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A Proposed Algorithm for Determining the Suitable Number of Significant Digits of Force Transducer Calibration Constants

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ABSTRACT---- ***Precision measurement is one of the important goals of measurement and calibration. Positive measures are designed to provide researches with the highest accuracy and precision levels. In force measurements, force measuring instrument manufacturers are striving to achieve the best force measurement resolution to accompany the high level of calibration measurement capabilities achieved by the primary deadweight machines. In the calibration of the force transducers, polynomial equations which correlate, the applied load on the transducer and its corresponding output signal in mV/V are deduced. These equations contain numerical constants A, B and C. This paper introduces a mechanism to determine the suitable number of significant digits for these constants. Error analysis procedure for the calibration polynomial equation is proposed. This proposed algorithm safeguards the most accurate and realistic method for rounding the calibration constants***

Keywords---- Significant digits, Force transducer, Rounding, uncertainty, calibration constants

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1. INTRODUCTION

It is well known that it is always said do not round the proceeding calculations. Rounding middle, values may tend to rounding errors in the final interpreted results. Rounding might be only executed after the final calculations have been calculated. In the field of metrology and measurements, the measured and calculated values have little or no true meaning and thus, it is useless, unless the figure (digit) in that values were considered to be important and the significant figure was properly identified and defined. Significant figures are especially effective in the field of measurement results interpretations, medicine, food test science, and engineering. Error in reporting and identification of significant figure is being remarked even in adjective researches [1]. Based on surveying the published articles demonstrates that many researchers were not given adequate interest to significant figure determination. It is especially common to see the estimated results having too many significant figures that show significant number of people, who generate data, use the data, review research articles, and edit journals, may need theoretical and practical guidelines in defining, determining and interpreting the significant figures of the presented results. It is well known that the reported measurement result error exists among merologists can indicate that the significant figure as an important issue[3]. To decide the suitable numbers of significant figure for the reported measurements results not a distinct or easy task. One of the most known methodology that rounding the reported measurement result, correction, or error to the same number of decimal places as the least significant digit of the uncertainty or results with both value and uncertainty being in the same units. Both the measurement result and uncertainty will be rounded to the same level of significance [4-5]. Even though increasing the number of significant figures in the process of mathematical operations is usually an unintended careless error, its consequences may not be distinguishable from the intentional and therefore unethical alteration of data[6].

Under the significant figure convention, the basic principle regarding the significant figures in calculations is that the calculated values can be no more precise than the data used in the calculation, and the reported result should reflect this issue. In all calculations, the number of significant figures is expressed by the least precise factor in the calculations used (a chain is only as strong as its weakest link) [7].

2. MATHEMATICAL BACKGROUND OF THE PROPOSED MECHANISM

A radical feature that all quantitatively evaluated measurements carry are the uncertainty associated with those measurements' errors. Uncertainty known as the associated parameters with the result of a measurement that describe the variations of the results that could reasonably be attributed to the measured quantity such as (mass, amount, number, or volume). Since knowledge of the measurement uncertainty implies increased confidence in the validity of a measurement, one of the essential skills of a laboratory analyst is the ability to correctly determine and intelligently report measurement uncertainties.

Uncertainty reporting has to be taken into consideration the rounding process. In force measurement the metrologists use the force proving instruments (such as force transducers) to calibrate the universal testing machines. To achieve the traceability those, force transducers have to be calibrated. In accordance with the relevant standard such as ISO376:2011 and ASTM E74 the calibration will be conducted for 10 point all over the full range of the force transducer. To get the intermediate points for usage purposes it is required to have calibration equations for those force transducers. This calibration equation obtained from curve fitting for the calibration results so constants will be produced as indicated below. The following equation shows the correlation between the applied load in kN and the deflection of the force transducer in mV/V[5]:

$$\mathrm{D} = \mathrm{A} \times F + \mathrm{B} \times F^2 + C \times F^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where A, B and C are the equation constants. These constants are obtained from the curve fitting calibration data and awarded in the calibration certificate. To show the effect of the accuracy of these awarded constants on the accuracy of the calculated (expected) force transducer deflection, error analysis for equation (1) has to be performed. The applied load (F) is not the concerned factor, so it is considered a constant[5].

$$\delta D = \frac{\partial D}{\partial A}\delta A + \frac{\partial D}{\partial B}\delta B + \frac{\partial D}{\partial A}\delta C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\delta \mathrm{D} = \mathrm{F}\delta \mathrm{A} + \mathrm{F}^2 \delta B + F^3 \delta C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The right-hand side value has to not exceed 0.4 of the resolution (0.4R) of the displaying device, so do not cause after rounding error value equal to the resolution value.

