UNCERTAINTY EVALUATION ON THE CALIBRATION OF DC & AC CURRENT GENERATED BY COMBINATION OF AC/DC CURRENT SOURCE AND CURRENT COIL USING SUBSTITUTION METHOD

EVALUASI KETIDAKPASTIAN PADA KALIBRASI ARUS DC & AC YANG DIHASILKAN OLEH KOMBINASI ANTARA SUMBER ARUS AC/DC DAN CURRENT COIL MENGGUNAKAN METODE SUSBTITUSI

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ABSTRAK

Development of measurement method for calibrating current coil continues to be made to maintain measurement traceability for high DC and AC current scope which are generally used for clamp meter calibration services in Laboratory of National Measurement Standard for Electricity and Time (Lab NMS ET). This paper describes the uncertainty evaluation method developed in Lab NMS ET for calibrating high DC and AC current from 50 A up to 990 A generated by a single system consisted of a DC/AC current source and a 50-turn current coil. The uncertainty analysis was carried out based on the calibration principle using the substitution method combined with the principle of multiplication between output current of a DC/AC current source and a 50-turn current coil. It resulted in six source of uncertainty component derived from the current source, the current coil, and a meter. Their sensitivity coefficients were calculated as well to adapt the unit of each uncertainty budget to the final unit in Ampere (A). Using this uncertainty evaluation principle, at the measuring range of 50 A to 990 A, the expanded uncertainties for DC current were spanned from 0.69% to 1%. As for AC current, they were spanned from 0.8% to 1.4%. The major uncertainty contribution comes from the current coil which is representation of uncertainty due to various factors affecting the current coil performance. Validation had been carried out and the normalized error (EN number) values were in the range -0.48 to -0.16 for DC current measurements and in the range of -0.06 to 0.16 for AC current measurements.

Keywords: current coil, multiproduct calibrator, calibration, uncertainty, substitution method, EN number.

ABSTRACT

Pengembangan metode pengukuran untuk proses kalibrasi current coil terus dilakukan guna menjaga ketertelusuran pengukuran lingkup arus DC dan arus AC tinggi yang pada umumnya digunakan untuk layanan kalibrasi alat ukur berupa clamp meter di Laboratorium Standar Nasional Satuan

Ukuran Kelistrikan dan Waktu (Lab SNSU KW). Pada karya tulis ilmiah ini dipaparkan tentang metode evaluasi ketidakpastian yang dikembangkan di Lab SNSU KW untuk kalibrasi arus DC dan AC tinggi dari 50 A hingga 990 A yang dihasilkan oleh satu kesatuan sistem yang tersusun atas satu buah sumber arus AC/DC dan satu buah current coil 50 llitan. Analisa ketidakpastian dilakukan berdasarkan prinsip kalibrasi menggunakan metode substitusi yang digabungkan dengan prinsip perkalian antara arus keluaran sumber arus AC/DC dan current coil 50 lilitan. Hal ini menghasilkan enam (6) budget ketidakpastian yang bersumber dari sumber arus, current coil, dan sebuah meter. Koefisien sensitivitasnya juga dihitung untuk menyesuaikan satuan dari tiap budget ketidakpastian pada satuan akhir dalam Ampere (A). Dengan menggunakan evaluasi ketidakpastian ini, pada rentang titik ukur 50 A hingga 990 A, ketidakpastian bentangan yang dihasilkan untuk arus DC terentang dari 0,69% hingga 1%. Sedangkan untuk arus AC terentang dari 0,8% hingga 1,4%. *Kontribusi ketidakpastian terbesar bersumber dari current coil yang merupakan representasi dari ketidakpastian yang disebabkan oleh berbagai macam faktor yang mempengaruhi unjuk kerja dari current coil tersebut. Validasi telah dilakukan dan didapatkan nilai normalized error (EN number) berada pada rentang -0.48 hingga -0.16 untuk pengukuran arus DC dan pada rentang -0.06 hingga 0.16 untuk pengukuran arus AC.*

Kata kunci: *current coil, multiproduct calibrator, kalibrasi, ketidakpastian, metode subtitusi, EN number.*

1. INTRODUCTION

In many industrial processes, electrical current measurement is essential for technical and economic reasons, especially if it is related to high level of production quality. The current measurement can be made with different techniques of varying accuracy, application difficulty, and costs. One of applications for accurate current measurement in industry is high current measurement using clamp meter (Galliana & Capra, 2012).

Clamp meter is generally used to measure current up to 1500 A or higher and widely used at power frequency and DC. To maintain the instrument traceability to International System of Unit (SI Unit), like other measurement instruments, the clamp meter has to be calibrated for certain period of time. The calibration usually carried out by using a coil combined by a current source commonly called by multiproduct calibrator (Costa, 2008). As part of traceability chain to keep the instrument values are connected to realization of SI unit, the coil or widely also called by current coil, and of course the current source, have to be calibrated. There were some methods that had been published calibration. One of them was research about current coil calibration conducted by Olencki and Mroz in Poland in 2017 (Olencki & Mróz, 2017). Their research focused on the utilization of current coil for calibrating power clamp meters in AC current range from 5 to 1000 A. Different from what will be discussed in this paper, two uncertainty contributions they tried to calculate were ACE (Amplitude Coil Effect) and PCE (Phase Coil Effect) which quite influential in the calibration of power clamp meters.

