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CONTRIBUTIONS REGARDING THE FMEA ANALYSIS OF A CMM MEASURING PROCESS

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Abstract: *The current paper presents the creation of the methodological basis (procedure, used forms, the DAMIC model, risk matrix) for undertaking a FMEA analysis for a coordinate measurement process. In the first step information was collected regarding errors that might occur in the measurement process, their effects as well as error prevention and detection methods. The paper also includes the improvement measures undertaken, their implementation, the risk index reevaluation method and the communication of obtained results.*
Key words: *FMEA analysis, measurement process, the DAMIC model, MMC, risk analysis*

1. INTRODUCTION

The FMEA (Failure Mode and Effects Analysis) has been first developed in the mid 60's in the United States by NASA, for the Apollo project (the first Moon landing). After its use in satellite development and nuclear plants, the analysis was used in the automobile industry and its suppliers. Today it is a valuable quality management instrument.

FMEA is used for avoiding potential nonconformities by prioritizing the risk of them occurring. At the same time it achieves a balance between development and manufacturing of the product. [5]

In most cases production is a succession of manufacturing and control operations. Manufacturing quality assurance (by use of the FMEA method) puts a greater accent on the manufacturing operations and less on the control ones.

The production control process can be regarded as one process having successive operations. By doing so, the errors that can occur in the measurement process and their causes can be seen more easily and preventive and detection methods can be used to avoid them.

Errors can have:

- Common causes and effects;
- Causes and effects associated with each individual measurement or monitoring equipment.

As a consequence, the FMEA analysis can be done for the whole control process or for the main measuring equipment such as CMMs.

To undertake a FMEA analysis for the measurement process a certain part must be chosen. Possible parts to be chosen:

- Have had client complaints on the measured characteristics;
- Have had measurement errors for the machining process;
- Are problematic parts or are new parts with a new measurement strategy.

By using a selection matrix one can determine the parts for which the FMEA analysis will be applied.

The criteria for selecting the parts are: Parts that require new measuring programs; Critical parts; Functionally important parts; Parts that have had a modified measurement strategy; Parts with modified measuring conditions; Parts that have influence on the manufacturing process; Parts that have complaints from customers.

2. THE METHODOLOGICAL BASIS FOR DOING A FMEA ANALYSIS AND ITS APLICATION

2.1 The DAMIC model

When performing a FMEA analysis, people from different departments (no more than 6-8 people) are involved, from the: research and development, production planning, control, customer service, and quality assurance departments. By doing so, it is assured that all the involved departments bring their expertise to the table. The success of the analysis depends in great part on the creativity of the team.

At the moment the FMEA analysis is done in accordance with the DAMIC model: Definition, Analysis, Measures, Implementation and Communication (Figure 1).

Defining the system requires the following activities: establishing the purpose of the FMEA (a new analysis or updating of an older one etc.), forming the team and defining the responsibilities, establishing of communication channels, identifying the necessary resources and assuring them, determining the documentation method for the results and providing the necessary documentation.

The **analysis** is done by the FMEA team. The form and results obtained in this step must be presented to the management of the company. The results consist of information on activities undertaken, risk study and optimization and the necessary improvement measures.

The **measures** to be undertaken and the operation mode follow. If the risk priority index (RPZ) or either of the occurrence or detection indexes is high, the process must be improved. The RPZ index can be lowered by:

- Modifying the measurement concept as to exclude the causes of the errors;
- Improving the measurement concept as to diminish the causes of the errors;
- Improving the error prevention methods;
- Better error detection methods, if possible to avoid other verifications.

Implementation, evaluation, verification, validation and monitoring of the process is the next stage.

The corrective measures are applied with taking into account the causes of the errors or the way the error occurs. These measures are accompanied by a deadline and an implementation responsible. The FMEA team members can delegate responsibilities to other people but are accountable for the implementation of the measures.

After deploying the improvement measures, a new evaluation of the A and E indexes is made, the value for the B index remaining unchanged. The RPZ index is reevaluated. If the index is still very high the improvement process is repeated until the index is lowered enough.