For example, the displaying device can be considered to give resolution equals to 0.000001 mV/V. For simplicity this limit (0.4R) can be divided into three equal parts i.e.

$$\mathrm{F}\delta\mathrm{A} \leq 1.3e^{-7}\mathrm{mv/v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\mathrm{F}^2\delta\mathrm{B} \leq 1.3e^{-7}\mathrm{mv/v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$\mathrm{F}^3\delta\mathrm{C} \leq 1.3e^{-7}\mathrm{mv/v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

In equations (4-6) if the maximum applied force in the calibration data is concerned, the optimum number of significant digits can be obtained and can be valid for the whole applied force range, through the detection of the maximum allowable error from the following equations:

$$\text{Max. allowable } \delta\mathrm{A} = \frac{1.3e^{-7}}{F_{max}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$\text{Max. allowable } \delta\mathrm{B} = \frac{1.3e^{-7}}{F_{max}^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$\text{Max. allowable } \delta\mathrm{C} = \frac{1.3e^{-7}}{F_{max}^3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The following section gives numerical examples for calibration data of three different force transducers. These transducers have capacities of 10 kN, 300 kN and 3000 kN. The following figure shows the flow chart of the proposed algorithm to get the optimum number of significant digits for the calibration constants A, B and C.

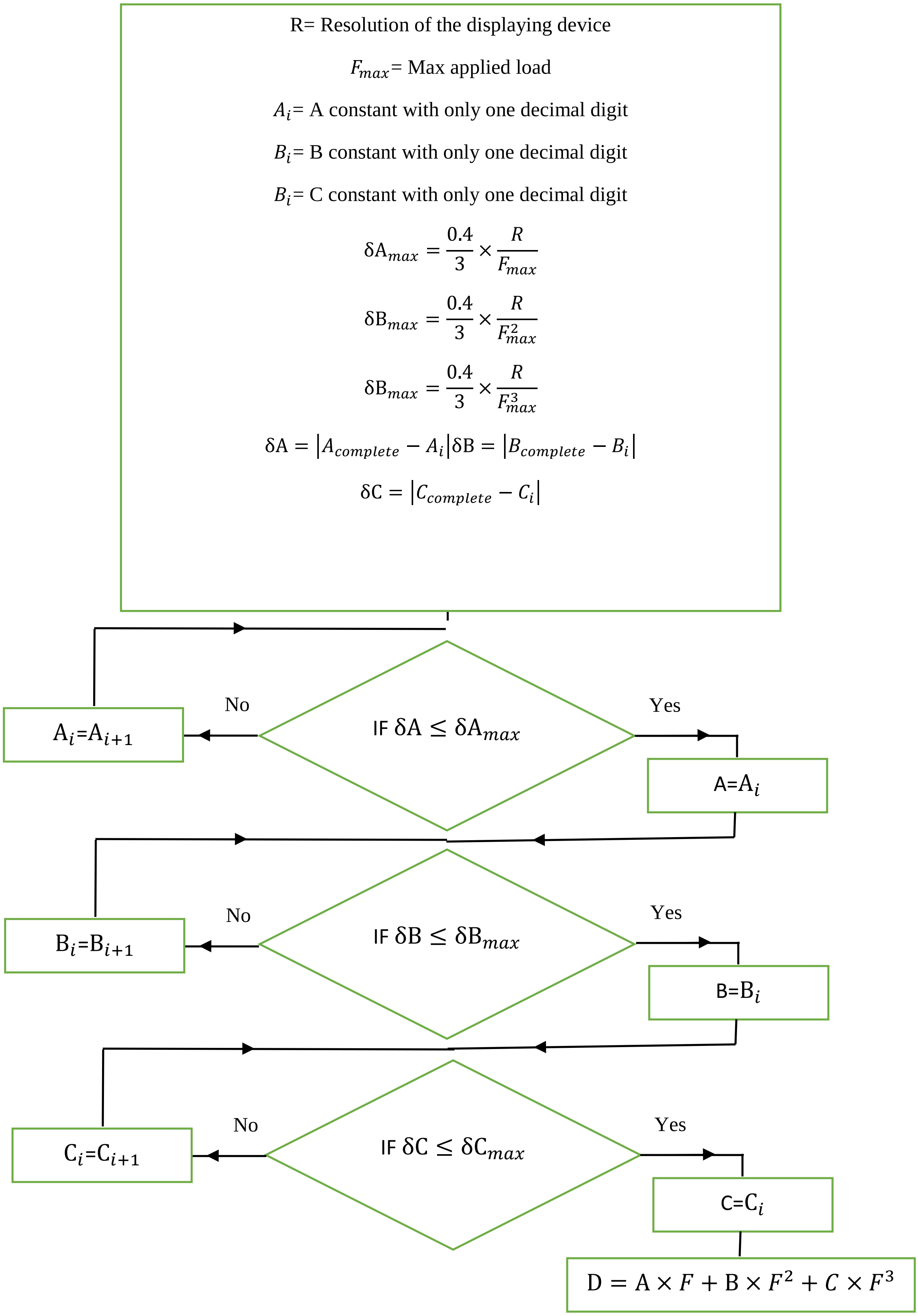

Fig. 1. Schematic for the proceeding of the proposed mechanism

3. RESULTS AND DISCUSSION

Tables 1, 2 and 3 show the calculation results for 10 kN, 300 kN and 3000 kN respectively. The tables show the applied load in kN and the corresponding average response of the displaying device in mV/V. The curve fitted response is the calculated response from the fitted calibration equations with the complete obtained significant digits for the equation constants A, B and C. The first calculated responses are calculated from the curve fitting constants A, B and C with taking number of significant digits satisfy equations (7-9), meanwhile the second and third response calculations are obtained from the curve fitting constants with number of significant digits less than the concerned number of digits with the first case by one and two digits respectively.

