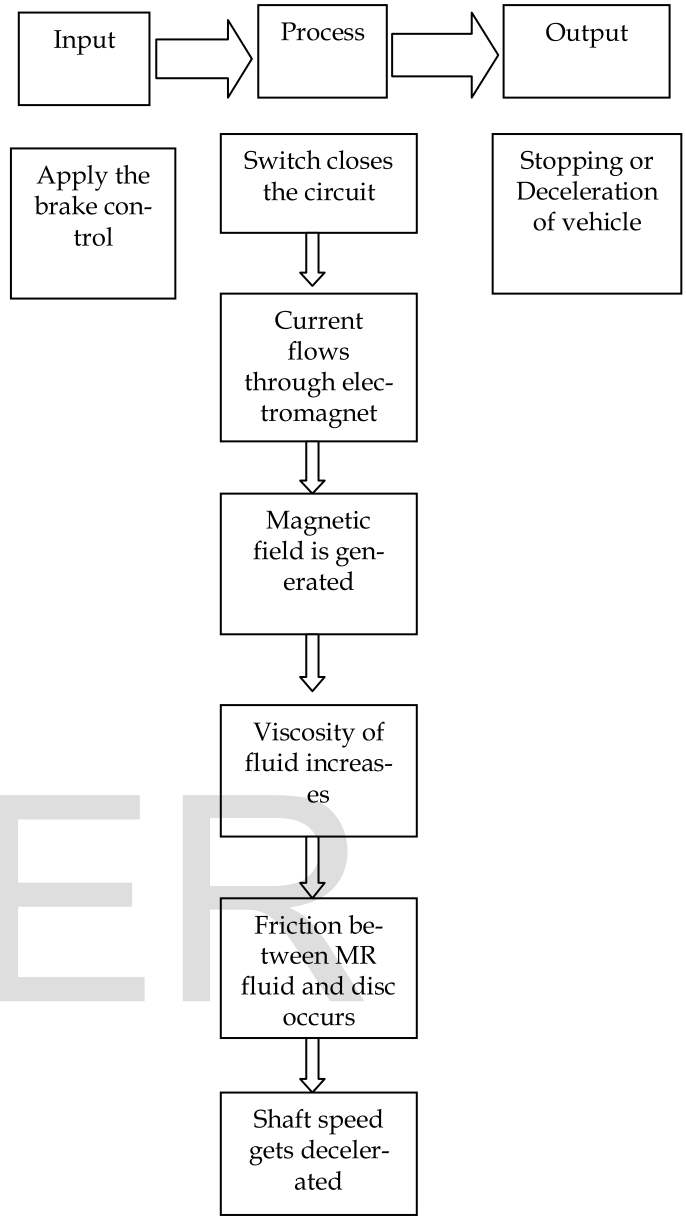

FIG. 2 FUNCTIONAL BLOCK DIAGRAM (FBD) OF MR BRAKE

2.6 FMEA Spreadsheet

The FMEA spreadsheet is a form that consolidates the FBD and fault tree in a manner that facilitates organizing the relative importance or risks of the failure mode. The FMEA spreadsheet has several columns. User can modify number of columns as per suitable requirements. The table 1 describes the standard spreadsheet and the columns from the spreadsheet described are as follow:

Failure Modes & Effect Analysis
FMEA#: **Company/Organization Name:**
Assembly:
Owner:
Date:
Team Members:

TABLE **1**
STANDARD FMEA SPREADSHEET

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
NO.	Failure Mode	Cause	Effects	Fault Detection	S	O	D	RPN	H	FRU	Recommendtions	Who?	When?	Audit

2.6.1 Standard FMEA Spreadsheet

1. **Line or row number:** (We do not have this one and should add it to the form).
2. **Failure mode:** A brief description of the low-level failure mode.
3. **Cause:** What could cause failure to occur?
4. **Effects:** What effect does this failure have on the top-level design on process?
5. **Fault detection:** What could have been put in place to minimize or prevent the failure mode from occurring?
6. **Severity(S):** A metric in units from 1 to 10, with 1 as minor and 10 as major. Severity is thought of from the point of view of the customer or end user.
7. **Occurrence (O):** A metric in units from 1 to 10 with 10 the most frequent and 1 the least frequent. It is an estimate of the probable period before observing an oc-

currence; generally thought of as a field failure issue.

