CONTRIBUTIONS REGARDING THE APPLICATION OF FMEA ANALYSIS TO MEASURING WITH A COORDINATE MEASURING MACHINE

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Abstract: *The current paper presents the research results of applying the FMEA method to the process of measuring with Coordinate Measuring Machines. The research focused on the risk indicators (A, B and E) used in the FMEA method. With the participative method of brainstorming information was gathered regarding the errors that can occur in the measurement process, their causes and their effects, as well as preventive and error discovery methods. The information was then processed by means of different quality instruments (cause-effect diagram, flow diagram, matrix diagram) resulting in a ranking of risk coefficients used in the FMEA method.*
Key words*: FMEA method, cause-effect diagram, flow diagram, measurement errors*

1. INTRODUCTION

The FMEA method was developed for the first time in the United States, in the mid 60's, by NASA for the Apollo project (the first lunar landing). After being used in satellite development as well as in the building of nuclear plants, it was used in the automotive industry and by its suppliers. Today it is an important tool in the quality management system.
FMEA is a method of avoiding potential nonconformities by ranking the risk of them occurring. At the same time it balances product development and manufacturing (VDA 4, 2009).
Depending on each case, applying the FMEA method requires the following steps:

- identification of potential and existing product errors and estimating their effects on the client (internal and external). The internal client is the next step in the production chain on which the nonconformity has a negative effect on. The external client is the buyer;
- establishing possible causes for the error;
- evaluating the existing control processes and corrective measures in regard to identifying and avoiding errors;
- risk assessment for:
  - the risk of an error occurring;
  - the importance of the error for the client (internal, external);
  - the probability of error detection before product delivery to the client (internal, external);
- calculation of the risk prioritization index (RPZ) for evaluating the cumulated risk potential;
- identification of errors with a high potential risk;
- establishing the appropriate measures for avoiding and eliminating errors (these methods can refer to design, production or control processes);
- establishing the action plans for the implementation of quality improvement methods (Who? What? Where? With what? When?). (AMG, 2005)

The FMEA analysis is done in interdisciplinary groups where the departments involved in product development take part under the guidance of a moderator. Collaborators from the departments of design and development, the manufacturing planning, manufacturing, control, client services, and quality assurance usually take part in a FMEA analysis. The number of persons present shouldn't exceed 6-8 people. By doing this, every department involved in the development of the product bring their expertise in the analysis. Its success depends mostly on the team's creativity.
The FMEA – Process analysis is done by using the DAMIC (Definition-Analysis-corrective Measures-Implementation-Communication) model presented in Figure 1.

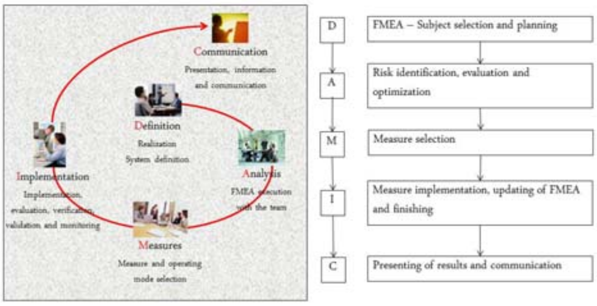

Fig.1. The DAMIC model (VDA4, 2009)

All the potential errors, effects and causes, as well as the evaluation of A, B and E indexes are part of the form presented in Table 1.

Table 1. The FMEA form (filled)