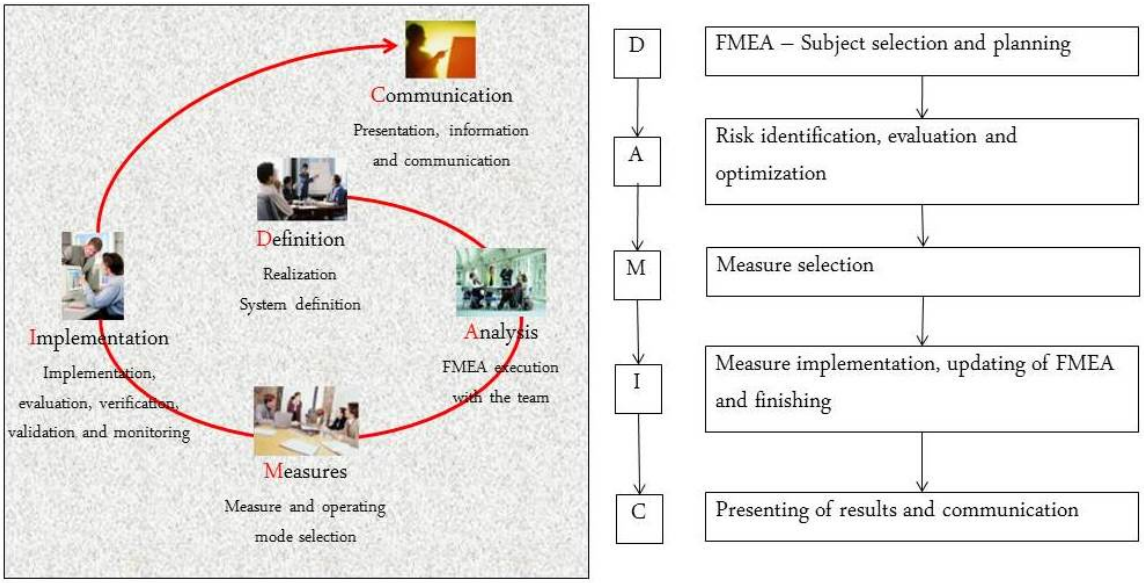

Fig.1. The DAMIC model [3]

Communication means presenting the results and informing the stakeholders.

The acquired experience must be put into the service of the organization:

- Transmitting the information to stakeholders;
- Presenting the FMEA results;
- Updating the knowledge database;
- Redefining responsibilities.

2.2 The FMEA analysis procedure

In the FMEA for the measurement process form two states can be found: the initial state and the improved state – the state after the improvements have been implemented (Figure 2).

The initial state, defined in the analysis stage, fills columns 0 through 10 of the form. In the order of the operations (Col. 1) the errors that can appear are evaluated (Col. 4) and their causes (Col. 5) and effects (Col. 2) determined.

Next, for each error, prevention (Col. 6) and detection (Col. 8) measures are determined. The main difference between the two is that the former uses quality assurance instruments and the latter uses quality control tools.

The following evaluations are done for determining the importance, B, (Col. 3), occurrence, A, (Col. 7) and detection, E, (Col. 9) indexes by using carefully chosen assessment criteria.

This first part ends with calculating the RPZ index (Col. 10) and its evaluation, done as follows:

- Drawing the risk diagram with the risk in descending order;
- Using a risk matrix in accordance with VDA 4 (Figure 3).

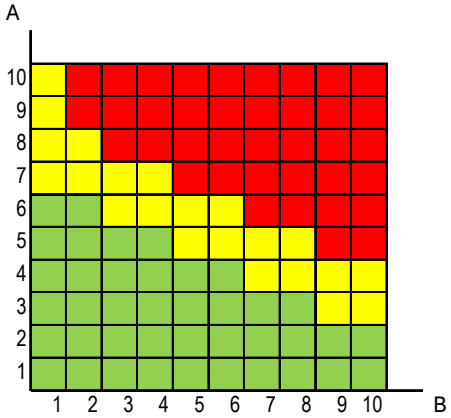

Fig.3. The risk matrix

The risk matrix has the following areas:

- The red zone – action is required, the risk must be reduced through appropriate measures;
- The yellow zone – any action is optional;
- The green zone- no action is required.

