DETERMINATION OF THE INFLUENCE OF THE NATURAL THERMO-COUPLE THERMO-VOLTAGE CHARACTERISTICS IN THE MODELLING OF MACHINING PROCESSES BY TURNING

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Abstract: This paper presents results of empirical modelling of thermo-voltage characteristics of the natural thermocouple cutting tool-workpiece during research of the metal cutting process by machining with turning. The focus is on the gained measurement uncertainty and its contribution and significance on the further modelling of the machining process. The approach of taking in consideration of this uncertainty contribution is recommended as essential in the modelling of cutting average temperature measured by the method of natural thermocouple.

Keywords: Measuring, natural thermocouple, uncertainty.

INTRODUCTION

One significant quantity of interest in the process of the empirical modelling of the cutting process by machining with turning is the average cutting temperature. On the figure 1, there are presented the stages of the research process which can be divided on two parts. The first part is representing measuring of single quantity value during one cut. The second part is using of the single measurement as one point of the Design of Experiments (DOE) experimental research plan, which further results by the fitted empirical model. One convenient form of presenting of the final result is power mathematical model, as the gained degrees of the model are showing the degree of influence of certain cutting parameters (cutting speed, depth of cut, feed rate, cutting tool radius, etc.) on the investigated phenomena (average temperature in the cutting process). Such model can directly be used as recommendations for optimization of the cutting process. Within the DOE methodology there is estimation of the adequacy of the fitted empirical model by the Fisher's test and the experimental error. However this approach might be not consider systematic errors, and can underestimate the real measuring uncertainty. Moreover, we propose that final empirical model coefficients uncertainty should be done by using type B uncertainty evaluation, together with the uncertainty budget in order to be presented the reliability of the gained mathematical model, to identify the significant sources of errors and in order to be included in the knowledge base of the developing smart machining systems (SMS) [1].

Herein we give a contribution by applying the proposed approach during research of the average temperature in machining process by turning. The scope of this paper is to calculate and to present the uncertainty that arise from one significant source, the thermoelectric characteristics of the natural thermocouple workpiece-cutting tool, while the other sources of the uncertainty of the measuring the single temperature, and the uncertainty of the mathematical coefficients of the fitted empirical model will be considered in our next papers.

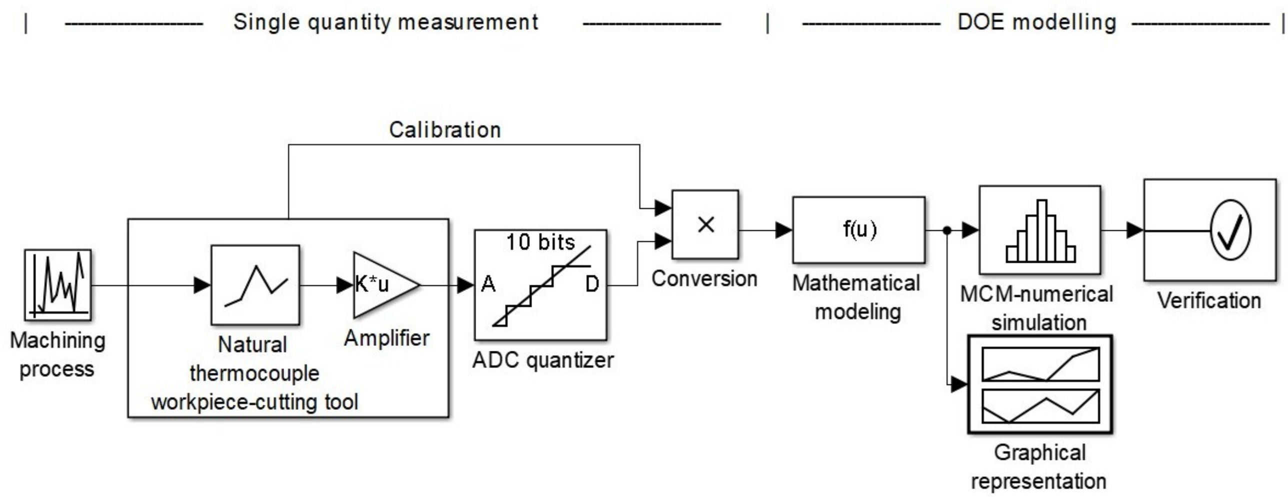

Fig.1 - *Cutting temperature research process chain.*

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METHODOLOGY AND RESULTS

The natural thermocouple during the machining process by turning is consisted of the workipece and the cutting tool plate. In order to determine their thermoelectric characteristics it is developed a special experimental stand as showed on figure 2 [2]. The natural thermocouple represented by piece of the workpiece material C1630 and, cutting tool plates from mixed ceramics MC2 have been placed in the middle of the furnace marked by 3 on figure 2. Efforts for lowering of the oxidations on the joint are done by applying of inert gas in the furnace, marked by 9, figure 2. The temperature have been measured by thermocouple *PtRh6-PtRh30*, marked by 4 on figure 2, and the generated thermo-voltage by the natural thermocouple have been measured by voltmeter marked by 8 on the left side on the figure 2.

