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Process FMEA of Articulated Arm Coordinate Measuring Machine (AACMM) Measurement Process for Verification of Aeroengine Parts

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ABSTRACT: This paper gives a detailed Process Failure Mode and Effects Analysis (PFMEA) for Articulated Arm Coordinate Measuring Machine (AACMM) measurement process for the inspection of Aeroengine parts. The paper gives details comprehensive about the unique challenges of AACMM, focusing on potential failure modes, their severity, occurrence, detection, and corresponding Risk Priority Number (RPN). A FMEA for critical process steps is provided, along with control plans and revised RPN values. The paper emphasises the importance of operator skill, environmental control and data integrity in mitigating risks associated with AACMM.

KEYWORDS: PFMEA, Risk assessment, Articulated CMM, Risk Priority Number, Severity, Occurrence, Detection

NOMENCLATURE:

PFMEA	Process Failure Mode and Effects Analysis
RPN	Risk Priority Number
AACMM	Articulated Arm Coordinate Measuring Machine
CMM	Coordinate Measuring Machine
CP	Control Plan
CFT	Cross Functional Team
SOD	Severity Occurrence Detection
MCS	Machine Coordinate System
PCS	Part Coordinate System

I. INTRODUCTION

Aeroengine parts require precise geometrical and dimensional verification to meet strict safety and performance standards. The AACMM is widely used in the aerospace industry for this purpose. AACMM (Fig.1) is a type of CMM that features a multi-jointed arm with several rotational axes. Each joint can rotate and pivot at articulated joints and angles are measured by the absolute encoders. These machines offer flexibility, portability and reasonably high accuracy to measure complex aeroengine part geometries. However, the measurement process is susceptible to various failure modes that can affect the quality of the product. Hence, their kinematic errors, operator dependency and susceptibility to environmental factors necessitate a robust PFMEA to identify and mitigate risks. PFMEA is an analytical tool to evaluate and identify potential failures modes related to operational processes [1]. These processes can include manufacturing, safety, inspection, management processes. FMEA can be applied to a whole process from beginning to end and also to a specific process like AACMM measurement process [1, 2]. This paper presents a comprehensive PFMEA for the use of an AACMM in measuring aeroengine parts, focusing on identification of the potential failure modes, evaluating risks associated and implementing control measures to minimize these risks.



Fig.1 AACMM during inspection process

There are numerous challenges with AACMM which include kinematic (due to articulated structure), operator influence, environmental sensitivity and part accessibility etc. Hence a robust PFMEA is crucial to identify the potential failure modes and risks involved. The AACMM measurement process consists of the following key steps given in the Fig.2 process steps.

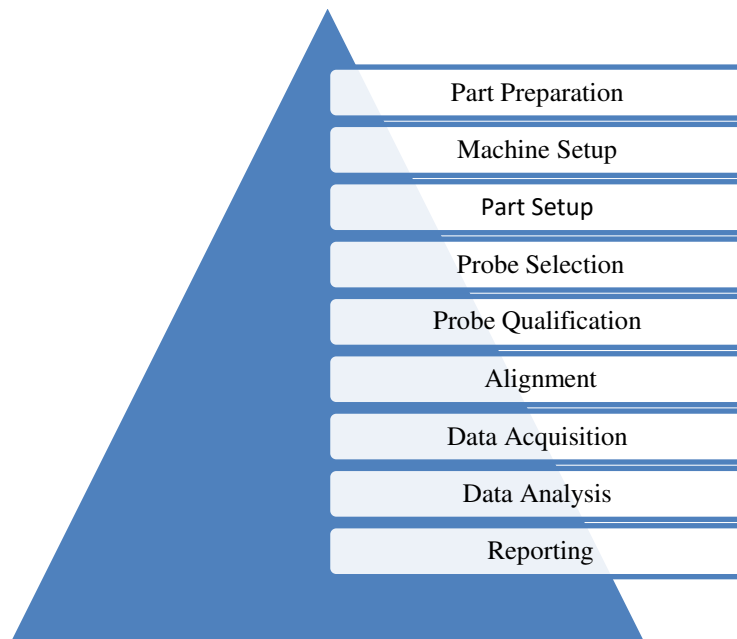


Fig. 2 AACMM measurement process steps

II. PFMEA METHODOLOGY

The PFMEA methodology is utilised to systematically identify and evaluate potential failure modes in the AACMM measurement process (Fig.3).