Another research is what was done by Amalia & Faisal to calibrate 10-turn and 50-turn current coil by using a standard current source called by multiproduct calibrator. In their method, a single current coil was calibrated and then its correction and uncertainty are evaluated in the form of percent to the turn number (N) (Amalia & Faisal, 2019). Their uncertainty evaluation was conducted more complex and complicated because they use current multiplication and division principle to evaluate the uncertainties. Furthermore, when users use this current coil and multiproduct calibrator as standard to calibrate a clamp meter, the uncertainty for either standard current coil or standard multiproduct calibrator has to be evaluated individually. related to current coil The weakness of this calibration style is the complicated process of evaluating uncertainty because they have to do some uncertainty calculation with multiplication or division mathematical model and have to consider a lot of sensitivity coefficients as well. Another thing is it tends to cause miss calculation if the calibration technician does not have enough knowledge about the system, mathematical model, and the calibration certificate used.

To simplify the clamp meter calibration process, a method has been developed in the Laboratory of National Measurement Standard for Electricity and Time (Lab NMS ET) as part of the National Standardization Agency of Indonesia to be able to calibrate a system which able to produce high DC and AC currents up to 1000 A. This system then can be used as standard system to calibrate a clamp meter more easily and simply. The system consists of multiproduct calibrators under test and current coil under test calibrated as a single system. Therefore, the calibration certificate is valid if and only if the multiproduct calibrator is used in pairs with the current coil. When users use this system as a standard to calibrate their clamp meters under tests, the standard uncertainties do not need to be evaluated individually. They also do not need to perform complicated uncertainty and sensitivity coefficient calculation using complicated formulation so it is expected can simplify the work and able to reduce the calculation error.

Calibration methods of high DC and AC current, produced by a system which is a combination of multiproduct calibrator under test and current coil under test, which was developed utilizes a standard multiproduct calibrator and a current coil, and is assisted as well by a transfer standard called a clamp meter. The uncertainty evaluation method outlined in this paper was developed based on the calibration principle using the substitution method combined with the multiplication principle of DC and AC current generated by standard multiproduct calibrator and the turn number of current coil (N) to obtain high DC and AC currents. Mathematical model, uncer-tainty budgets, uncertainty distributions, sensitivity coefficients, the uncertainty calculation process, and its validation are described explicitly in this paper and are expected to provide clear guidance on how this evaluation method can be used and have good performance.

2. BASIC THEORY

2.1 Working Principle of Current Coil

The current coil is an instrument consisting of a number of wires wound into one unit. The number of wire turns is usually notated by N and is called by turn-number because the wires are rolled together within two same points. The output current of current coil is representation of magnetic field which is the product of a force called by magneto motive force (mmf) generated when a current is passed through all of the wires. The unit of mmf is defined as the ampere-turn (At) and 1 At is the amount of force that is generated by a direct current of 1 A flowing in a single loop turn in a vacuum. The total mmf that is produced is defined by the product turn number and current. Therefore, if a single strand of wire is looped into 50 turns (N), the current in the wire would be multiplied by 50 to obtain the mmf (Costa, 2008).

2.2 Substitution Method Principle

Substitution method is a method for eliminating systematic measurement errors caused by errors in the measuring instrument used to compare the quantity being measured with a standard. In the substitution method, the value of the quantity being measured is not found indirectly from a reading of the measuring instrument. The value is obtained from the amount of the standard value which is selected or regulated in such a way so that the reading of the measuring instrument remains the same when the quantity being measured is replaced by the standard (Shirokov K.P., 2010). The substitution topology has only a single measurement position in which the units under calibration UUC (I_{MPCX}) and STD (I_{MPCS}) are switched alternately (Bramley, Tavener, & Pickering, 2007).

The substitution method is evaluated by using ratio between the units under calibration (UUC) which is divided by reference (STD). The method generally relies on the two–step measurement procedure as follows:

a. Measuring the Unit Under Calibration (UUC), with the reading values by an instrument notated by I_{MPCx}^{CM}.
b. Measuring a standard instrument having known value (STD), with the reading values by an instrument notated by I_{MPCs}^{CM}.

Both measurements have to be conducted with the same instrument within a short time delay, and the two instruments (UUC and STD) should have the same nominal value. The readings of the instrument are combined with the known value of STD to give the actual value of UUC. Moreover, the two steps above are repeated *n* times, giving a measurement sample N of *n* ordered pairs of complex numbers N = {(I_{MPCX}^{CM} , I_{MPCs}^{CM})i}, with $i = 1...n$.

Then the ratio will be express by Equation (1) as follows (Callegaro & Bich, 2001):

$$R = \frac{I_{MPCX}{}^{CM}}{I_{MPCS}{}^{CM}} \tag{1}$$

with:

R is ratio of the current coil

I_{MPCX}^{CM} is UUC reading value by a meter

I_{MPCS}^{CM} is STD reading value by a meter

3. METHODS

3.1. Measurement Method

Unit calibrated in this research was DC and AC current generated by a black box system, a system which is combination of an AC/DC current source (Source X) and a current coil X (CCX) with the turn-number of 50. Therefore, the calibration results by using the evaluation method explained in this paper is valid and only be allowed if and only if the CCX is operated together with the source X. Next, the black box system will be called by UUCx. The calibration was carried out by using a standard called Multiproduct Calibrator (MPC), an auxiliary device called 50-turn Current Coil type F-5500 (CC), and a transfer standard called Clamp Meter (CM). MPC is a current source having ability to generate DC and AC current signal up to maximum of 20 A, while CC is an instrument having ability to multiply 50 times the current input applied to it, and M is a meter used to measure the output current of CC and UUCx.