8. **Detection Ranking (D):** A metric in units from 1 to 10 with 1 as very high probability that the failure mode will be detected and 10 as very high probability that it will not.
9. **Risk Priority Number (RPN):** A metric that is the product of occurrence, severity and detection ranking. This number can range between 1 and 1000. The higher the RPN number the higher the risk of the failure mode.
10. **Hazard or Safety (H):** Does this failure mode create a hazard? Does this failure mode create a safety problem?
11. **Field Replaceable Unit (FRU):** Used to generate a recommendation for FRUs to your field service department.
12. **Recommended Action (What):** A brief description of what the FMEA team recommends will have to be done to mitigate the failure mode.
13. **Who:** The person or persons assigned to the recommended action.
14. **When:** The date on which the recommended action is to be completed.
15. **Audit (A):** A check-off placeholder that indicates that the recommended action has been completed to the satisfaction of the FMEA team.

2.7 Risk Priority Number (RPN) Ranking

For calculating the RPN number it is essential to know the Occurrence, Severity and Detect ability ranking. The scale for calculating Occurrence, Severity and Detect ability ranking, use ratings as given in table 2.

2.7.1 Risk Priority Number (RPN) Calculation

RPN is nothing but risk priority number**.** When the severity, occurrence and delectability columns have been completed, the next step is to calculate RPN by multiplying three metrics together. The RPN number can range between 1to1000. Risk Priority Number is calculated by,

RPN=S*O*D

Where,

RPN=Risk Priority Number,
S=Severity,
O=occurrence,
D=Detection.

After you have completed entering all the RPN numbers, you will observe that the FMEA is beginning to take shape. Usually, there will be many numbers below a certain level or baseline. There will be few numbers above that baseline as well. The magnitude of RPN will highlight the top areas that need to be considered for improvement

TABLE **2**
RPN RANKING(Levin,2008)

	Occurrence Rating		**Severity Rating**		**Detect ability Rating**
1	Failure is unlikely or remote	1	Essentially no effect	1	Certain detection
2	Less than 1 per 100000	2	Not noticeable by customer	2	Very probable detection
3	Less than 1 per 10000	3	Noticed by discriminating customer	3	Probable detection
4	Less than 1 per 2000	4	Noticed by typical customer	4	Moderate detection probability
5	Less than 1 per 500	5	Slight customer satisfaction	5	Likely detection
6	Less than 1 per 100	6	Some measurable deterioration	6	Low detection probability
7	Less than 1 per 20	7	Degraded performance	7	Very low detection likely
8	Less than 1 per 10	8	Loss of function	8	Remote detection likely
9	Less than 1 per 5	9	Main function loss, customer dissatisfaction	9	Very remote detection
10	Less than 1 per 2	10	Total system loss, customer very dissatisfied	10	Uncertainty of detection

2.8 FMEA Spreadsheet for MR Brake

We have done the FMEA Spreadsheet for magneto-rheological Brake (MR Brake). Table 3 represents the overall Spreadsheet for MR Brake and recommendations have been tubulated in Table 4.