If the RPZ index and/or the sum of the A and B indexes are over 125, improvement is needed.

FMEA -measurement process
(Possible error and effects analysis)

FMEA No. : _____ Pag. 1 of 1
Proc. Resp. _____
Equip. name : _____ Moderator : _____
Stock no. : _____ Part Name : _____ Responsible Dept. : _____ Approved: _____
Equip. state : new ___, revision ___, repair Part No. : _____ Program Design (No./Date) : _____ Date : _____ Planned date:
Meas. Pr. type: sample __, pre-series __, se Revision _____ Program Rev. (No./Date): _____ Rev. date : _____
Team : _____

Operation No.	Measurement process operation / phase	Potential effects of measurement errors	Importance B	Potential measurement errors	Potential measurement error causes	Preventive measures	Occurrence A	Detection measures	Detection E	RPZ	Improvement measures	Responsible / Date	Improvement results: Undertaken measures	Importance B	Occurance A	Detection E	RPZ
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	What effects need to be monitored?			What can be wrong?		What can be done?			How great is the risk?		How to reduce the risk?					How great is the risk?	
					Initial state								Improved state				

Fig.2. The FMEA form for a measurement process [7]

In the improvement stage, the moderator monitors the implementation of the improvement measures and writes them in the right section of the FMEA form in column 13. A new risk evaluation is performed. At this point the importance index (B) stays the same while the occurrence (A) and detection (E) indexes change. When the RPZ index cannot be lowered anymore, column 18 is filled in with the final date for risk optimization.

2.3. Applying the FMEA method to a coordinate measuring process

The current research has been performed and applied in the Quality Assurance Department of Star Transmission Cugir, Romania, a company part of the Daimler AG Group.

In the Definition stage, by using the criteria presented in section 2.1., the measuring process for a sprocket was chosen for the analysis (Table 1).

The team had the following structure:

- *The process responsible* was the measurement program and strategy designer;
- *The moderator* was part of the Quality Department;
- *The experts* were: the technologist from the Planning/Production Department (the control plan designer), control personnel from the Quality Assurance Department, the metrologist from the Metrology Department and maintenance personnel from the Maintenance Department.

Table 1

The selection matric [6]

	Parts	**Sprocket**	**Crankshaft**	**Gear**	**Idler gear**
	Situations in which the FMEA analysis would be applied	**1**	**2**	**3**	**4**
1	When creating a new measurement plan	⊗	⊕	∅	∅
2	If the product is critical from a safety point of view	-	-	-	-
3	The part is functionally important	⊕	∅	-	⊕
4	The measurement strategy changed	⊕	∅	-	∅
5	The measuring conditions changed	-	-	-	-
6	It has influences on the manufacturing process	⊕	⊕	∅	∅
7	When complaints from the customer were received	-	-	-	-
	Absolute FMEA priority	18	8	2	6
	Relative FMEA priority	10,0	4,4	1,1	3,3
	FMEA analysis	✓			

Matrix	**Symbol**	**Value**	**Verification**
high	⊗	9	✓
medium	⊕	3	
low	∅	1	

The documents used were prepared by the moderator and consisted of the following:

- The technical drawing sent by the client for the sprocket;
- The control plan for the measuring process;
- The control strategy and program;
- Instructions for using additional devices;
- Tables with styli used for each operation;
- Records regarding CMM preventive maintenance;
- Records regarding the client's complaints.

In the Analysis stage, the control process for the sprocket (Figure 4) was split into multiple processes and phases.

Fig. 4. The analyzed sprocket

Each process was analyzed and the measurement errors were identified for the operator, the equipment, the part, the environment and the measurement strategy (Figure 5) and the effects it has at the client side were determined.