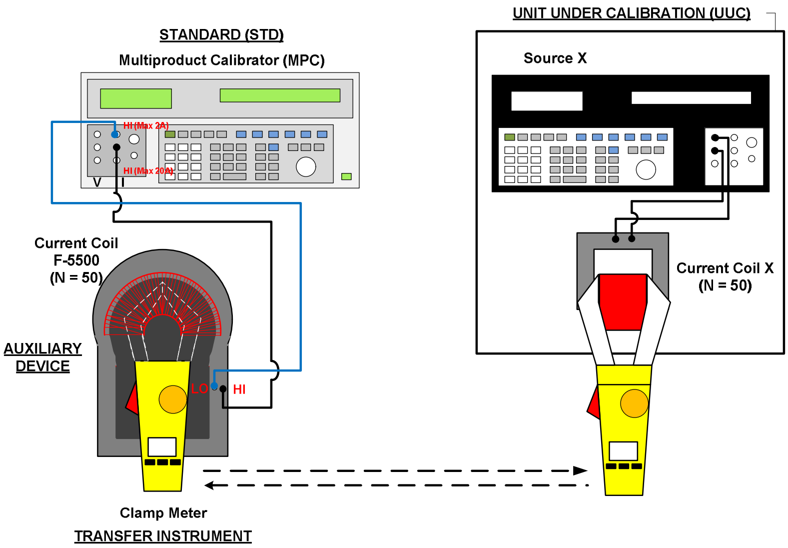

Figure 1. Schematic Diagram for calibrating DC and AC current using substitution method.

The measurement points for DC and AC current parameter is shown in Table 1 and for each measurement point, 5 times of data retrieval were carried out. The calibration method used in this research is called by substitution method. Hence, at each measurement point, every time the data was taken, the measurement is performed alternately between CC and UUCx. When measuring the CC, as shown by Figure 1, the current generate by MPC, which value is obtained using Equation 2 and presented by Table 1, is flowed directly to CC by using 2 wire cabling. After passing the CC, the current will be enlarged 50 times and be read by CM. The UUCx measurement is performed right away after CM finishes measuring the CC by clamped CM to CCX of UUCx.

Table 1. The measurement points for both DC and AC current, and current should be generated by MPC calculated using Equation 2 (AC measurement points are performed at 55 Hz of Frequency).

Measurement Points (Ix_nom)	Curent Supplied from MPC (Ical)
50 A	1 A
100 A	2 A
150 A	3 A
200 A	4 A
250 A	5 A
300 A	6 A
350 A	7 A
400 A	8 A
450 A	9 A
500 A	10 A
550 A	11 A
600 A	12 A
650 A	13 A
700 A	14 A
750 A	15 A
800 A	16 A
850 A	17 A
900 A	18 A
950 A	19 A
990 A	19,8 A

$$I_{cal} = \frac{I_{x\_nom}}{50} \tag{2}$$

with :
I_{cal} is current supplied from MPC

I_{x_nom} is measurement point

The final value sought in this calibration case is in the form of correction of DC and AC current levels supplied by UUCx. The mathematical model used is developed based on the ratio formulation presented in Equation (3) and mathematically expressed by Equation (4).

$$R = \frac{I_x}{I_s} \tag{3}$$

$$I_{x\_actual} = R \cdot (I_{cal} \cdot N) \tag{4}$$

where:

I_x = current reading by CM when measuring UUCx

I_s = current reading by CM when measuring CC

R = ratio of measurement current

I_{x_actual} = actual current that generated by UUCx

I_{cal} = current that supplied by MPC

N = winding number CC (50)

For each measuring point, the correction of the DC and AC current levels of UUCx is the difference between the actual current generated by UUCx (I_{x_actual}) and the value of the current measurement point (I_{x_nom}), or mathematically formulated by Equation (5). By combining Equations (4) and (5) and by adding some correction components attached to R, MPC and CC, a formulation, which is the final mathematical model used to evaluate corrections and uncertainties in this research, can be derived as presented by Equation (6).

$$C_x = I_{x\_actual} - I_{x\_nom} \tag{5}$$

$$C_x = [(R + C_{meter} + C_{res} + C_{esdm}) \cdot (I_{cal} + C_{sertcal} + C_{spekcal}) \cdot (N + C_{spekN})] - I_{x\_nom} \tag{6}$$

where:

C_x = correction of DC and AC current level on UUCx

I_{x_actual} = actual current that generated by UUCx

I_{x_nom} = the current measurement point at UUCx which correction value will be found

C_{meter} = correction that comes from many factors affecting CM reading such as temperature, humidity, stability, linearity, laying position of CM, etc.