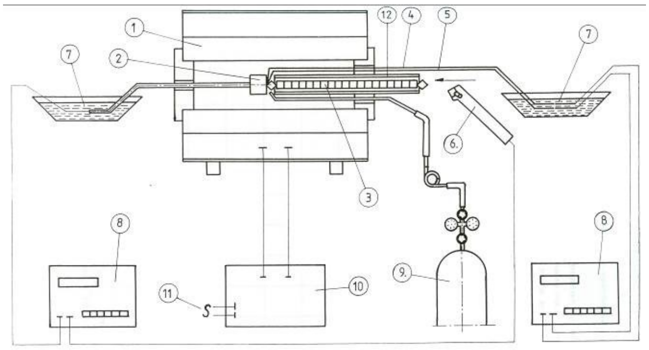

Fig.2 - *Experimental setup for determining of the thermoelectric characteristics of the natural thermocouple C1630-MC2 [2].*

The results of the measuring are presented in Table I, and the fitted mathematical representation have been showed on figure 3 and by (1), [2].

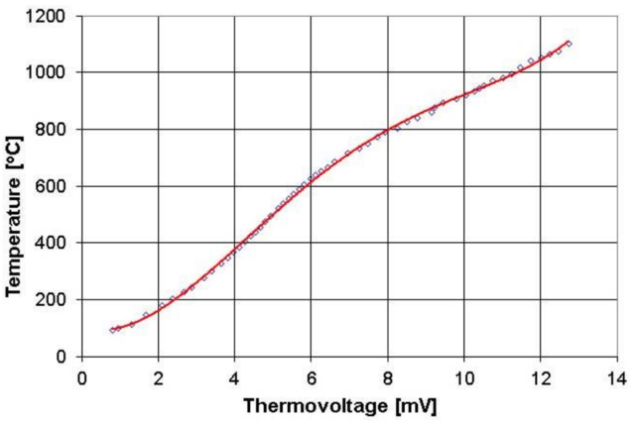

Fig.3 - *Thermoelectric characteristics of the natural thermocouple C 1630 - MC2.*

$$T = 0.1711 \cdot u_T^4 - 4.9428 \cdot u_T^3 + 44.737 \cdot u_T^2 - 42.494 \cdot u_T + 104.13 \quad (1)$$

The selected 4th order of the fitted mathematical model of the thermoelectric characteristics have been selected as minimum necessary degree, in order, the fitted line to follow the trend of the measured points.

The published papers in the field uses similar mathematical models of the thermoelectric characteristics, while the error which arises by using this equation in order to make a conversion from the measured voltage to temperature units is not considered as important.

Table I
Thermoelectric characteristics of the natural thermocouple C1630 - MC2 [2].

i	u_T [mV]	T_i [ºC]	i	u_T [mV]	T_i [ºC]
1	0.80	93	29	6.27	653
2	0.97	100	30	6.43	666
3	1.30	113	31	6.62	684
4	1.69	146	32	6.96	715
5	2.10	180	33	7.26	731
6	2.38	203	34	7.48	749
7	2.68	226	35	7.73	772
8	2.87	242	36	7.93	790
9	3.20	277	37	8.26	804
10	3.41	301	38	8.51	825
11	3.65	328	39	8.77	841
12	3.83	348	40	9.15	860
13	3.98	366	41	9.24	875
14	4.13	384	42	9.45	893
15	4.28	403	43	9.80	908
16	4.42	423	44	10.04	921
17	4.54	438	45	10.27	933
18	4.67	455	46	10.41	944
19	4.80	474	47	10.52	955
20	4.94	494	48	10.76	969
21	5.14	522	49	11.03	981
22	5.28	537	50	11.24	995
23	5.42	556	51	11.48	1016
24	5.54	571	52	11.75	1041
25	5.68	588	53	12.02	1050
26	5.82	604	54	12.24	1064
27	6.00	625	55	12.47	1073
28	6.12	638	56	12.73	1100

After analysis of the possible sources of uncertainty from the thermoelectric characteristics we propose that in the uncertainty budget should be included three error sources: error of the least square method upon which the thermoelectric characteristics is fitted, the error which arises from the artificial thermocouple *PtRh6-PtRh30*, marked by 4 on figure 2 and the error which arise from the voltmeter, which have been used to record the thermo-voltage of the natural thermocouple during the calibration.