Op. no.	Operation / measurement process phase	Potential effects of error measurements	Importance	Potential measurement errors	Potential causes for measurement error	Preventive measures	Occurrence	Detection measures	Detection	RPN	Improvement measures	Responsible / Date	Results of improvements: Undertaken measures	Importance	Occurrence	Detection	RPN	Finalising date for risk optimization
			B				A		E					G	F	D		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Machine calibration	Part declared scrap, it being compliant	8	The measurements are unreliable	Abateri ale sistemelor de masurat lungimi	Periodic inspection of the CMM	3	Yearly service check-up	3	72	no measures							
				Incorrect measurements	Omitere efectuare calibrare la masina	Intructions regarding CMM calibration	3	Daily styli calibration	1	24	no measures							
		Improper CMM calibration	7		Lipsa efectuarii corectiilor de pozitie a capului de masurare la calibrarea masinii	Periodic inspection of the CMM	3	Yearly service check-up	3	63	no measures							
3	Workspace preparation / CMM initialization	Deviation of the critical/security characteristics	10	Incorrect measurements	dispozitive aditionale defecte / uzate	Instructions regarding the usage of additional devices	5	Part alignment check before program start	3	150	Verification of additional devices at shift change	Comp. Quality Assurance / 24.05.2013	Verification of additional devices at shift change	(10) 10	(3) 3	(3) 3	(90) 90	24.05.2013
		Positioning errors of assembly components	9	The machine jams	Aerul comprimat nu este filtrat (lipsa filtru sau filtru infundat)	Preventive maintenance plan for the CMM	9	Filter check according to documentation	10	810	Reduction of the filter verification interval and train the workers	Comp. Maintenance / 31.05.2013	Update the TMR for Reduction of the filter verification interval to every 6 months	(9) 9	(3) 3	(4) 4	(108) 108	31.05.2013
		Styli deterioration (breakage)	4	Imposibility of measurement	Murdarie si coroziune la ghidajele cu role	Daily cleaning of the CMM	10	Visual control	8	320	Update the TMR for machine cleaning and service ceck-up every 6 months	Comp. Maintenance / 31.05.2013	Update the TMR to reduce the interval of machine cleaning and service ceck-up to every 6 months	(4) 4	(5) 5	(3) 3	(60) 60	31.05.2013
		Collision of probe head	6	The machine jams	Murdarie si coroziune la ghidajele cu role	Daily cleaning of the CMM	10	Visual control	8	480	Update the TMR for machine cleaning and service ceck-up every 6 months	Comp. Maintenance / 31.05.2013	Update the TMR to reduce the interval of machine cleaning and service ceck-up to every 6 months	(6) 6	(5) 5	(3) 3	(90) 90	31.05.2013
		Part declared compliant, it being scrap	8	The measurements are unreliable	sisteme de palpare defecte	Periodic verification of stylus calibration with a gauge part	2	Daily styli calibration	1	16	fără măsuri							

2. FMEA – FIELDS OF APPLICATION

The method is used in product development as well as in manufacturing. It can be done:

- Preemptively:
  - ➪ as soon as possible: together with product planning and development;
  - ➪ with innovative products or processes;
  - ➪ when there are special security or environmental requirements.
- Correctively:
  - ➪ for products or manufacturing processes that have problems;
  - ➪ when warranty costs are high, for product and/or process optimization (AMG, 2005).

The current paper presents the application of the FMEA method to a measuring process done on a Coordinate Measuring Machine (CMM).

3. QUALITY INSTRUMENTS USED FOR CONTROL SYSTEM ERROR ANALYSIS

The quality instruments used for analysis, evaluation, improving and error control are used for numeric data (control cards, histograms, dispersion diagrams, Pareto diagrams) as well as alpha-numeric data (affinity diagram, tree diagram, flow diagram, cause-effect diagram, priority matrix)

3.1 Flow diagram for a measurement process using a CMM

Figure 2 presents a flow diagram for a measurement process using a CMM.