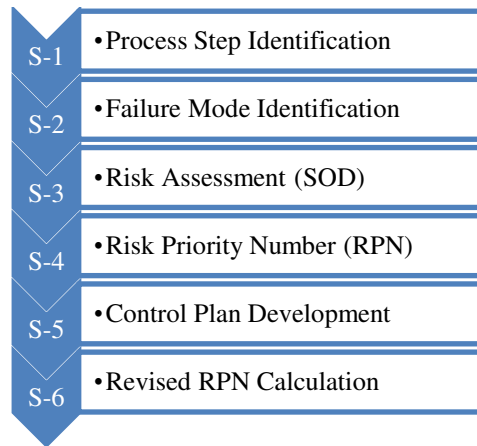


Fig.3 PFMEA process

Process step identification involves breaking down of the measurement process into individual steps and gives detailed description of the AACMM measurement process. S-2 is about identification of the potential failure modes associated with each step and can be performed through brainstorming by Cross Functional Team (CFT). Risk assessment is the next step and it involves assigning Severity (S), Occurrence (O) and Detection ratings to each failure mode identified in the previous step. These are ratings for the impact, likelihood and detectability of the failure modes. S-4 is about determination of the Risk Priority Number. It is calculated as the product of S, O and D determined in S-3. It determines the overall risk priority for each failure. In the next step actions are implemented to mitigate the high RPN risks as determined in the previous step. In the last step (S-6) effectiveness of the control measures is evaluated by calculating the revised RPN. The SODs are ranked on the scale of 1-10 depending on the definition [3].

III. PFMEA ANALYSIS OF AACMM PROCESS FOR AEROENGINE PARTS

The AACMM measurement process can have numerous failure modes depending upon the process step. Various failures with potential effects and causes brainstormed by a cross functional team are given in the following Table 1.

Table 1. Potential Failure modes, effects and causes in AACMM measurement process

Sl No.	Process Step	Potential Failure Mode	Potential Effects of Failure	Potential Causes of Failure
1.	Part preparation	Contamination	Reduced probing accuracy	<ul style="list-style-type: none"> Improper cleaning procedure Presence of foreign material
2.	Machine Setup	Incorrect AACMM Calibration	Inaccurate measurements leading to non-conforming parts	<ul style="list-style-type: none"> Human error wear on machine parts
3.	Part positioning	Misalignment between PCS and MCS or incorrect part orientation	<ul style="list-style-type: none"> Inaccurate measurements Part damage 	<ul style="list-style-type: none"> Improper clamping/fixtures Human error
4.	Probe Selection	Incorrect probe selection	Inaccurate data collection and missed features	<ul style="list-style-type: none"> Inadequate probe selection criteria Probe wear
5.	Probe Qualification	Inaccurate probe qualification	<ul style="list-style-type: none"> Inconsistent measurements Increased measurement uncertainty 	<ul style="list-style-type: none"> Probe tip/Qualification sphere wear Human error

6.	Arm Positioning	Arm instability during measurement	Inaccurate and fluctuating readings/results	<ul style="list-style-type: none"> Worn joints of AACMM Operator error
7.	Measurement Execution	AACMM or software errors	Inaccurate or incomplete measurements	<ul style="list-style-type: none"> Software bugs Machine malfunction
8.	Probe Contact	Insufficient or excessive probe force	<ul style="list-style-type: none"> Dimensional errors Probe damage 	<ul style="list-style-type: none"> Human error Software glitch Machine Hardware malfunction
9.	Environmental Control	Thermal drift or humidity changes	Dimensional inaccuracies	<ul style="list-style-type: none"> Inadequate work environmental control
10.	Data Analysis & interpretation	Misinterpretation of the measurement results	Inaccurate part acceptance or rejection	<ul style="list-style-type: none"> Human error Inadequate training
11.	Portability	Instability of portable setup	Measurements errors due to movement	<ul style="list-style-type: none"> Unstable surface Operator handling

IV. RESULTS & DISCUSSIONS

The PFMEA analysis is carried out through the estimation of the RPN. The following table 2 gives the SOD for the various potential failure modes, current controls and respective RPNs are enumerated.