C_{res} = correction caused by ratio resolution

C_{esdm} = correction came from the ratio calculation results repeatability

$C_{sertcal}$ = correction form calibration certificate MPC

$C_{spekcal}$ = correction of MPC originating from linearity, loading effect, thermal effect, etc.

C_{spekN} = correction on CC sourced from linerity, loading effect, thermal effect, etc.

In this paper, C_{meter}, C_{res}, C_{esdm}, $C_{spekcal}$, and C_{spekN} are assumed to have zero values and related existing error are compensated in the uncertainty calculation. Therefore, the final mathematical model to find the DC and AC current level correction of UUCx can be derived to Equation (7).

$$C_x[A] = \{R \cdot (I_{cal}[A] + C_{sertcal}[A]) \cdot N\} - I_{x\_nom}[A] \quad (7)$$

With:

$C_x\,[A]$ =correction current DC and AC level on UUCx (in Ampere unit)

R =ratio of measurement current

$I_{cal}\,[A]$ =current that supplied by MPC (In Ampere unit)

$C_{sertcal}$ [A] =correction form calibration certificate MPC (In Ampere unit)

N =winding number CC (50)

I_{x_nom} [A] =the current measurement point at UUCx which correction value will be found (in Ampere Unit]

3.2. Uncertainty Evaluation

The uncertainty evaluation on the calibration conducted in this study is based on Equation (6) with the sensitivity coefficient of each uncertainty budget calculated using the mathematical model of the first partial derivative of Equation (7). Therefore, based on Equation (6), the uncertainty budgets can be listed as follows:

a. Factors influencing the CM reading

The current which was read by CM when it was clamped on both CC and UUCx is affected by many factors, such as environmental condition (temperature, humidity), stability, linearity, unstable CM reading due to the uniformity of the laying position of the CM on both the CC and UUCx, and etc. Because the research on how big the influence of these factors has not been conducted yet, the uncertainty value for this contribution is estimated based on 10% of the CM technical specifications (National Accreditation Body of Indonesia, 2011)

This uncertainty is assumed to be rectangular distributed so that it can be formulated using Equation (8). The formulation for calculating the sensitivity coefficient for this uncertainty budget is the first partial derivative of equation (7) with respect to R and is obtained as shown on Equation (9).

$$u_1 = \frac{\frac{U_1}{I_{x\_nom}}}{\sqrt{3}} \quad (8)$$

$$c_1 = (I_{cal} + C_{sertcal}) \cdot N \quad (9)$$

where:

u_1 = uncertainty budget caused by factors influencing CM reading

U_1 = absolute uncertainty obtained from 10 % of CM technical specification

I_{x_nom} = the current measurement point of UUCx

c_1 = sensitivity coefficient for u_1

I_{cal} = current supplied by MPC

$C_{sertcal}$ = correction form MPC calibration certificate

N = winding number of CC (50)

b. Ratio resolution

Uncertainty budget coming from resolution is the smallest value change on the value of R obtained using Equation (3). Because the value of R is calculated from two instruments reading measured using one meter, this uncertainty is assumed to be triangularly distributed and mathematically formulated by Equation (10). Using the first partial derivative principle of Equation (7) with respect to R, the sensitivity coefficient for this budget uncertainty is presented in Equation (11).

$$u_2 = \frac{0.5.a}{\sqrt{6}} \quad (10)$$

$$c_2 = (I_{cal} + C_{sertcal}) \cdot N \quad (11)$$

where :

u_2 = uncertainty caused by the ratio resolution

a = resolution of ratio (R)

c_2 = sensitivity coefficient for u_2

I_{cal} = current supplied by MPC

$C_{sertcal}$ = correction form MPC calibration certificate

N = winding number of CC (50)

c. ESDM

The uncertainty from the ESDM (Experimental Standard Deviation of the Mean) is an uncertainty caused by the repeatability of the CC and UUCx readings by the CM which value is represented by the value of R. This uncertainty value will then be notated by u_3 and evaluated by type-A method based on 5 (five) values of R (JCGM, 2008).

d. MPC Certificate as Standard

MPC, as the measurement standard in this study, has been calibrated and has a calibration certificate (certificate number : S.050896) issued in 2017. Therefore, the uncertainty coming from the MPC calibration certificate have to be considered also as one of the uncertainty budgets. Following the provisions in the MPC calibration certificate, this budget uncertainty is assumed to be normally distributed so that it can be formulated as in Equation (12) with a sensitivity coefficient that can be expressed using Equation (13), is obtained by deriving Equation (7) partially with respect to I_{cal}.

$$u_4 = \frac{U_4}{2} \quad (12)$$

$$c_4 = R.(N + C_N) \quad (13)$$

where:

u_4 = uncertainty budget coming from MPC calibration certificate

U_4 = absolute uncertainty obtained from MPC calibration certificate

c_4 = sensitivity coefficient for u_4

R = ratio of measurement current

N = winding number of CC (50)

e. Factors influencing the current value generated by MPC

When MPC generates current in certain level, the actual value of this current can be affected by many factors, such as environmental condition (temperature, humidity, pressure, etc), MPC stability, MPC linearity, gain, loading effect, MPC drift, and many more. However, unfortunately, the data and analysis for these factors is not carried out yet. Therefore, in this research, the budget uncertainty values caused by these factors are determined by technical specification of MPC. Next, this uncertainty budget is called by MPC specification uncertainty.