Table 1. Results analysis of 10 kN force transducer results:

Load (kN)	**Average Response (mV/V)**	**Curve fitted Response mV/V**	**1^{st} Calculated Response mV/V**	**2^{nd} Calculated Response mV/V**	**3^{rd} Calculated Response mV/V**
1	0.200290	0.200293	0.200293	0.200294	0.200298
2	0.400583	0.400578	0.400578	0.400579	0.400587
3	0.600843	0.600847	0.600847	0.600848	0.600860
4	0.801087	0.801093	0.801093	0.801094	0.801110
5	1.001297	1.001309	1.001309	1.001311	1.001330
6	1.201487	1.201489	1.201489	1.201491	1.201513
7	1.401700	1.401625	1.401625	1.401628	1.401653
8	1.601655	1.601711	1.601711	1.601714	1.601742
9	1.801723	1.801739	1.801739	1.801743	1.801773
10	2.001720	2.001703	2.001703	2.001707	2.001740

	A	B	C
Maximum allowable error δ	1.300000E-08	1.300000E-09	1.300000E-10
Absolute value of δ for the 1^{st} cal. Res.	9.05813E-10	4.64736E-10	4.40005E-11

	A	B	C
Complete Const.	0.200295600905813	-0.000000976535264145813	-0.00000115534400047762
1^{st} Cal.	0.2002956	-0.000000977	-0.0000011553
2^{nd} Cal.	0.200296	-0.00000098	-0.000001155
3^{rd} Cal.	0.20030	-0.0000010	-0.00000116

Table 2. Results analysis of 300 kN force transducer results

Load (kN)	**Average Response (mV/V)**	**Curve fitted Response mV/V**	**1^{st} Calculated Response mV/V**	**2^{nd} Calculated Response mV/V**	**3^{rd} Calculated Response mV/V**
30	0.200136	0.200117	0.200117	0.200116	0.200122
60	0.400209	0.400216	0.400216	0.400214	0.400226
90	0.600284	0.600295	0.600294	0.600292	0.600310
120	0.800346	0.800350	0.800350	0.800346	0.800370
150	1.000382	1.000379	1.000379	1.000375	1.000404
180	1.200389	1.200380	1.200380	1.200374	1.200409
210	1.400360	1.400349	1.400349	1.400343	1.400382
240	1.600272	1.600285	1.600285	1.600277	1.600321
270	1.800177	1.800184	1.800183	1.800175	1.800223
300	2.000049	2.000043	2.000043	2.000033	2.000085