The error of the least square method upon which the thermoelectric characteristics has been fitted have been estimated by using the recommendations ("Least-squares fitting") given in [3], section H.3.2 with amount of 7.67 ºK. The standard uncertainty of the artificial thermocouple have been calculated from the manufacturer's data with amount of 0.86 ºK. The standard uncertainty due to resolution of the voltmeter of 10 μV, have been estimated with amount of 0.25 ºK (conversion of the units from mV to ºK have been done by using the same thermoelectric characteristic in the measuring example point u_T=7.38213 mV).

Although we have been used well accepted methodology for standard uncertainty estimation, the significance of results is that there is lack of similar approaches in this field in order to make a comparison due to neglecting of this parameters. Moreover herein we show that the amount of uncertainty that arises from used least square method to fit the thermoelectric characteristics (1) is very significant. Additionally, for the same data from Table I, we have decided to calculate the amount of uncertainty if we consider that the thermoelectric characteristic is linear, as widely accepted in the research field (example in [4]). The fitted linear thermoelectric characteristic will have the form given by (2).

$$T = 88.161 \cdot u_T + 40.247 \quad (2)$$

The error of the least square method for (2) have been estimated with amount of 22.3 ºK.

The question that arises here is, while we are measuring the temperature by the method of nature thermocouple, can we use the thermoelectric characteristic and not consider like significant the error which arises from its modeling, or we should consider using the model (1) that has standard uncertainty of least square fitting of 7.67 ºK, or we can use linear model (2) that has standard uncertainty of least square fitting of 22.3 ºK in order to use more simple model. In order to give answer to this question we must recall to our data from our other works ([5], etc.) which are beyond the scope of this paper and which are part of comprehensive study on this topic, according to which, the standard uncertainty with amount of 7.67 ºK has relative contribution to the budget of measurement uncertainty of single temperature measurement by 30-70%, depending of the experimental measurement point. This means that, our new proposal for including the measurement uncertainty of the thermoelectric characteristics (especially contribution that arises from the applied least square method) is essential and should not be neglected in any measurement in the field and similar.

We propose that the standard uncertainty of thermoelectric characteristics should be combined with other important uncertainties which arise from the cutting process itself, the cutting parameters (feed rate, depth of cut, etc.), while measuring the single quantity. Other our proposal is that after making many single measurements which are part of the experimental plan, further to propagate these measurement uncertainties and to present them like a parameter of the final mathematical model (relationship) of the researched quantity and the cutting process parameters, which is final goal of the research.

Using linear form of thermoelectric characteristics, which are simpler and results with bigger uncertainties, like our example (2), with standard uncertainty which arises from the least square method of 22.3 ºK, should be avoided as they will make relative contribution of more than 95% during one single measurement and not reliable results.

Empirical mathematical models are very important part of the research process in the metal cutting. With the new development of the SMS's, they are essential part of the knowledge base which is needed as the SMS are limited on which parameters can monitor in real time. However many of the experimental research methods, like the method of natural thermocouple are considered like not enough reliable. Herein we have shown that with right approach we can determine if these methods are or not reliable and accurate and which are the error sources. In our example we found that the neglected error which arises from the thermoelectric characteristics modelling is actually half of the all measuring uncertainty while using the method of natural thermocouple for determining the average temperature in the cutting process by turning. Having this values we can focus further on lowering of this uncertainty and by joining the uncertainty parameter we can encourage using this method within the knowledge base of SMS.

CONCLUSIONS

This paper rise a question about the most common approaches in the published works in the field of metal cutting processes, which are neglecting or underestimating the error that arises from using thermoelectric characteristics of the natural thermocouple cutting tool – workpiece, making this method to be avoided as not reliable. Through an example based on own experimental data, the values of the standard uncertainty components that arise from the calibration of the natural thermocouple C1630-MC2 have been presented.

It is proposed that special considerations should be given to the selection of the order of the thermoelectric mathematical model, because fitting calibration curve with high values of standard uncertainty will lead to high value of uncertainty of the measurement where the thermoelectric characteristic will be used, and further making measurement result not reliable.

Our next works will be focused on publishing of the uncertainty of the mathematical model of the researched average temperature in the cutting process which includes and combines the standard uncertainty of the thermoelectric characteristics of natural thermocouple.

Further work should be focused on lowering of the error contribution from the calibration of the natural thermocouple as main source of errors in the experimental research and making this method accurate and interesting for use in the knowledge base of the developing SMS's.

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