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TABLE 3
FMEA FOR MAGNETO-RHEOLOGICAL (MR) BRAKE

Sr. No.	Failure Mode	Cause	Effects	Fault Detection	S	O	D	RPN
1.	Open circuit	Corroded switch	Brake not actuating	Visual inspection	09	01	02	**18**
		Damage to conductor	Brake not actuating	Visual inspection	10	02	03	**60**
		Improper mounting of switch	Brake not actuating	Visual inspection	09	04	03	**108**
		Use of weak spring	Brake not actuating	Visual inspection	09	04	03	**108**
		Improper Connection	Brake not actuating	Diagnostic check	09	05	02	**90**
2.	Leakage of MR Fluid	Improper Mounting of seal	Brake Inadequate	Visual inspection	09	04	03	**108**
		Breakage of seal	Brake Inadequate	Visual inspection	10	03	01	**60**
		Cracked casing	Brake Inadequate	Visual inspection	10	01	02	**10**
		Dimensional inaccuracy of mating parts	Brake Inadequate	Measurement and Inspection	10	04	06	**240**
3.	No supply or insufficient current	Discharged battery	Brake not actuating	Diagnostic check	10	04	03	**150**
		Failure of charging system	Brake not actuating	Diagnostic check	08	03	03	**72**
		Short circuit	Brake not actuating	Diagnostic check	09	05	02	**90**
		Damaged battery	Brake not actuating	Diagnostic check	10	02	04	**80**
		Loose contact of terminals	Brake not actuating	Visual inspection	09	06	01	**54**
		Failure of relay	Brake Inadequate	Diagnostic check	09	03	02	**54**
4.	Degradation of MR Fluid	Thickening of MR fluid due to aging	Brake not actuating	Laboratory testing	08	02	04	**64**
		Thinning of MR fluid due to temperature	Brake Inadequate	Laboratory testing	10	04	04	**160**
		Contamination	Brake Inadequate	Laboratory testing	09	04	04	**144**
		Change in chemical composition	Brake Inadequate	Laboratory testing	09	03	04	**108**
		Incorrect chemical formulation	Brake Inadequate	Laboratory testing	09	03	04	**108**
5.	Increased gap size	Due to wear of disc or stator	Brake Inadequate	Measurement and Inspection	07	03	02	**54**
		Deflection of casing, disc or stator	Brake Inadequate	Measurement and Inspection	07	02	02	**28**
		Due to bearing failure	Brake Inadequate	Visual inspection	07	05	03	**105**
6.	Bearing failure	Wear due to lack of lubrication	Brake Inadequate	Visual inspection	07	04	03	**84**
		Vibrations	Brake Inadequate	Visual inspection	07	05	04	**140**
		Seizure due to improper mounting or improper fit	Brake Inadequate	Visual inspection	07	06	02	**84**
7.	Insufficient torque	Incorrect selection of MR Fluid	Brake Inadequate	Laboratory testing	07	01	05	**35**
		High gap size	Brake Inadequate	Measurement and Inspection	07	02	02	**28**

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		Low magnetic field strength	Brake Inadequate	Laboratory testing	07	03	04	**84**
		Heavy weight of brake assembly	Brake Inadequate	Measurement and Inspection	07	02	02	**28**
		Less surface area	Brake Inadequate	Measurement and Inspection	07	02	04	**56**
		Magnetic saturation	Brake Inadequate	Laboratory testing	07	04	05	**140**
		Insufficient current	Brake Inadequate	Diagnostic check	07	05	01	**35**

RECOMMENDATIONS:-

TABLE 4
RECOMMENDATIONS ON OVERALL FMEA

Sr. No.	**RPN RANGE**	**CAUSE**	**RPN**	**RECOMMENDATIONS**
1.	Above 500	NIL	-	-
2.	Above 200-300	Dimensional inaccuracy of mating parts	240	• Tolerance and fits to be ensured and 100% inspection to be made compulsory in process plan itself. • Gauges should be used during inspection/Quality Control process. • SQC tools like x and R chart should be used so as to control the process.
3.	Above 100-200	Use of weak spring	108	• Hardening of spring is recommended.
		Improper mounting of switch	108	• A visual check should be made compulsory to ensure proper mounting of switches. • Proper connection of switch be ensured and testing be made mandatory.
		Discharged battery	150	• Water top up and cleanliness of terminals be ensured after every two months. • Periodic check on charging system is recommended.
		Thinning of MR fluid due to temperature	160	• Material of high thermal conductivity like Aluminum and alloys is recommended for casing of MR Brake. • During design stage, feasibility for cooling /ventilation be studied.
		Contamination	144	• Good quality seals based on criterion of compatibility with MR fluid be selected. • Seals should be mounted properly during the assembly of the brake.
		Change in chemical composition	108	• Correct formulation of MR fluid be ensured during design stage. • Periodic certification for MR fluid composition be made mandatory during the usage period.
		Incorrect chemical formulation	108	• Selection of MR fluid be based on functional requirements. • Chemical analysis and certification of batch sampling be made mandatory.
		Vibration	140	• Proper mounting of bearing should be ensured in the form of alignment of shaft outer diameter and bearing inner race.
		Due to bearing failure	105	• Bearing of appropriate load carrying capacity be used during design and assembly. • Periodic lubrication of bearing be ensured. • Bearing be mounted properly on the shaft.
		Magnetic saturation	140	• MR fluid with high magnetic saturation be selected/formulated. • Maximum current level for the MR Brake operation based on magnetic saturation limit be identified and set in the system.

