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Failure Modes and Effect Analysis of Electro-Pneumatics System

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Abstract: **This paper presents the FMEA (Failure Modes and Effect Analysis) as a methodology to analyze the electro-pneumatics system. A minor failure may lead to severe impact on the performance of the equipment. The Failure Mode and Effect analysis is a primarily a quality planning tool to identify failure and effect and prioritize the risk on system, product or service. It is used to establish control, prioritize process and prevent process errors. Thus, the various possible causes of failure and their effects of an electro-pneumatic system used in along with ways of prevention are discussed in the work.**

Keywords: **FMEA, Risk Priority Number (RPN), Recommendations, Detection Number, Severity Number, Occurrence.**

I. INTRODUCTION

Failure Modes and Effect Analysis (FMEA) was first developed design methodology by the aerospace industry for safety requirements. Failure Modes and Effect Analysis (FMEA) aims to identify the modes in which a product, service or process can fail and hence estimate the risk associated with the specific failure causes. Knowing the failure causes we can prioritize the actions to reduce risk of failure and make current control plan (process). Advantages of FMEA are:

- Improve the quality, reliability and safety of a product
- Increase customer satisfaction
- Reduce system cost/maintenance cost
- Collect information to reduce future failures
- Reduce potential for concerns

II. FAILURE MODES AND EFFECT ANALYSIS

FMEA is quantitative, systematic method that helps to narrow down Key Process Input Variable (KPIVs) to a manageable number for improvement or further analysis. It reduces cost by identifying system, products and process improvements early in the development cycle.

A. When to use FMEA?

- Designing a new system, product or processes.
- When designs is implemented in new applications.
- System, product or process has been defined but before starting a detailed final design.
- When changing existing system, product or design.

B. Types of FMEA:

There are three types of FMEA.

- Design FMEA: Analyses a new process, product or service design before rollout to understand how it could fail once released. Exposes problems that may result in safety hazards, defects in product or service production processes.
- Process FMEA: Used to improve existing transactional and operational processes to understand how people, materials, equipment, methods and environment cause process problems.
- System FMEA: Analyses systems and subsystems in the early stage of concepts and design.

C. Stages of FMEA:

TABLE I shows the three stages for Failure Modes and Effect Analysis

TABLE I: THREE PHASES OF FMEA

Phase	Question	Output
Identify	What can go wrong?	Failure cause and effect
Analyse	What is the number failure has occurred and what are the consequences	Risk Priority Evaluation= (severity*occurrence*detection)
Act	What can be done to eliminate the failure	Design solution, make plans, etc.

There are of two types namely: Design FMEA and Process FMEA. Design FMEA is to identify the known failure modes and then ranking failures according to the relative impact on the product. The objective of Process FMEA is to improve the existing process and find out how it can affect the system, environment and human. A product is considered to be failed when it does not give desired result or when it malfunctions in some way. It is not necessary that failures can happen only because of design or process failure but also can happen because of the operator error. FMEA is to eliminate the root cause effect of any failure so as to improve the process and make ensure 100% customer satisfaction. Process FMEA is an effort to prevent failures due to process before they happen so as to assess the risk associated with those failure mode, to rank the issues in terms of severity, occurrence and detection and hence find the alternative measures to prevent the failure.

Process FMEA consider five main elements of the process namely: People, Materials, Equipment, Methods and Environment. Each of the failure modes has its own effects, causes and risks. Each potential failure mode of process or product are rated on each of (Severity, Occurrence and Detection) ranging from 1 to 10, low to high. RPN is calculated by using the formula (Severity*Occurrence*Detection). RPN is used to rank the urge for preventive actions to be taken for each failure mode and effect.

D. Severity:

It is the parameter of the impact of the effect of the potential failure modes. In this we have to determine all failure modes based on the functional requirements and their effects. Figure II shows rating scale for severity.

TABLE II: RATING SCALE FOR SEVERITY

Rating	Meaning	Example
10	Hazardous-without warning	Death
9	Hazardous-with warning	may endanger machine/operator
8	Very high	loss of primary function
7	High	reduction of primary function
6	Moderate	loss of comfort function
5	Low	reduction of comfort function
4	Very low	lowered effectiveness
3	Minor	Non-returnable appearance observed several times
2	Very minor	Non-returnable appearance noticed once
1	None	no effect

E. Occurrence:

Occurrence is the chance that the one of cause or mechanism will occur. It is necessary to look at cause of failure and number of times it occurred. A failed design is considered as a design weakness. Table III shows the rating scale of occurrence.