Table 2. Current Controls and RPNs for identified potential failure modes in AACMM measurement process

SI No.	Potential Failure Mode	Severity (S)	Occurrence (O)	Current Controls	Detection (D)	RPN = S x O x D
1.	Contamination	8	4	<ul style="list-style-type: none"> Regular cleaning of the probe tip and part Operator visual inspection of part and probe for contamination 	4	128
2.	Incorrect AACMM Calibration	9	5	<ul style="list-style-type: none"> Regular calibration Operator training 	3	135
3.	Misalignment between PCS and MCS or incorrect part orientation	8	4	<ul style="list-style-type: none"> Visual inspection Manual alignment 	4	128
4.	Incorrect probe selection	8	4	<ul style="list-style-type: none"> Probe selection list Maintenance 	5	160
5.	Inaccurate probe qualification	9	4	<ul style="list-style-type: none"> Manual calibration of probes Operator training on correct qualification procedure 	4	144
6.	Arm instability during measurement	7	4	<ul style="list-style-type: none"> Regular Maintenance Operator training 	5	140
7.	AACMM or software errors	9	3	<ul style="list-style-type: none"> AACMM maintenance Operator training on troubleshooting Regular software updates Machine Diagnostics 	5	135

8.	Excessive probe force	8	5	<ul style="list-style-type: none"> Operator training Visual inspection Periodic calibration 	4	160
9.	Thermal drift or humidity changes	7	5	<ul style="list-style-type: none"> Controlled environment Monitoring 	4	140
10.	Misinterpretation of the measurement results	8	6	<ul style="list-style-type: none"> Data analysis software Operator training 	5	240
11.	Instability of portable setup	8	4	<ul style="list-style-type: none"> Unstable surface Operator handling 	5	160

Analysing the risk priority matrix for the RPNs, the numbers above the threshold of 100 are analysed, control plans, strategies are deliberated and implemented. The revised SOD and RPNs are shown in the following table 3

Table 3. Control plans and revised SOD and RPNs for identified potential failure modes

SI No.	Potential Failure Mode	RPN	Recommended actions /Control Plans	Revised SOD & RPN
1.	Contamination	128	<ul style="list-style-type: none"> Standardized cleaning procedures for procedure and frequency Improved environmental controls for reducing contamination 	$8 \times 2 \times 2 = 32$
2.	Incorrect AACMM Calibration	135	<ul style="list-style-type: none"> Enhanced training 	$9 \times 4 \times 2 = 72$
3.	Misalignment between PCS and MCS or incorrect part orientation	128	<ul style="list-style-type: none"> Improved fixturing Programmed alignment 	$8 \times 2 \times 2 = 32$
4.	Incorrect probe selection	160	<ul style="list-style-type: none"> Probe selection overview by supervisor Stricter maintenance 	$8 \times 2 \times 3 = 48$
5.	Inaccurate probe qualification	144	<ul style="list-style-type: none"> Enhanced operator training Probe qualification verification 	$9 \times 2 \times 2 = 36$
6.	Arm instability during measurement	140	<ul style="list-style-type: none"> Improved arm stabilisation Enhanced operator training on arm handling 	$7 \times 2 \times 3 = 42$
7.	AACMM or software errors	135	<ul style="list-style-type: none"> Frequent software updates Regular strict maintenance 	$9 \times 2 \times 3 = 54$
8.	Excessive probe force	160	<ul style="list-style-type: none"> Enhanced operator training Maximum usage of measurement programs 	$8 \times 2 \times 2 = 32$
9.	Thermal drift or humidity changes	140	<ul style="list-style-type: none"> Enhanced environmental control Continuous monitoring 	$7 \times 2 \times 3 = 42$
10.	Misinterpretation of the measurement results	240	<ul style="list-style-type: none"> Enhanced training Programmed data interpretation 	$8 \times 3 \times 2 = 48$
11.	Instability of portable setup	160	<ul style="list-style-type: none"> Proper stabilisation setup Refinement of the training 	$8 \times 2 \times 3 = 48$

The comparative analysis chart between the initial and revised RPNs is depicted in Fig 3. It clearly demonstrates the effectiveness of the risk mitigation actions in reducing the risk associated with each potential failure mode. Initial values were above the set limit of 100 with a maximum of 240 for misinterpretation of the measurement results and a minimum value of 128 for misalignment and contamination. The revised values have been mitigated to less than 100. The regular reviews and updation to this process ensures that the new emerging risks are promptly taken into account and addressed accordingly, maintaining the robustness of the AACMM measurement process.