2.8.1 FMEA spreadsheet for Magneto-rheological Brake (MR Brake) –Design stage:

We have done the FMEA spreadsheet for Magneto-rheological Brake (MR Brake) –Design stage. Table 5 represents the spreadsheet for MR Brake in design stage and in table 6, recommendations have been tabulated.

TABLE 5
FMEA FOR MR BRAKE (DESIGN STAGE)

Sr. No.	Failure Mode	Cause	Effects	Fault Detection	S	O	D	RPN
1.	Leakage of MR Fluid	Dimensional inaccuracy of mating parts	Brake inadequate	Prototype testing	10	04	06	**240**
2.	Degradation of MR Fluid	Incorrect chemical formulation	Brake inadequate	Prototype testing	09	03	04	**108**
		Thinning of MR fluid due to temperature	Brake inadequate	Prototype testing	10	04	04	**160**
3.	Increased gap size	Due to wear of disc or stator	Brake inadequate	Prototype testing	07	03	02	**54**
4.	Bearing failure	Vibrations	Brake inadequate	Prototype testing	07	05	04	**140**
5.	Insufficient torque	Incorrect selection of MR fluid	Brake inadequate	Prototype testing	07	01	05	**35**
		High gap size	Brake inadequate	Prototype testing	07	02	02	**28**
		Low magnetic field strength	Brake Inadequate	Prototype testing	07	03	04	**84**
		Heavy weight of brake assembly	Brake inadequate	Prototype testing	07	02	02	**28**
		Less surface area	Brake inadequate	Prototype testing	07	02	04	**56**
		Magnetic saturation	Brake inadequate	Prototype testing	07	04	05	**140**
		Insufficient current	Brake inadequate	Prototype testing	07	05	01	**35**

RECOMMENDATIONS:-

TABLE 6
RECOMMENDATIONS ON DESIGN STAGE FMEA

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Sr. No.	RPN RANGE	CAUSE	RPN	RECOMMENDATIONS
1.	Above 500	Nil	-	-
2.	Above 200-300	Dimensional inaccuracy of mating parts	240	• Tolerance and fits be selected for shaft and disc assembly.
3.	Above 100-200	Incorrect chemical formulation	108	• Selection of MR fluid be based on functional requirements. • Chemical analysis and certification of batch sampling be made mandatory.
		Vibrations from bearing	140	• Appropriate bearing be selected based on static and dynamic load capacity of the same. • Instructions with regard to proper mounting of bearing should be included in the design document.
		Magnetic saturation	140	• MR fluid with high magnetic saturation be selected/formulated. The minimum magnetic saturation limit should be 250kA/m. • Maximum current level for the MR Brake operation based on magnetic saturation limit be identified and set in the system. It should never exceed 2.0 amps.
		Thinning of MR fluid due to temperature	160	• A temperature indicator/gauge be provided on the display panel of vehicle.

2.8.2 FMEA for Magneto-rheological Brake (MR Brake) (Manufacturing and Assembly Stage):

We have done the spreadsheet FMEA for Magneto-rheological Brake (MR Brake) (Manufacturing and Assembly Stage). Table 7 represents the FMEA for Magneto-rheological Brake (MR Brake) in (Manufacturing and Assembly Stage). And we also tabulated recommendations in Table 8.

TABLE 7

FMEA FOR MR BRAKE (MANUFACTURING AND ASSEMBLY STAGE)

Sr. No.	Failure Mode	Cause	Effects	Fault Detection	S	O	D	RPN
1.	Leakage of MR Fluid	Improper Mounting of seal	Brake inadequate	Assembly Testing	09	04	03	**108**
		Dimensional inaccuracy of mating parts	Brake inadequate	Online Inspection	10	04	06	**240**
2.	No supply or insufficient current	Loose contact of terminals	Brake not actuating	Assembly Testing	09	06	01	**54**
3.	Degradation of MR Fluid	Incorrect chemical formulation	Brake inadequate	Assembly Testing	09	03	04	**108**
4.	Increased gap size	Deflection of casing, disc or stator	Brake inadequate	Online Inspection	07	02	02	**28**
5.	Bearing failure	Seizure due to improper mounting or improper fit	Brake inadequate	Assembly Testing	07	06	02	**84**
6.	Insufficient torque	High gap size	Brake inadequate	Assembly Testing	07	02	02	**28**