TABLE III: RATING SCALE FOR OCCURENCE

Rating		**Meaning**
10	Very high	Failure is almost inevitable
9 8	High	This process or similar process have often failed
7 6	Moderate	This process has occasionally failed but not in major proportions
5 4 3	Low	Isolated failures associated with similar processes
2	Very Low	Failure likely to happen
1	Remote	Failure unlikely

F. Detection:

Detection rank is determined by the prevention of failure modes from occurring. It is assessment of the probability that the current process will detect s potential weakness or sub failure mode by failure mode of that part/component before it effect the whole system. Table IV shows the rating scale for detection.

TABLE IV: RATING SCALE FOR DETECTION

Rating		Meaning
10	No detection	Controls cannot detect the existence of the failure
9	Very low	Controls probably will not detect the existence of failure mode
8 7	Low	Low chance to detect the fault
6 5	Moderate	Controls may/may not detect the failure mode
4 3	High	Controls have a high probability of detecting failure mode, process automatically
2 1	Very high	Controls almost certain to detect the failure modes

G. Risk Priority Number (RPN):

It is a method to analyse the risk that could occur from potential failures modes identified whole doing Failure Mode and Effect Analysis.

RPN= Severity*Occurrence*Detection

The RPN value for each potential system problem is used to compare issues within analysis, corrective actions may be recommended or required to reduce the risk of occurrence of failure, increase the likelihood of prior detection so that it could be rectifies at early stage and hence reduce severity of the failure effect

H. FMEA Procedure:

There are steps in order to determine a Process Failure Modes and effect Analysis. Fig.1 below shows the steps to find out the Risk Priority Number.