Following the MPC Technical Specification Book, this uncertainty budget is assumed normally distributed with confidence level of 99% (Fluke Corporation, 2003). So, the uncertainty value can be calculated using Equation (14) with the sensitivity coefficient calculated using Equation (15).

$$u_5 = \frac{U_5}{2.6} \tag{14}$$

$$c_5 = R.(N + C_N) \tag{15}$$

where:

u_5 = MPC specification uncertainty budget

U_5 = absolute MPC specification uncertainty taken form specification of MPC

c_5 = sensitivity coefficient for u_5

R = ratio of measurement current

N = winding number of CC (50)

f. Factors influencing the current multiplying process carried out by CC

Just like what happened to MPC, the current flowing through CC and be multiplied by 50 is also influenced by many factors, such as environmental conditions (temperature, humidity, etc.), stability, clamp/coil interaction, and many more. Therefore, these factors must also be considered in calculating uncertainty. In this paper, the uncertainty value caused by these factors is taken from the CC technical specifications, assumed to have rectangular distribution, and formulated as equation (16) (Fluke Corporation, 2002). The formulation for calculating the sensitivity coefficient is obtained using the first partial derivative of Equation (7) with respect to N as shown in Equation (17).

$$u_6 = \frac{\frac{U_6}{I_{cal}}}{\sqrt{3}} \quad (16)$$

$$c_6 = R \cdot (I_{cal} + C_{sertcal}) \quad (17)$$

where:

u_6 = uncertainty budget caused by factors influencing the current multiplying process carried out by CC

U_6 = absolute CC uncertainty taken from specification of CC

I_{cal} = current supplied by MPC

c_6 = sensitivity coefficient for u_6

$C_{sertcal}$ = correction form MPC calibration certificate.

4. RESULTS AND DISCUSSIONS

Correction values as calibration results found using Equation (7) graphically can be seen in Figure 2 for all measurement points of AC and DC current. Based on Figure 2, it can be seen that generally, for both DC and AC current measurement, the correction values relatively get smaller as the measuring points values get larger, although there is an oscillation of the correction values along the graph from the lowest to the highest measuring points.

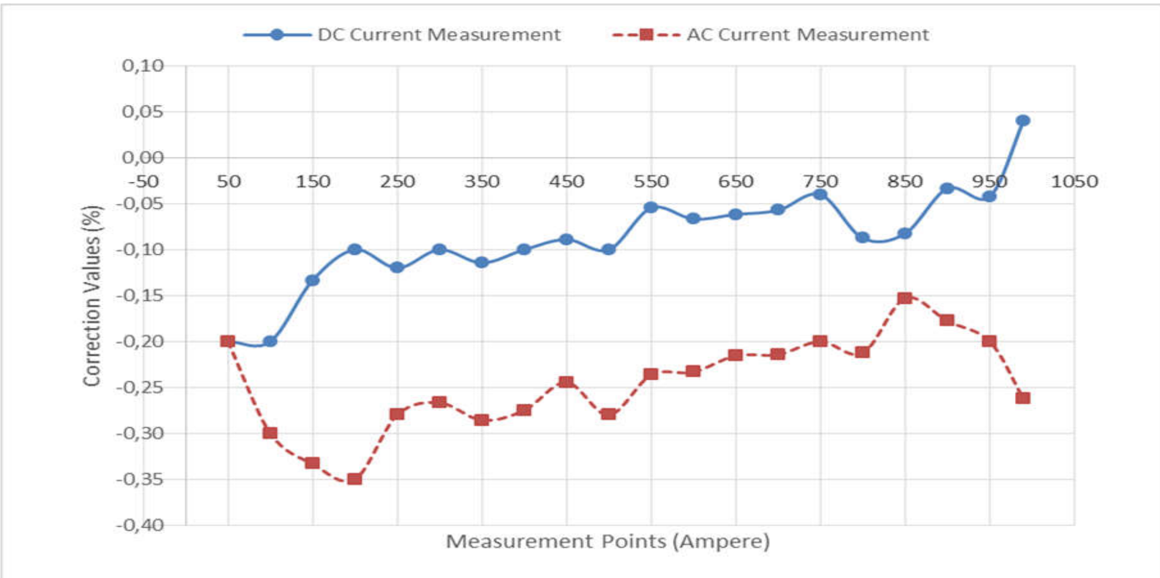

Figure 2. DC and AC measurement correction values.

The uncertainty evaluated in this calibration method is expanded uncertainty with the confidence level of 95% and coverage factor (k) of 2. The formulation to evaluate it refers to the guideline of GUM. All uncertainty budgets values as well as their sensitivity coefficient calculated for DC and AC measurement are provided by Table 2 and Table 3, respectively. All uncertainty values for each budget are shown in column IV and their uncertainty coefficient values are shown in the column VI. The sensitivity coefficient is a coefficient used to adjust the unit of each uncertainty budget to the desired final unit, i.e. Ampere (A). In the last column (column VII) is the contribution of each uncertainty budget to the final uncertainty of calibration. Based on data in this column, the final uncertainty (expanded uncertainty) of the calibration was calculated and analyzed based on Equation (6).