RECOMMENDATIONS:-

TABLE 8

RECOMMENDATIONS ON MANUFACTURING AND ASSEMBLY STAGE FMEA

Sr. No.	RPN RANGE	CAUSE	RPN	RECOMMENDATIONS
1.	Above 500	Nil	-	-
2.	Above 200-300	Dimensional inaccuracy of mating parts	240	• Tolerance and fits to be ensured and 100% inspection to be made compulsory in process plan itself. • Gauges should be used during inspection/Quality Control process. • SQC tools like X and R chart should be used so as to control the process.
3.	Above 100-200	Improper mounting of switch	108	• Proper connection of switch be ensured and testing be made mandatory.
		Incorrect chemical formulation	108	• Batch sampling at appropriate frequency be made mandatory. • Third party certification be introduced at certain time intervals.

2.8.3 FMEA for Magneto-rheological Brake (MR Brake) (Field Stage):

We have done the Spreadsheet for Magneto-rheological Brake (MR Brake) (Field Stage). Table 9 represents the FMEA for MR Brake in Field Stage and the recommendations for the same have been tubulated in Table 10.

TABLE 9

FMEA FOR MR BRAKE (FIELD STAGE)

Sr. No.	Failure Mode	Cause	Effects	Fault Detection	S	O	D	RPN
1.	Open circuit	Damage of conductor	Brake not actuating	Visual inspection	10	02	03	**60**
2.	Leakage of MR Fluid	Breakage of seal	Brake inadequate	Visual inspection	10	03	01	**60**
		Cracked casing	Brake inadequate	Visual inspection	10	01	02	**10**
3.	No supply or insufficient current	Discharged battery	Brake not actuating	Diagnostic check	10	04	03	**120**
		Failure of charging system	Brake not actuating	Diagnostic check	08	03	03	**72**
		Short circuit	Brake not actuating	Diagnostic check	09	05	02	**90**
		Damaged battery	Brake not actuating	Diagnostic check	10	02	04	**80**
		Loose contact of terminals	Brake not actuating	Diagnostic check	09	06	01	**54**
		Failure of relay	Brake inadequate	Diagnostic check	09	03	02	**54**
4.	Degradation of MR Fluid	Thickening of MR fluid due to aging	Brake not actuating	Laboratory testing	08	02	04	**64**
5.	Bearing failure	Wear due to lack of lubrication	Brake inadequate	Visual inspection	07	04	03	**84**
6.	Insufficient torque	Insufficient current	Brake inadequate	Diagnostic check	07	05	01	**35**

RECOMMENDATIONS:-

TABLE 10

RECOMMENDATIONS ON FIELD STAGE FMEA

Sr. No.	RPN RANGE	CAUSE	RPN	RECOMMENDATIONS
1.	Above 500	Nil	-	-
2.	Above 200-300	Nil	-	-
3.	Above 100-200	Discharged battery	150	• Guidelines for battery servicing be included in user service manual. • A check on charging system be suggested in the service manual.
		Thinning of MR fluid due to temperature	160	• User be sensitized about the effect of temperature on the operation of MR fluid. • Further use of brake application be avoided on hearing blinking noise which should be made to occur when temperature exceeds 140^{o} C.
		Due to bearing failure	105	• Instruction with regard to bearing lubrication be added in the service manual.

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Thus, FMEA for MR Brake in all stages has been carried out and recommendations to avoid failure which are more severe have been identified.

3 Conclusion

Stage-wise FMEA for MR Brake has been evaluated and it has identified severe failure modes. To avoid these failure modes, the recommendations have been suggested on the same, such as:

a. Tolerance and fits to be ensured and 100% inspection to be made compulsory in process plan of leakage of MR Fluid.
b. SQC tools like x and R chart should be used so as to control the Manufacturing process of disc and stator.
c. During design stage, feasibility for cooling /ventilation should be studied.
d. Proper mounting of bearing should be ensured in the form of alignment of shaft outer diameter and bearing inner race.

With the implementation of these recommendations, one can improve the reliability of MR Brake system. Still, battery technology is not that much reliable so that we cannot substitute the conventional hydraulic system by MR Brake system, since MR Brake largely depends on battery. So, MR Brakes are recommended to be used in combination with conventional hydraulic brake system for motor vehicles.

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