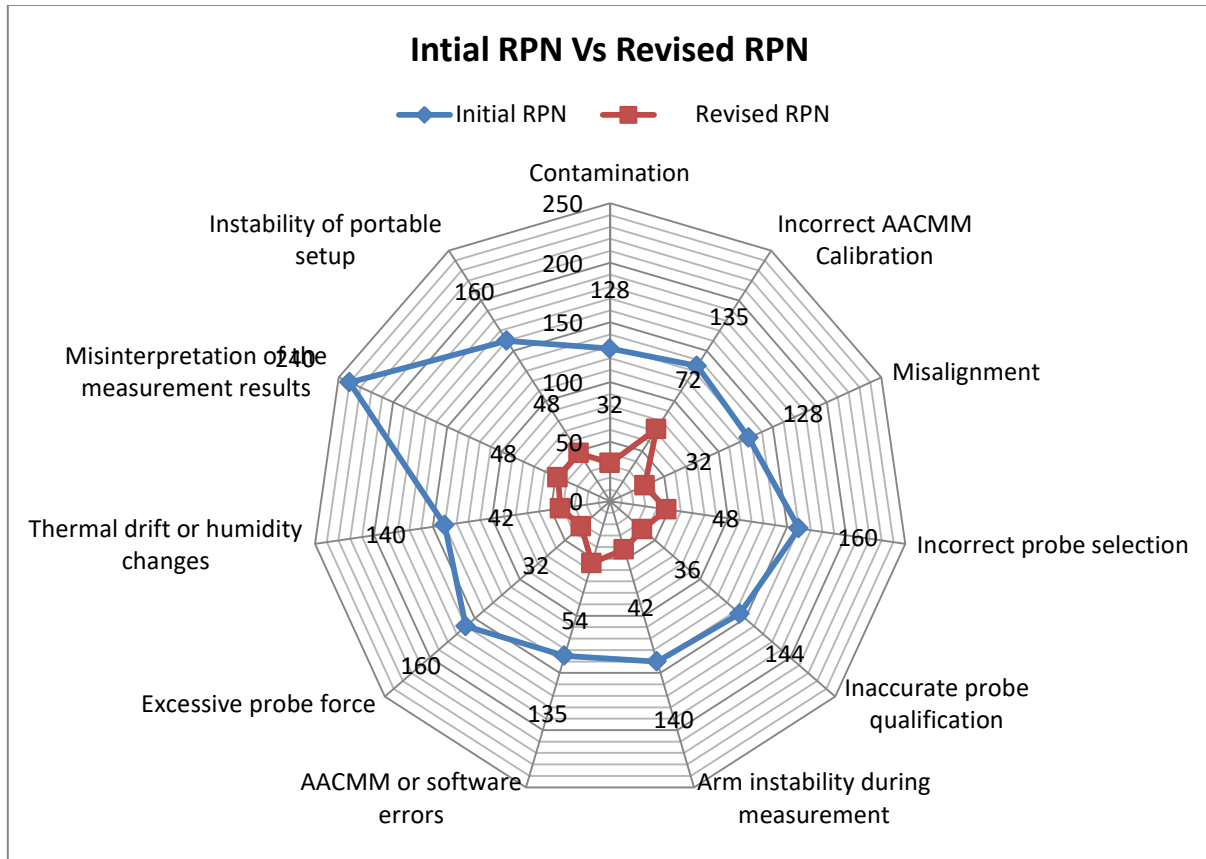


Fig 4. Initial RPN vs Revised RPN for identified potential failure modes

V. CONCLUSION

A comprehensive PFMEA is crucial for managing the inherent challenges of AACMM measurement of aeroengine parts. The PFMEA analysis of the AACMM measurement process for aeroengine parts has highlighted critical failure modes that can occur during the process. The risks associated with these potential failure modes are identified and RPNs are enumerated. It has highlighted the control plans to mitigate these risks effectively. By implementing the control plans such as enhanced training, strict maintenance schedules, enhanced environmental controls and programmed operations etc, the risks associated with each potential failure mode have been substantially mitigated. Such mitigation ensures a more reliable and accurate measurement process, an essential requirement for the verification of the aeroengine parts.

The revised SOD and RPN values demonstrate that the suggested control plans effectively mitigate the identified risks, enhancing the quality and precision of the measurements. PFMEA is a dynamic process and regular review are required for the changes and implementation of the continuous improvement practices which are essential to maintain high standards in the measurement and verification of the aeroengine parts.

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