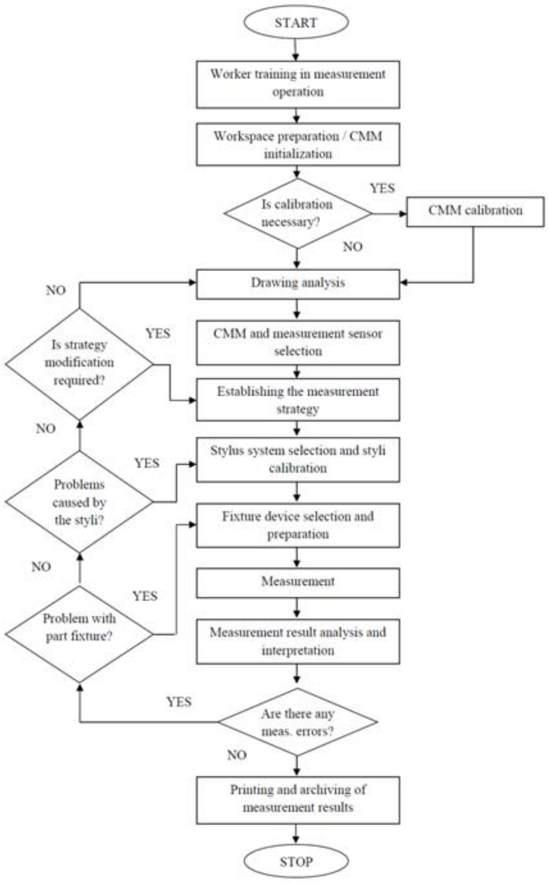

Fig.2. Flow diagram for a measurement process using a CMM

3.2 Establishing the errors, causes, effects and prevention / error detection in the measurement process using a CMM

Error and cause identification

In the analysis of the measuring process for identifying of errors that might occur in the measurement process as well as the effects of measuring errors and the effects on the end client, a brainstorming session is done with the specialists operating the CMM. This method was used for preventive measure discovery and measurement error detection.

The main causes for measurement errors that can affect the measurement process are:

- ❑ temperature variation;
- ❑ lack of cleanliness;
- ❑ incorrect/erroneous measures;

- ❑ improper service/calibration;
- ❑ used or dirty guiding mechanisms;
- ❑ reduced metrological performance;
- ❑ improper measurement strategy;
- ❑ part improperly fixed;
- ❑ improperly executed parts;
- ❑ used styli;
- ❑ improper point acquisition;
- ❑ incorrect acquisition of real geometry;
- ❑ inadequate statistical settings;
- ❑ errors in result interpretation;
- ❑ incorrect interpretation of the drawing;
- ❑ incorrect 3D model;
- ❑ wrong measurement protocol.

The cause-effect diagram (Ishikawa) was the first instruments of quality used for grouping the measurement errors from measuring with a CMM. The grouping was done taking into account five factors: the user, the part, the environment, the CMM and the measurement strategy. The cause-effect diagram resulting from the brainstorming session together with the provisions of (VDA 5, 2010) and (Pfeifer & Schmitt, 2010) are presented in Figure 3.

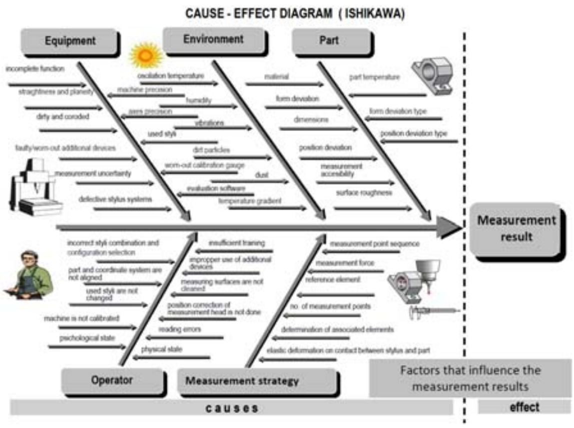

Fig.3. The cause-effect diagram for a measurement process, (VDA5, 2010)

Error effect identification

A number of 21 potential measurement error effects were identified of which:

- ➪ the production process is not approved;
- ➪ influences on measurement equipment capability;
- ➪ digression of critical/security characteristics;
- ➪ digression of less important characteristics;
- ➪ positioning errors for assembly components;
- ➪ styli wearing out (breaking)
- ➪ part being rejected although it is compliant;
- ➪ invalid part being declared valid;
- ➪ assembly clearances, noise during operation, improper fitting;
- ➪ CMM guideway blockage;
- ➪ erroneous approval of manufacturing process;
- ➪ influences on the manufacturing process adjustment;
- ➪ no effect on measurement results.