	A	B	C
Maximum allowable error δ	**4.44444E-10**	**1.48148E-12**	**4.93827E-15**
Absolute value of δ for the 1^{st} cal. Res.	3.36991E-10	2.03336E-13	4.48784E-15

	A	**B**	**C**
Complete Const.	**0.00667083033699066**	**-0.00000000840220333586091**	**-0.0000000000166655121587059**
1^{st} Cal.	**0.00667083**	**-0.000000008402**	**-0.00000000001667**
2^{nd} Cal.	**0.0066708**	**-0.00000000840**	**-0.0000000000167**
3^{rd} Cal.	**0.006671**	**-0.0000000084**	**-0.000000000017**

Table 3. Results analysis of 3000 kN force transducer results:

Load (kN)	Average Response (mV/V)	Curve fitted Response mV/V	1st Calculated Response mV/V	2nd Calculated Response mV/V	3rd Calculated Response mV/V
300	0.200021	0.199986	0.199986	0.199986	0.199986
600	0.400015	0.400024	0.400024	0.400024	0.400025
900	0.600089	0.600110	0.600110	0.600109	0.600110
1200	0.800238	0.800237	0.800237	0.800237	0.800238
1500	1.000405	1.000403	1.000403	1.000402	1.000404
1800	1.200609	1.200601	1.200601	1.200601	1.200602
2100	1.400836	1.400828	1.400828	1.400828	1.400829
2400	1.601068	1.601078	1.601078	1.601078	1.601080
2700	1.801345	1.801348	1.801347	1.801347	1.801349
3000	2.001634	2.001631	2.001631	2.001631	2.001633

	A	B	C
Maximum allowable error δ	4.44444E-11	1.48148E-14	4.93827E-18
Absolute value of δ for the 1st cal. Res.	3.9436E-11	1.19988E-15	1.05246E-18

	A	B	C
Complete Const.	0.000666529339435986	0.000000000314068800123713	- 0.0000000000000290189475351071
1st Cal.	0.0006665293	0.00000000031407	-0.00000000000002902
2nd Cal.	0.000666529	0.0000000003141	-0.0000000000000290
3rd Cal.	0.00066653	0.000000000314	-0.000000000000029

4. CONCLUSION

From this article it was concluded that the contacts produced from the curve fitting is not the most realistic to interpret the calibration equation. Satisfactions of the maximum allowable error is required and it can be achieved using the constants derived at the first calculated responses which were calculated from the curve fitting constants A, B and C with taking number of significant digits satisfy equations (7-9). This approach can be utilized to predict the optimum no of significant figure to have more accurate presentations of the results.

5. REFERENCES

[1] Rodr.guez LC et al. Estimation of performance characteristics of an analytical method using the data set of the calibration experiment. Analytical Letters. 1993;**26**(6):16 DOI: 10.1080/00032719308019900

[2] Gu H et al. Selecting the correct weighting factors for linear and quadratic calibration curves with least-squares regression algorithm in bioanalytical LC-MS/MS assays and impacts of using incorrect weighting factors on curve stability, data quality, and assay performance. Analytical Chemistry. 2014;**86**(18):8959-8966' DOI: 10.1021/ac5018265

[3] Hayashi Y et al. Detection limit estimated from slope of calibration curve: An application to competitive ELISA. Analytical Sciences. 2005;**21**(2):167-169 DOI: 10.5772/intechopen.72932

[4] Zhao Y et al. Reasons for calibration standard curve slope variation in LC-MS assays and how to address it. Bioanalysis. 2014;**6**(11):1439-1443 DOI:10.4155/bio.14.71

[5] Oliveira EC. Internal standard versus external standard calibration: An uncertainty Case study of a liquid chromatography analysis. Quimica Nova. 2010;**33**(4):19 DOI:10.1590/S0100-40422010000400041

[6] Tan A, Awaiye K. Use of internal standards in LC-MS bioanalysis. In: Li W, Zhang J, Tse FLS, editors. Handbook of LC-MS Bioanalysis: Best Practices, Experimental Protocols, and Regulations. John Wiley & Sons Inc.; 2013. pp. 217-227 DOI:10.1002/9781118671276.CH17

[7] Vicki Barwick Preparation of Calibration Curves A Guide to Best Practice " LGC/VAM/2003/032. Valid Analytical Measurement (VAM) DOI: 10.13140/RG.2.2.36338.76488