Graphically, the proportion of each uncertainty budget contribution listed both on the Table 2 and Table 3 are illustrated by bar carts in Figure 3. Based on this figure, it can be seen that the major uncertainty contribution, both for DC and AC measurement, comes from CC which is the uncertainty caused by various factors related to the current coil. This uncertainty values was calculated by utilizing the CC specification state on the CC technical book. The suspect is because the CC has capability to enlarge 50 times the value of current applied to it. So, when there is a certain level of current passed through the CC, all noises of it caused by environmental or operational factors are enlarged also. Moreover, the distribution of this uncertainty budget is rectangular distribution which is the most conservative distribution. It is the safest yet can give a quite big contribution. This distribution is chosen because there is not enough information related to the distribution of the CC specification.

Tabel 2. Uncertainty budgets at the DC current measurements point of 500 A.

Measurement Point ($I_{x\ nom}$): 500 A Current Supplied by MPC (I_{cal}) : 10 A

I	II	III		IV		V	VI		VII	
No.	**Uncertainty Budgets**	**Value**		**Uncertainty (ui)**		**Distribution**	**Sensitivity Coefficient (ci)**		**Absolute Uncertainty (Ui)**	
1	Factors influencing the CM reading			0,0012	A/A	Rectangular	500	A	0,61	A
2	Ratio Resolution			0,00020	A/A	Triangular	500	A	0,10	A
3	Mean of the Ratio	0,99909		0,000049	A/A	Type A	500	A	0,024	A
4	MPC Certificate	-0,00025	A	0,0021	A	Normal	50		0,11	A
5	MPC Specification			0,0021	A	Normal	50		0,11	A
6	Factors influencing the current multiplying process carried out by CC			0,17	A/A	Rectangular	10	A	1,7	A
	Correction	-0,5	A	Combined Uncertainty					1,8	A
				Coverage Factor of the Confidence Level of 95%					2	
				Expanded Uncertainty (on the Confidence Level of 95%)					3,7	A

Tabel 3. Uncertainty budgets at the AC current measurements point of 500 A

Measurement Point (I_{x_nom}): 500 A Current Supplied by MPC (I_{cal}) : 10 A

I	II	III		IV		V	VI		VII	
No.	**Uncertainty Budgets**	**Value**		**Uncertainty (ui)**		**Distribution**	**Sensitivity Coefficient (ci)**		**Absolute Uncertaint y (Ui)**	
1	Factors influencing the CM reading			0,0012	A/A	Rectangular	500	A	0,61	A
2	Ratio Resolution			0,00020	A/A	Triangular	500	A	0,10	A
3	Mean of the Ratio	0,99683		0,000063	A/A	Type A	500	A	0,031	A
4	MPC Certificate	0,00456	A	0,0056	A	Normal	50		0,28	A
5	MPC Specification			0,0054	A	Normal	50		0,27	A
6	Factors influencing the current multiplying process carried out by CC			0,21	A/A	Rectangular	10	A	2,1	A
	Correction	-1,4	A	Combined Uncertainty					2,3	A
				Coverage Factor of the Confidence Level of 95%					2	
				Expanded Uncertainty (on the Confidence Level of 95%)					4,5	A

The CC uncertainty budget affects nearly 95% of the combined uncertainty which means that if the UUC calibrated has higher accuracy and needs more accurate calibration results, the development of calibration method has to focus on how to minimize the affection of this uncertainty budget.

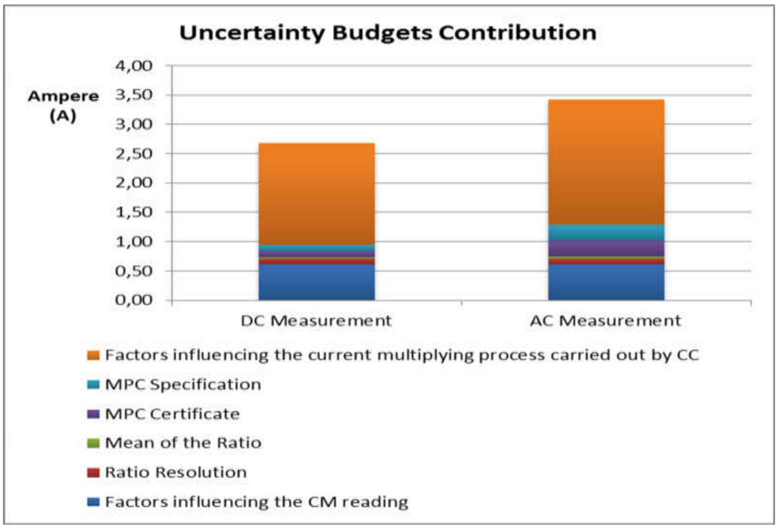

Figure 3. Graph of each uncertainty budget contribution.

Overall, for all DC measurement points, the expanded uncertainties span from 0.69% to 1 % with the largest correction of -0.2 % at the measurement point of 50 A and 100 A as shown by correction graph in Figure 2. While for the

AC measurement, for all measurement points, the expanded uncertainties span from 0.8% to 1.4 % and as illustrated by Figure 2, the largest correction is occurred at the measurement point of 200 A with the value of -0.35%.