Preventive measure identification

A number of 33 preventive measures were identified of which the most important are:

- ➪ daily CMM clean-up;
- ➪ training the user in taking measurements;
- ➪ using a styli database needed for different types of features and operations;
- ➪ guides for using additional devices;
- ➪ guides for machine calibration;
- ➪ instructions for verification of calibration gauge;
- ➪ periodical verification of stylus calibration;
- ➪ preventive maintenance plan for the CMM;
- ➪ possibility of choosing weather to use or not use a CAD model;
- ➪ guides for making position corrections of measuring stylus when calibrating the CMM.

Discovery measures

A number of 23 measurement error discovery measures were identified, among which:

- ➪ visual check;
- ➪ daily stylus calibration;
- ➪ stylus system status verification at the start of the shift;
- ➪ regular verification of qualification gauge;
- ➪ service check-up;
- ➪ verification with a different measurement system;
- ➪ daily temperature check;
- ➪ daily air humidity check;
- ➪ repeat measurement for outliers.

3.3 Ranking of occurrence index (A), importance index (B) and detection index (E)

The priority matrix of influence factors on measurement results was obtained by comparing the factors and grading them (with 0, 1 or 2) which made ranking possible, (Bulgaru & Bolboaca, 2004).

The method was used for ranking the effects of potential measurement errors, of preventive and discovery methods.

Each influence factor was analyzed in comparison to the other factors starting from the left.

A grade of 2 was given if the influence factor if the influence factor from the left has greater influence than the one in the upper side, 1 if the influence is equal and 0 if the influence factor from the left has a lower weight than the one in the upper zone.

Figure 4 presents the matrix for measurement error effects.

	Error measurement effects	Grade	1 The manufacturing process is not approved	2 Influences on the measurement equipment capability	3 Influences on process capability on a short/long term	4 Deviation of the critical/security characteristics	5 Deviation of less important characteristics	6 Positioning errors of assembly components	7 Styli deterioration (breakage)	8 Collision of probe head	9 Blockage on machine guideways	10 Improper CMM calibration	11 Improper styli calibration	12 Part declared scrap, it being compliant	13 Part declared compliant, it being scrap	14 Assembly clearances	15 Noise while in operation	16 Improper fitting	17 Long manufacturing process approval times	18 Premature machine wear (pneumatic guideways)	19 Erroneous approval of manufacturing process	20 Influences on manufacturing process adjustment	21 No effect on measurement result
1	The manufacturing process is not approved	28		0	0	2	1	1	0	0	0	0	1	1	1	1	1	1	0	0	1	1	0
2	Influences on the measurement equipment	25	2		0	0	1	1	1	1	1	0	1	1	1	0	0	1	0	1	2	1	0
3	Influences on process capability on a short/long term	14	2	2		2	1	1	2	2	1	2	1	1	1	1	1	1	1	1	2	1	0
4	Deviation of the critical/security characteristics	30	0	2	0		0	1	0	1	0	1	0	0	0	1	1	1	0	0	1	1	0
5	Deviation of less important characteristics	10	1	1	1	2		2	2	2	1	2	1	2	2	2	1	2	1	1	2	1	1
6	Positioning errors of assembly components	29	1	1	1	1	0		0	1	0	1	0	0	1	1	1	1	0	0	1	0	0
7	Styli deterioration (breakage)	13	2	1	0	2	0	2		2	2	2	1	0	2	2	2	2	1	1	2	1	0
8	Collision of probe head	23	2	1	0	1	0	1	0		0	1	1	0	2	2	2	2	0	0	1	1	0
9	Blockage on machine guideways	11	2	1	1	2	1	2	0	2		2	1	2	2	2	2	2	1	1	2	1	0
10	Improper CMM calibration	25	2	2	0	1	0	1	0	1	0		0	2	2	1	1	1	0	0	1	0	0
11	Improper styli calibration	14	1	1	1	2	1	2	1	1	1	2		1	2	2	2	2	1	1	2	0	0
12	Part declared scrap, it being compliant	13	1	1	1	2	0	2	2	2	0	0	1		2	2	2	2	1	2	2	1	1
13	Part declared compliant, it being scrap	27	1	1	1	2	0	1	0	0	0	0	0	0		2	2	2	0	0	1	0	0
14	Assembly clearances	31	1	2	1	1	0	1	0	0	0	1	0	0	0		1	1	0	0	0	0	0
15	Noise while in operation	29	1	2	1	1	1	1	0	0	0	1	0	0	0	1		1	0	0	1	0	0
16	Improper fitting	31	1	1	1	1	0	1	0	0	0	1	0	0	0	1	1		0	0	1	0	0
17	Long manufacturing process approval times	10	2	2	1	2	1	2	1	2	1	2	1	1	2	2	2	2		1	2	1	0
18	Premature machine wear (pneumatic guideways)	12	2	1	1	2	1	2	1	2	1	2	1	0	2	2	2	2	1		2	1	0
19	Erroneous approval of manufacturing process	30	1	0	0	1	0	1	0	1	0	1	0	0	1	2	1	1	0	0		0	0
20	Influences on manufacturing process adjustment	13	1	1	1	1	1	2	1	1	1	2	2	1	2	2	2	2	1	1	2		0
21	No effect on measurement result	2	2	2	2	2	1	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	
			28	25	14	30	10	29	13	23	11	25	14	13	27	31	29	31	10	12	30	13	2