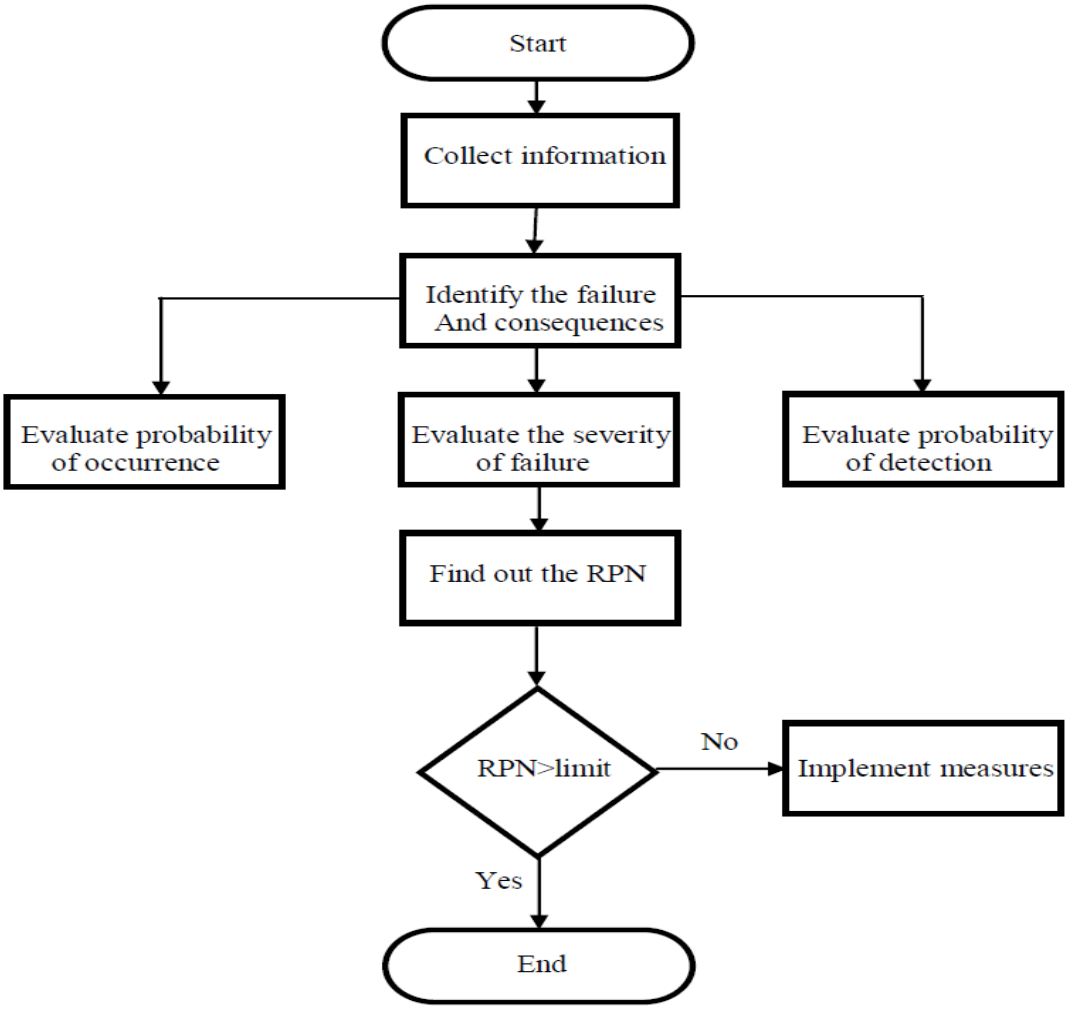

Fig: 1. STEPS FOR FAILURE MODES AND EFFECT ANALYSIS

III. CASE STUDY AND FMEA IMPLEMENTATION

Case study is conducted and FMEA technique is applied to the electro-pneumatic system. For the analysis, the system breakdown details for the past three years are taken. The ranking of severity, occurrence and detection is selected on the basis of the parameters been discussed.

A. Electro-pneumatic:

Pneumatic control system using electricity as actuating medium is termed as Electro-pneumatic control system. Nowadays pneumatic devices use clean and dry air as an energy source for the system. The actuator then converts compressed air into mechanical motion. The type of motion depend on design of actuators. Solenoid operated control valve uses two energy forms- electricity and air.

B. Advantages:

- Quick and sure action
- Less maintenance
- Minimum wastage of energy
- Availability of air
- Cleanliness

C. Uses:

- Door open/close operation
- Material stacking
- Embossing part
- Refinery

D. Working of Electro-pneumatic system:

In Electro-pneumatic system the control of pneumatic cylinder are electrically actuated valves hence has advantage over all other forms. The path of electricity is controlled using switches which is used to make or break electricity contact which controls pneumatic valves. These system are hence termed as electrically or electromagnetically operated valves.

A solenoid is used in such pneumatic valves to act as the actuating elements. A pneumatic control system consists of a pneumatic driving element and an electromechanical control part consist of a solenoid, push button switches, relays, limit switches, etc. The energised coil attracts or repel the valve. When the switch is closed current flows through the coil and the coil get energized it results the valve to move in such a way that it switch the valve and air flows through the cylinder and cylinder piston and cylinder gets filled. When switch is open the solenoid get de-energised and hence the connections breaks off. Electro-pneumatic system are basically classified into three parts: Energy, Control elements and Actuators.

E. Energy:

It consists of compressor, reservoir, and air dryer, etc.

- Compressor: It is a machine that compresses air or other type of gas from a low inlet pressure to higher desired pressure level. This is achieved by decreasing the volume of gas of positive displacement unit.
- Reservoir: It is used to store the compressed air and act as a downstream to stabilises the compressed air
- Air dryer: It is used to remove water from air, the condensate which are found in form of relative air humidity.

F. Control elements:

It consists of valves which are basically used for control flow, direction and pressure of air.

Direction Control Valve: Directional control valve is attach with solenoid so that it can move backward and forward. The movement of the valve allow compressed air to go into the airway. Other type of valves includes: Non return Valve, flow control valve, pressure control valve. There are different types of valves been used in Electro-pneumatic system which are:

- 2/2 way directional valve: It is used to drive air motors and pneumatic tools
- 3/2 way directional valve normally closed type: It is used to drive single acting cylinder or act as on/off switch.
- 3/2 way directional valve normally open type: It is used to drive single acting cylinder
- 5/2 way directional valve: It is used to drive double acting cylinder with individual exhaust.