The uncertainty evaluation results were then validated by using the system (UUCx) to calibrate a UUC called by clamp meter (CMx). The results of the CMx calibration using standard UUCx, which is calibrated and analyzed using uncertainty calculation method in this paper, were then compared with the results of CMx calibration using standard current coil (CCstd) which was calibrated using the method described in Amalia & Faisal paper (Amalia & Faisal, 2019). As shown in Figure 4 and Figure 5, respectively for DC and AC current calibration, CMx measurement results using standard UUCx are bigger than those using CCstad standard yet they still correspond to each other. The phenomenon occurs for all of measurement points both in DC and AC current measurement.

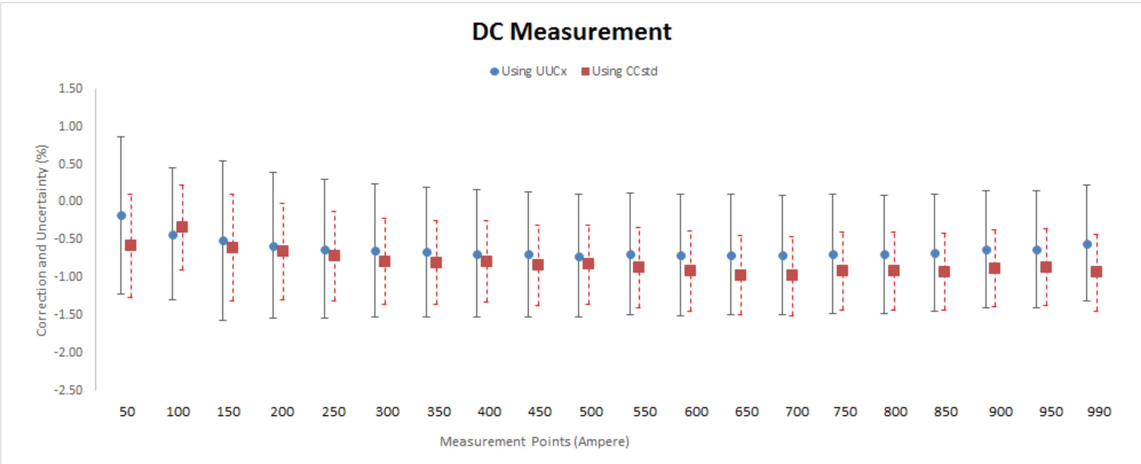

Figure 4. Comparison graph of CMx calibration results for DC current.

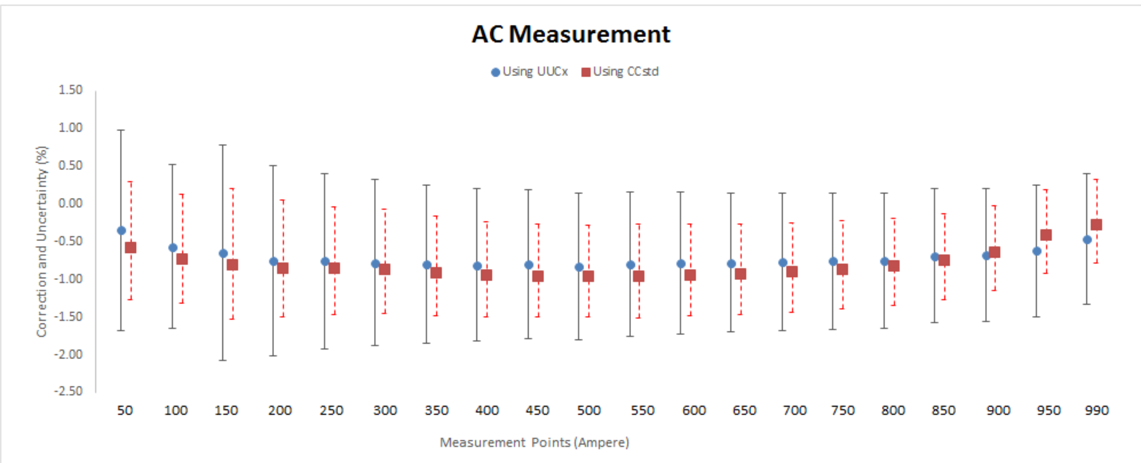

Figure 5. Comparison graph of CMx calibration results for AC current.