Fig.4. The matrix for measurement error effects

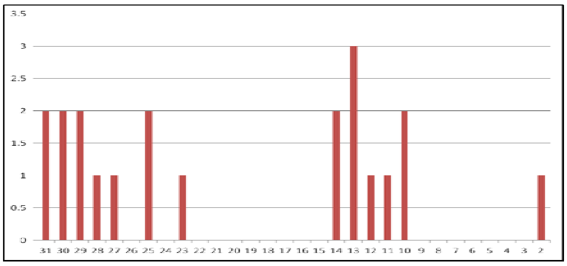

Fig.5. Histogram of points for measurement error effects

After analyzing the diagram they were grouped then graded on a scale from 1 to 10. The point chart is presented in Table 2.

A list of importance criteria was created sorting the potential effects in accordance with the points from 10 to 1 in descending order. These potential effects are shown in Table 3.

Table 2. Chart with points for measurement error effects

Potential effects of measurement errors	Influence weight on the measurement result										Points
	very high		high		moderate			low		none	
	10	9	8	7	6	5	4	3	2	1	
The manufacturing process is not approved			⍰								28
Influences on the measurement equipment capability				⍰							25
Influences on process capability on a short/long term						⍰					14
Deviation of the critical/security characteristics	⍰										30
Deviation of less important characteristics									⍰		10
Positioning errors of assembly components		⍰									29
Styli deterioration (breakage)							⍰				13
Collision of probe head					⍰						23
Blockage on machine guideways								⍰			11
Improper CMM calibration				⍰							25
Improper styli calibration						⍰					14
Part declared scrap, it being compliant							⍰				13
Part declared compliant, it being scrap			⍰								27
Assembly clearances	⍰										31
Noise while in operation		⍰									29
Improper fitting	⍰										31
Long manufacturing process approval times									⍰		10
Premature machine wear (pneumatic guideways)								⍰			12
Erroneous approval of manufacturing process	⍰										30
Influences on manufacturing process adjustment							⍰				13
No effect on measurement result										⍰	2

Table 3. Classification of importance index (B)