G. Actuators:

It consists of pneumatic cylinders, pneumatic motors, etc. Actuators are motor which are used to move and control a system. It is operated by mechanically, pneumatically or electrically, etc.

H. Electronics components:

There are six basic electrical devices been used to control fluid power which are:

- Push button Switches: These are used to make or break the electrical circuit for solenoid operated valves. They are primarily used for starting and stopping of operation of machinery. Push button are of two types are momentarily push button which return to their unactuated position when they are released and maintained contact push button- Maintained push button has a latching mechanism to hold it in the required position.

- Relays: They are of an electromagnet devices that control the position of contacts. The operated position is assumed when the magnet is energised. The switches used are either normally closed (NC) or Normally Open (NO) type. In normally closed type switch, the contacts gets broken when actuated whereas in NO it is the opposite of NC.

- Limit Switches: Any switch that is actuated due fluid force component consisting of piston rod and a position of load is termed as limit switch. The limit switch gives an electrical signal whereas limit switch are mechanically actuated.

- Pressure Switches: Pressure switch are used to sense any change in pressure. Diaphragm is used to expand or contracts in response to increase or decrease in pressure. When pressure is applied at the inlet the diaphragm expands and pushes the spring loaded plunger to make/break contact.

- Solenoid: Solenoid is electrically actuated directional control valves which forms a platform between the two ports of electro-pneumatic control. They are switched with the help of solenoid. These are divided into two types namely spring return valves which only remain in actuated position as long as current flows through the solenoid and double solenoid valves which retain the last switched position even when no current flows through the solenoid.

- Temperature switch: They are automatically sense a change in temperature and opens or closes the electrical switch when a predetermined temperature is reached which can be operated either normally open or normally closed.

TABLE V: FMEA CHART

Components	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	DET	Action Recommended	Action taken	Risk Priority Number
Directional Control Valve - Attach with solenoid so that it can move forward and backward thus allow compressed air go into the airway	Failed to allow compressed air to go into the airway of the valve	There is no movement in the directional control valve	8	Pressure outside parameter	4	7	Replace dirty filters, clogged inlet line	Replacement	224
				Incorrect assembly during maintenance	2	7	Check all the connections from the start	Repair the faulty part	112
				Water in the air supply line	6	4	Check Filter, Regulator, Lubrication	Repair the FRL unit	192
				Wear of part	3	4	Replacement	Replacement	96
				No signal/No gas supply	2	3	Check there is no leakage in the system	Hose replaced	48
				Spring problem	3	6	Replacement	Replacement of the spring	144
				Leakage	4	5	Replacement	Replacement	160
				Crack in housing	2	4	Replace or Repair	Repair	64
Non return valves- It allows air to flow in one direction, but blocks it from flowing back in the opposite direction	Failed to pass the air through airway/block the air in opposite direction	There is malfunctioning/no movement of the valve	8	Pressure outside parameter	4	7	1.Replace dirty filters, clogged inlet line 2.Tighten leaky connection	Replacement	224
				Diaphragm failure	1	7	Check there should be no crack in diaphragm	Replacement of the diaphragm	56
				Mechanical failure-spring/ball	2	5	Check the spring/ball minute detail	Replacement of the spring	80