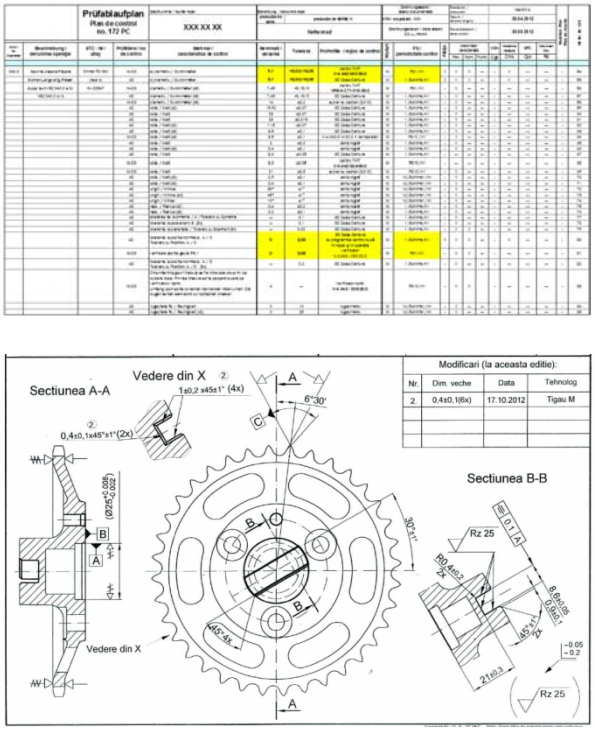

Fig. 5. The control plan

The measurement process under analysis was the one done on a Zeiss Contura G2 CMM (Figure 6). For this process a flux diagram was developed (Figure 7).

The first step of the analysis focused on the study of the technical drawing and on the measuring strategy for the following operations:

- Drilling ∅ 5,1 D9;
- Milling of slot 8,6 ± 0,05;
- Frontal plane milling;
- Drilling 3X Ø 7,45 + 0,15.

Fig. 6. The Zeiss Contura G2 CMM

The analysis of the technical drawing yielded:

- The critical characteristics for measuring and part alignment;
- Determining the stylus system type and configuration (Figure 8);
- Determining the part positioning and fixing on the CMM table (Figure 9);
- Part fixture (Figure 10) needed for good centering of the part verified by insertion of a Ø 5,1, D9 bolt.

Calibration of the styli plays an important part in the measuring process. After calibration, the measuring strategy used has the following stages:

- Determining the measurement points;
- Determining the measurement speed;
- Determining the stylus measurement direction;
- Applying filters to the measured data for outlier elimination;
- Determining the order of the elements to be measured.

The potential errors and their causes and effects are determined by the experts on the team by using collaborative methods and by consulting a database of errors that occurred in similar situations. The acquired information is inserted in the FMEA form in columns 2, 4 and 5.