Importance	Importance criteria	Classification
Very high	Deviation from critical/ security characteristic and reglamentation, assembly clearances, impropper fitting, erroneous approval of manufacturing process	10
	Positioning errors of assembly components, noise while in operation	9
High	The manufacturing process is not approved, Part declared compliant, it being scrap	8
	Influences on the measurement equipment capability, improper CMM calibration	7
Moderate	Collision of probe head	6
	Influences on process capability on a short/long term, improper styli calibration	5
	Styli deterioration (breakage), part declared scrap, it being compliant, influences on manufacturing process adjustment	4
Low	Blockage on machine guideways, premature machine wear (pneumatic guideways)	3
	Deviation of less important characteristics, long manufacturing process approval times	2
No importance	No effect on measurement result	1

Table 4. Measurement error prevention matrix

	Prevention measures	Points
1	Daily cleaning of the CMM	9
2	User training in using the CMM	56
3	Database with styli used for a particular operation and feature	23
4	Styli change log	21
5	Instruction regarding part and coordinate system alignment	47
6	Instructions regarding the usage of additional devices	35
7	Machine calibration instructions	50
8	Instructions regarding the position error correction of the measuring head at machine calibration	59
9	Instructions for verifying the calibration gauge	49
10	Verification of the function keyboard	9
11	Periodic verification of stylus calibration with a gauge part	55
12	Periodic inspection of the CMM	49
13	Ensuring the possibility of working with or without a CAD model	22
14	Procurement of licenses for measurement evaluation software	22
15	Usage instructions of the calibration gauge	46
16	Preventive maintenance plan for the CMM	16
17	Systematic measurement error log	21
18	Air conditioned room	29
19	Correct selection of the measurement precision in accordance with measured part tolerance	52
20	Measurement plan with more points	32
21	Measurement plan with less points	26
22	Control technologies	57
23	Simulation program execution	15
24	Comparison between the drawing and machine precision	46
25	Temperature log with measurement point designation	17
26	Purchasing of vibration compensators	30
27	Noise level measurement log	20
28	Instructions regarding the measurement of part temperature	31
29	Software upgrade	29
30	Adequate measurement strategy	40
31	Rethinking of the work plan	14
32	Ensuring optimal work conditions	15
33	Workplace organization	15

The measurement error prevention matrix was created similarly with the error effects matrix, in Figure 4 and the resulting points for each item are presented in Table 4. Figure 6 presents the histogram for the priority matrix.

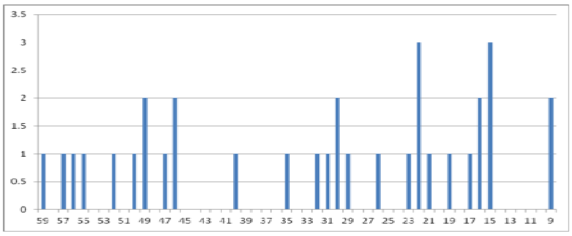

Fig.6. Histogram with the points for the error prevention measures

The chart with the points for the prevention measures is presented in Table 5.

Table 5. Chart with the points for error preventive measures

Masuri de prevenire	pondere asupra prevenirii aparitiei erorilor de masurare										Punctaj
	foarte mare		ridicata		moderata		redusa		foarte redusa	improbabil	
	10	9	8	7	6	5	4	3	2	1	
Program zilnic de curatenie a masinii de masurat	•										9
Instruire operator pentru efectuare operatie de masurare									•		56
Tabel cu tipurile de palpatoare utilizate pe reper si operatie				•							23
Registru de evidenta a schimbarii palpatorilor			•								21
Instructiune de lucru privind alinierea piesei cu sistemul de coordonate ale masinii							•				47
Instructiune de lucru privind utilizarea dispozitivelor						•					35
Instructiune de lucru privind efectuarea calibrarii masinii								•			50
Instructiune de lucru privind efectuarea corectiilor de pozitie a capului de masurare la calibrarea masinii									•		59
Instructiune de verificare a etalonului de calibrare								•			49
Verificarea functionarii tastaturii cu functiuni	•										9
Verificarea periodica a calibrarii palpatorilor pe o piesa									•		55
Efectuarea reviziei periodice a masinii de masurat								•			49
Asigurarea posibilitatii de a lucra cu sau fara un model CAD				•							22
Asigurarea licentei pentru software de evaluare a				•							22
Instructiune de utilizare a etalonului de calibrare							•				46
Plan de mentenanta preventiva a masinii de masurat		•									16
Registru de evidenta a abaterilor de masurare sistematice				•							22
Camera climatizata					•						29
Alegerea corecta a preciziei de masurare functie de toleranta piesei de masurat								•			52
Program de masurare in mai multe puncte						•					32
Program de masurare in mai putine puncte					•						26
Tehnologie de control									•		57
Efectuare simulare program		•									15
comparare precizie din desen cu precizia masinii							•				46
registru de evidenta a temperaturii cu indicarea punctului de măsurare			•								17
achizitionare compensatori de vibratii						•					30
registru de evidenta masuratori nivel de zgomot			•								19
instructiune de lucru privind masurarea temperaturii piesei						•					31
modernizare soft					•						30
Strategie de masurare adecvata						•					40
Regandirea programului de lucru	•										15
asigurare condiții optime de lucru	•										15
organizarea locului de muncă		•									16