				Incorrect assembly or maintenance	2	7	Check all the connections from the start	Repair the faulty part	112
				Water in the compressed air supply line	6	4	Check the FRL(Filter, Regulator, Lubrication) unit	Repair the FRL unit	192
				No signal/No gas supply	2	3	Check there is no leakage in the system	Hose replaced	48
				Leakage	3	5	1.Check the hose and pipe 2.Replace or Repair	Replacement	120
				Crack in housing	4	4	Replace or Repair	Repair	128
Flow Control Valves-It influence the volume of the flow of compressed air in both the direction	Unable to sense the volume of compressed air to be send to the airway	There is malfunctioning/no movement of the valve	8	Pressure outside parameter	4	7	1.Replace dirty filters, clogged inlet line 2.Tighten leaky connection	Replacement	224
				Diaphragm failure	1	7	Check there should be no crack in the diaphragm	Replacement of the diaphragm	56
				Mechanical failure	2	5	Check the spring/ball in minute detail	Replacement of the spring	80
				Incorrect assembly during maintenance	2	7	Check all the connections from the start	Repair the faulty part	112
				Water in the air supply line	6	4	Check Filter, Regulator, Lubrication	Repair the FRL unit	192
				Wear in parts	3	4	Replacement	Replacement	96
				No signal/No gas supply	2	3	Check there is no leakage in the system	Hose replaced	48
				Cracking of housing	3	4	Replace or Repair	Replacement	96
				Pressure failure	5	6	Replace dirty filters, clogged inlet line	Cleaning of inlet line	240
Pressure Regulators-It reduces a high input pressure to a low working pressure and provides a steady output, despite changes in the	Failed to maintain the range of pressure required for the operation	Insufficient/Excessive pressure	8	Diaphragm failure	1	8	Replacement	Replaced	64
				Leakage	4	5	1.Check the hose and pipe 2.Replace or Repair	Replacement	160
				Intake/Exhaust port failure	6	6	1.Replace dirty filters, clogged inlet line 2.Tighten leaky connection	Leaky inlet connections tightened	288

input pressure				Pressure switch not working	4	6	Replacement	Replaced	192
				Cable connector	3	6	Mechanical failure- broken or damaged connector	Cable connector repaired	144
				Electrical power failure	2	3	Check the electrical panel for proper connections	Electrical connections are corrected	48
Tubing- It is used to transport the compressed air to the desired destination	Compressed air is unable to reach its desired destination	Insufficient/Excessive pressure	6	Bending	6	7	Replacement	Replacement	252
				Clogging (Blocking)	5	5	1.Clean clogged inlet line 2.Change system fluid	Cleaning of inlet line	150
				Leakage	4	5	Tubing material ruptured	Replacement	120
				Fault in connection	3	7	Replace or repair	Replacement	126
Filters- It removes moisture and debris	Contamination problem is encountered	Icing or freezing of the exhaust air, causing the pump to cycle erratically	5	Water in the compressed air supply	3	5	Check FRL(Filter, Regulator and Lubrication unit)	Replacement	75
				Lockout valve failure	2	8	Mechanical failure-handle jammed	Replacement	80
				Clogging	6	3	Clean the pores	Replacement	90
Lubricators- It injection oil mist to help lubricate the moving parts of the system	Insufficient oil in the system	Difficulty in operation of moving parts	5	Clogging/ Blocking	4	4	1.Clean clogged inlet line	System fluid changed	80
				Duct blocked	2	3	Cleaning	Replacement of ducts	30
				Contamination	3	3	Cleaning	Cleaning	45
Silencers-It eliminates the noise coming from the system	Sound come from the system	Loud sound is heard from the system	4	Mechanical failure-ruptured part	2	2	Replacement	Replacement	16
Reservoirs - It stores the compressed air.	Failed to store the compressed air	Insufficient/Excessive pressure	7	Cracking of housing	3	6	Replace or Repair	Replacement	126
				External leak in the system	4	7	Tighten leaky inlet connection	Leaky inlet connections tightened	196
Electric controllers- it used to monitor a process condition in a machine and according give feedback	Failed to receive or send feedback for the closing and opening of switch	The operation of control valve is incomplete	8	Electrical power failure	3	4	Check the electrical panel for proper connections	Connections corrected	96
				Proximity sensor failure	4	5	Component failure inside proximity senor	Sensor Replaced	160
				PLC failure	2	3	Check the wiring of PLC	Snubber circuit can be used	48

IV. ANALYSIS

Detailed component analysis has been done to reduce its failure rates. Proper care should be taken while scheduling maintenance. This process has considered RPN because of its higher degree of severity, occurrence and detection. Proper maintenance and training to engineers can reduce RPN value. Higher RPN has been observed in case of leakage, worn out parts, etc. To reduce RPN these factors must be taken into consideration.

V. CONCLUSION

The work shows the FMEA study of electro-pneumatics system. The electro-pneumatics system is studied and failure modes are identified. Keeping in mind failure effects of faults severity is rated and then based on causes, prevention and number of occurrences, the detection value is rated. Failure modes and Effect Analysis helps to calculate RPN which helps to reduce the possible causes for the failure of component or system.

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