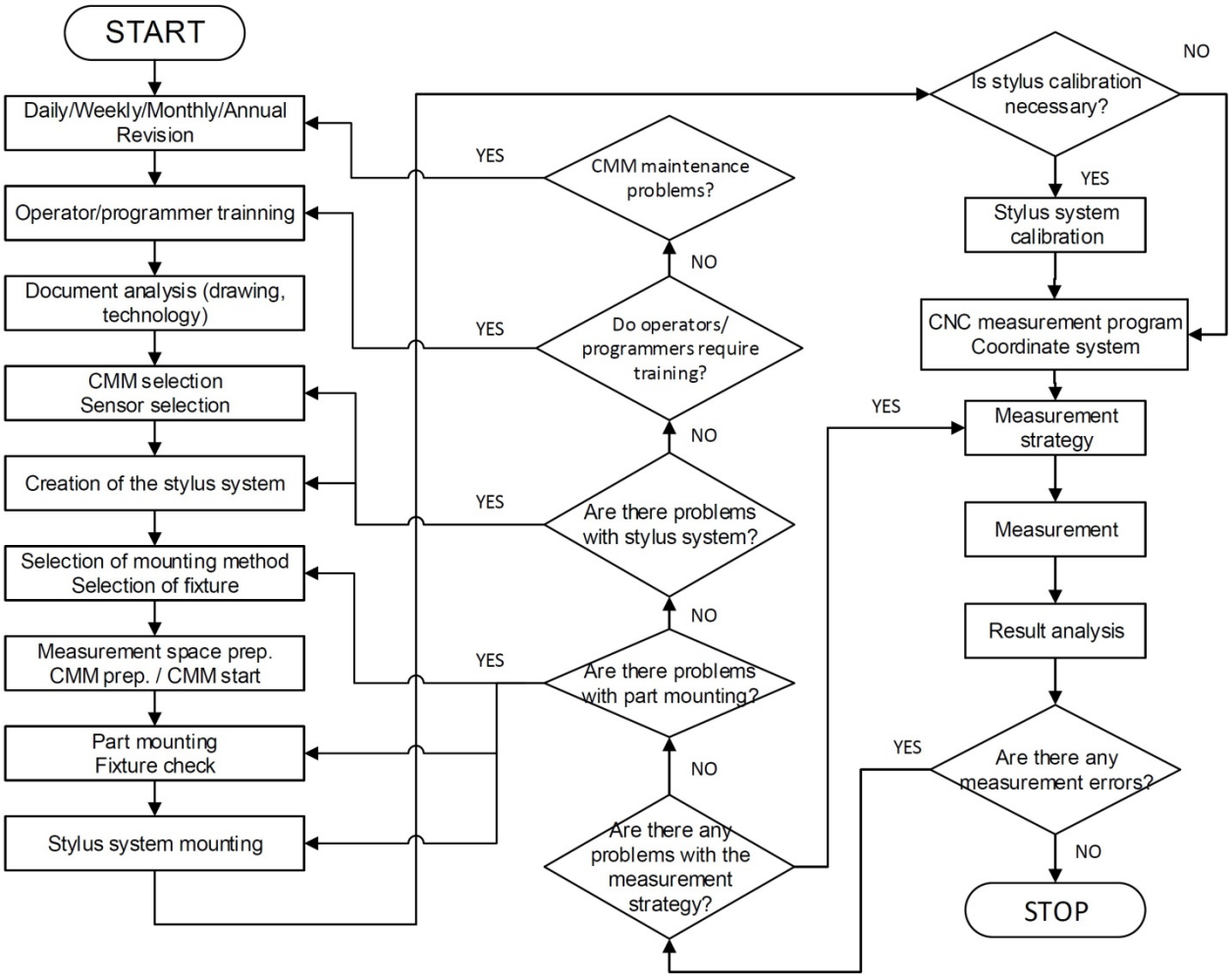

Fig. 7. The flow diagram for the coordinate measuring process on a CMM [6]

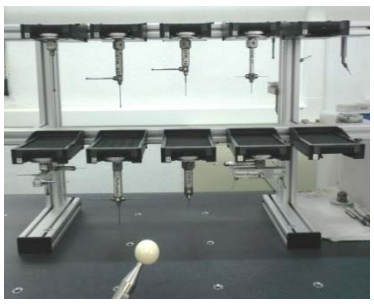

Fig. 8. The stylus system

Fig. 9. Fixture

Fig. 10. Part fixture verification

For each potential cause for error preventive and detection measures are determined that are written in the FMEA form in columns 6 and 8. The A, B and E indexes are evaluated on a scale from 1 to 10.

The moderator fills in the data for columns 3, 7 and 9 and then calculates the RPZ index and inputs it in column 10 (Figure 11).

In the Measures stage the team determines the improvements based on the risk matrix presented in Figure 3. The moderator fills in the columns 11 and 12 for all the stages of the measurement process.

Afterwards a risk assessment is done after the implementation of the measures and columns 14 through 17 are filled in. In case

there are no measures to be taken, the phrase "*No measures*" should be written.