For grading the prevention measures on a scale from 1 to 10, establishing the number of incidents per number of measures had an important role.

When performing this evaluation, the experience of the operators in the Quality Assurance Department of the company Star Transmission was taken into account as well as the number of measurements (max. 1000 measurements/day)

The occurrence criteria and the points are those presented in Table 6.

Table 6. Occurrence criteria and corresp. points

Occurrence criteria	Classi-fication
It is almost certain that measurement errors appear	9, 10
Frequent errors, the measurement process is not under control	7, 8
Occasional errors in the measurement process	5, 6
Isolated errors in the measurement process	3,4
The measurement process is completely under control	2
It is impossible to have errors	1

Considering the occurrence criteria, prevention measures and number of incidents/number of measurements taken a classification of the occurrence index (A) is presented in Table 7.

Table 7. Occurrence index classification (A)

Occurance probability	Occurrence criteria (Preventive measures)	Occurrence (event per measurement	Clasification
Very high	Error occurrence is almost certain (Daily mechine cleanup, verification of function keyboard, rethinking of work program, ensuring otimal work conditions)	more than 1 in 10 measurements	10
	Error occurrence is almost certain (CMM preventive maintenance plan, program simulation, workplace organization)	1 in 20 measurements	9
High	Frequent errors. The measurement process is not contolled (Log: styli change, systematic measurement errors, temperature with indication of measurement point, noise level measurement)	1 in 50 measurements	8
	Frequent errors. The measurement process is not contolled (Database with styli usedfor each feature and operation, ensurring measurements with or without a CAD model, measurement evaluation software licences)	1 in 75 measurements	7
Moderate	Occasional errors in the measurement process (Air-conditioned room, measurement plan with less points, software upgrade)	1 in 125 measurements	6
	Occasional errors in the measurement process (Instructions regarding usage of additional devices and part temperature measurement, measurement plan with more points, adequate measurement strategy, purchasing of vibration compensators)	1 in 250 measurements	5
Low	Isolated errors in the measurement process (Instructions regarding part alignment with machine coordinate system, instructions in using the calibration gauge, comparisson between drawing precision and machine precision)	1 in 500 measurements	4
	Isolated errors in the measurement process (Instructions regarding machine calibration and verification of calibration gauge, periodic machine revision, correct selection of measuring precision in accordance with the measured part's tolerences)	1 in 750 measurements	3
Very low	Measurement process is under control (Operator is trained in measuring, position correction of measurement head at machine calibration, control technologies, styli calibration periodic verification on a gauge part)	1 in 1000 measurements	2
Impossible	Error occurrence is impossible	0	1

The detection matrix for measurement errors was calculated and the results are presented in Table 8. Figure 7 presents the diagram from the priority matrix.