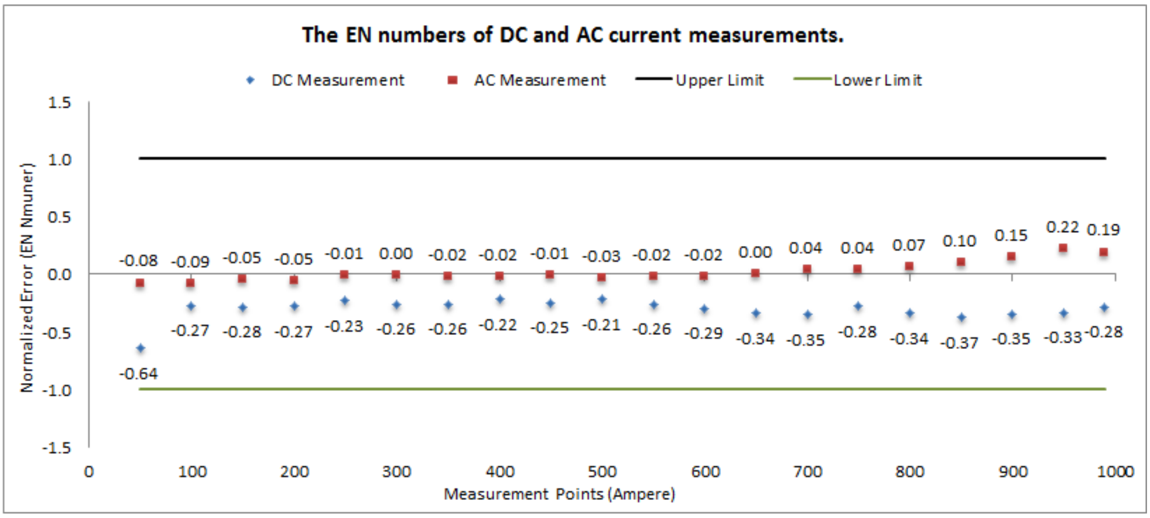

Figure 6. Graph of EN numbers of DC and AC current measurements.

Mathematically, the comparison also was validated using normalized error number (EN number) which the results are presented in Figure 6. Based on this figure, for DC current measurement, the EN numbers are in the range of -0.64 up to -0.21. While for the AC current measurement, the EN numbers are between -0.09 and 0.22. Both of these values range are within of -1 and +1 which is the absolute requirement that have to be met to state that the comparison between two measurements is in correspondence. Therefore, based on these EN numbers, it can be said that the results of CMx measurement using standard UUCx has good results. It also means that the uncertainty evaluation of the UUCx calibration carried out using method in this paper has good performance and can be utilized to perform calibration services for the same or similar UUC.

5. CONCLUSION

Uncertainty evaluation on calibration of high DC and AC current generated by a black box system (UUCx), which is combination of source X and CCX, as instrument under test by using substitution method had been conducted in this research. Uncertainty evaluation and analysist was developed using the ratio (R) principle and multiplication principle of currents generated by DC/AC current source and current coil turn-number to obtain the high current up to 990 A. Evaluation result shows show that for DC current, the expanded uncertainties span from 0.69% to 1%, while for AC current, they span from 0.8% to 1.4%. The major uncertainty contribution by using the evaluation described in this paper came from factors affecting the current multiplying process performed by CC which leads to further study about how to minimize the effect in the future if the UUC calibrated need the more accurate calibration results. Validation on the calibration uncertainty was performed as well and resulting the EN number of -0.64 up to -0.21 for DC current parameter and -0.09 up to 0.22 for AC current parameter, lies within the range of -1 to +1. This range of EN number resulted shows that the uncertainty evaluation method described in this paper has a good performance and can be used for calibration services.

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7. REFERENCES

Amalia, H., & Faisal, A. (2019). A Method for Calibrating 10-Turn and 50-Turn Current Coil Using Multiproduct Calibrator. *Jurnal Standardisasi*, *21*(3), 171–182. https://doi.org/http://dx.doi.org/10.31153/js.v21i3.749

Bramley, P., Tavener, J., & Pickering, J. (2007). Using a Substitution Measurement Topology to Eliminate the Effect of Common Mode Errors in Resistance Measurements used in Temperature Metrology. *NCSL International Workshop and Symposium*, *44*.

Callegaro, L., & Bich, W. (2001). Calibration of Imedances by The Substitution Method : Numerical Uncertainty Evaluation. In *11th IMEKO TC-4 Symp. - Trends in Electrical Measurement and Instrumentation* (pp. 481–484). Lisbon, Portugal.

Costa, M. (2008). Electrical Current Coil Metrological Confirmation for Current Clamp Meters Calibration. In *Journal of Physics : Conference Series* (Vol. 1065, p. 052014). IOP Publishing. https://doi.org/10.1088/1742-6596/1065/5/052014

Fluke Corporation. (2002). Instruction Sheet, Model 5500A / COIL, 50-Turn Current Coil. *United State of America.*

Fluke Corporation. (2003). Operators Manual 5520A Multi-Product Calibrator. *United State of America*.

Galliana, F., & Capra, P. P. (2012). Traceable Technique to Calibrate Clamp Meters in AC Current From 100 to 1500 A. *IEEE Transactions on Instrumentation and Measurement*, *61*(9), 2512–2518.

JCGM. (2008). *JCGM 100 : 2008,* Evaluation of measurement data: Guide to the expression of uncertainty in measurement (1st ed.). *JCGM*. https://doi.org/10.1373/clinchem.2003.030528

National Accreditation Body of Indonesia. (2011). *K*AN Guide on The Evaluation and Eexpression of Uncertainty in Measurement (3rd ed.). *Jakarta: Komite Akreditasi Nasional Indonesia*.

Olencki, A., & Mróz, P. (2017). Traceable technique to calibrate current coils for calibration of the power clamp meters in AC current range up to 1000 A. *Measurement*, *109*, 366–372. https://doi.org/10.1016/j.measurement.2017.05.024.

Shirokov K.P. (2010). Substitution Method. In *The Great Soviet Encyclopedia, 3rd Edition (1970-1979)*. Retrieved from https://encyclopedia2.thefreedictionary.com/Substitution+Method.