POSSIBLE ERROR AND EFFECTS ANALYSIS — FMEA No. : 1 A / 2013 — Pag. 1 of 1

(FMEA -measurement process) — Process Resp. : Stăniliă Gheorghe

Equipment name : Zeiss 3D Contura G2 — Moderator : Fulea Lucian

Stock number : STC - 3D - 02 (5000447) — Part Name : Kettenrad — Responsible Dept. : Quality Assurance — Approved: Ludwig Friedrich

Equipment state : new ___, revision ___, repaired ___ — Part No. : XXX XX XX — Program Design (No./Date) : xxx gaurire/12.11. — Date : 11.10.2013 — Planned date: 18.10.13

Meas. product type: sample __, pre-series __, series _x_ — Revision : ZGS XXX din ZZ.LL.AAAA — Program Rev. (No./Date): xxx gaurire/28.10. — Rev. date : 08.11.2013

Team : Stăru V. - maistru Asigurarea Calităţii, Calica M. - Asigurarea Calităţii, Ilaş S. - Planificare, Ţimpea O. - Metrologie, Culda L. - Mentenanţă, Munteanu R. - Achiziţii

Operation No.	Measurement process operation / phase	Potential effects of measurement errors	Importance B	Potential measurement errors	Potential measurement error causes	Preventive measures	Occurrence A	Detection measures	Detection E	RPZ	Improvement measures	Responsible / Date	Improvement results: Undertaken measures	Importance B	Occurance A	Detection E	RPZ	Date of finalization of risk optimisation
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
040.7	Establishing the measurement strategy	Deviation of critical/security characteristics	10	Incorrect acquisition of actual geometry	incorrect selection of styli combination and configuration	Database with styli used for a particular operation and feature	7	Measurement operator versatility	4	280	Operator training in measuring	Quality Assurance Dept. / 01.11.2013	Operator training in measuring	(10) 10	(2) 2	(4) 4	(80) 80	01.11.2013
					incorrect stylus selection	Database with styli used for a particular operation and feature	7	Measurement operator versatility	4	280	Operator training in measuring	Quality Assurance Dept. / 01.11.2013	Operator training in measuring	(10) 10	(2) 2	(4) 4	(80) 80	01.11.2013
					the order of measuring points acquisition	Operator training in measurement operations	2	Cross-measurements	2	40	no measures need							
					the number of measuring points	Measurement plan with more/less points	6	Repeat measurements for outliers	3	180	choosing an adecquate strategy	Quality Assurance Dept. / 29.11.2013		10	5	2	100	

Fig. 11. FMEA form filled in (excerpt) [6]

In the implementation stage the deployment of the corrective measures is monitored. For following up the implementation, a new form is created, the "*FMEA measures follow-up form*". Herein the moderator describes the progress of improvement measure deployment.

After the implementation of the corrective measures, the moderator fills in column 13 with the measures taken on the date of the FMEA analysis revision.

When reevaluating the RPZ index only the occurrence and detection indexes are modified in accordance with the values in the evaluation lists. The target values, foreseen after the measures would be implemented are written in parentheses.

When the risk index cannot be lowered anymore column 18 is filled in with the final risk optimization date.

When performing a new revision of the analysis, the undergone measures (the prevention and detection measures) will be written in the left side of the form, as the initial state.

In the Communication stage the moderator and the measurement process manager present the results of the FMEA analysis to all parties involved in the process.

The original FMEA form is kept in the Quality Assurance Departments' archive.

3. CONCLUSIONS

The paper presents an innovative way of applying the FMEA method to a coordinate measuring process. By applying this method, quality management is improved by evaluating the risk of each control operation.

The results obtained in the FMEA analysis are communicated to the team and to the company's management.

The information gathered are kept in a database that will be the basis for future analyses of similar measurement processes. This way, future errors in the measurement process can be avoided.

4. ACKNOWLEDGEMENT

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Contribuţii privind realizarea analizei FMEA la un proces de măsurare pe maşini de măsurat în coordonate

Rezumat. În această lucrare se prezintă crearea bazei metodologice (procedura, formulare utilizate, modelul DAMIC, matricea de risc) pentru realizarea unei analize FMEA pentru un proces de măsurare în coordonate. Utilizând metoda Brainstorming au fost culese informaţii referitoare la erorile care pot apărea în procesul de măsurare, cauzele şi efectele acestora precum şi măsurile de prevenire şi descoperire a erorilor. Se prezintă stabilirea măsurilor de îmbunătăţire, a implementării acestora, modul de reevaluare a indicilor de risc şi comunicarea rezultatelor obţinute.

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