Table 8. Measurement error detection measure matrix

	Detection measures	Points
1	Visual control	14
2	Daily styli calibration	39
3	Verification of calibration gauge at regular intervals	29
4	Verification of stylus system at shift change	25
5	Cut-off system for the motors when improper operation is detected	22
6	Yearly service check-up	31
7	Verification with a different stylus system	35
8	Operator supervision	22
9	Filter check according to documentation	3
10	Daily check of function keyboard operation	6
11	Daily verification of temperature	20
12	Temperature verification every 3 hours	21
13	Daily humidity check	6
14	Daily vibration check	9
15	Weekly noise measurement	5
16	Cross-measurements	35
17	Temperature measurement of part at control	23
18	Measurement operator versatility	29
19	Part alignment check before program start	32
20	Repeat measurements for outliers	32
21	Activity alternation	19
22	Roughness check according to control plan	28
23	Result interpretation from another operator	22

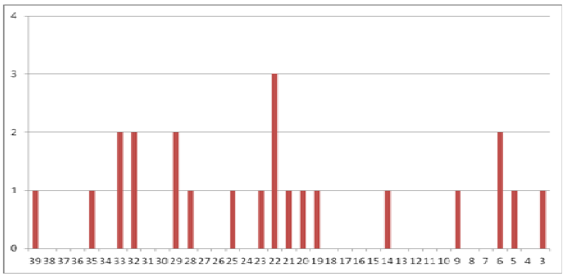

Fig.7. Grade histogram for error measurement detection measures

The chart for the detection measures points is presented in Table 9.

Table 9. Detection measures points chart

Detection measures	Detection probability										Points
	very unlikely		unlikely		moderate		likely		very likely		
	10	9	8	7	6	5	4	3	2	1	
Visual control			x								14
Daily styli calibration										x	39
Verification of calibration gauge at regular intervals							x				29
Verification of stylus system at shift change						x					25
Cut-off system for the motors when improper operation is detected					x						22
Yearly service check-up								x			33
Verification with a different stylus system									x		33
Operator supervision					x						22
Filter check according to documentation	x										3
Daily check of function keyboard operation		x									6
Daily verification of temperature				x							20
Temperature verification every 3 hours					x						21
Daily humidity check		x									6
Daily vibration check			x								9
Weekly noise measurement		x									5
Cross-measurements									x		35
Temperature measurement of part at control						x					23
Measurement operator versatility							x				29
Part alignment check before program start								x			32
Repeat measurements for outliers								x			32
Activity alternation				x							19
Roughness check according to control plan							x				28
Result interpretation from another operator					x						22

A regrouping of the detection measures in accordance with the points and a classification of the E index was made and is presented in Table 10.

Table 10. Classification of the detection index (E)

Detection probability	Criteria: probability of cause detection (NOK measurements) by the proposed detection measures	Classification
Very unlikely	Filter check according to MIC documentation	10
	Daily check of function keyboard operation, daily verification of temperature, daily humidity check, weekly noise measurement	9
Unlikely	Visual control, daily vibration check	8
	Daily verification of temperature, temperature measurement of part at control, activity alternation	7
Moderate	Cut-off system for the motors when improper operation is detected, operator supervision, temperature verification every 3 hours, result interpretation from another operator	6
	Verification of stylus system at shift change	5
Likely	Verification of calibration gauge at regular interva	4
	Yearly service check-up, part alignment check before program start, repeat measurements for outliers	3
Very likely	Verification with a different stylus system, Cross-measurements	2
	Daily styli calibration	1

4. CONCLUSIONS

For gathering the information regarding errors, their causes, and effects that take place while measuring with a CMM a technique named brainstorming was used. For processing the data Quality Assurance tools were used (e.g. the matrix diagram, the cause-effect diagram) and classical tools like the flow diagram and the histogram.

This led to the creation of a database with the identification of potential measurement errors, their potential effects as well as potential causes. For each potential cause measurement error detection and preventive measures were identified. To evaluate the risk in a measurement process the created database will be used (the lists of risk indexes – importance (B), occurrence (A) and detection (E)). The FMEA analysis will be documented by creating the necessary forms.

5. REFERENCES

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