SET-UP FOR PRECISION ROBOTIC EVALUATION
OF AC CURRENT CLAMP

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Abstract: Metrology often takes an important part in robotics. Reversed relation, where robotics is employed in metrology, however, is less often met. The paper investigates the use of a robot for evaluation of spatial uniformity of precision current clamp. Robot moves the clamp around the conductor, where effect of clamp windings position on a measured current can be observed at high resolution. The set-up is presented together with the measurement procedure and results, which include complete metrological evaluation of current clamp.

Keywords: Current clamp evaluation; robot;

1. INTRODUCTION

AC current clamp represents a simple current transformer, where the geometry of the primary winding is not fixed. Primary winding here is the conductor of the measured current. Because clamp needs to be open in order to be able to place it around the conductor, Rogowski coils as secondary winding have gaps between the ends of the coils. Secondary coil has also other irregularities in the spacing of the turns. The mutual inductance between the measured current and the current in the secondary coil, which is terminated with a resistor, is sensitive to the conductor position within the clamp jaws. Theoretical background of this effect has already been studied [1-6], while the experiments are limited to investigations at selected points due to lack of precision positioning facility. The purpose of introducing the robot is to get better knowledge of the extreme points and distribution of the sensitivity to geometry of conductor and secondary winding. Namely, the robot can position the clamp relative to conductor within the hundredth of a millimeter. This allows a better metrological evaluation of current measurements with precision current clamp.

2. MEASUREMENT SET-UP

Fig. 1 schematically shows the basic elements of the measurement set-up.
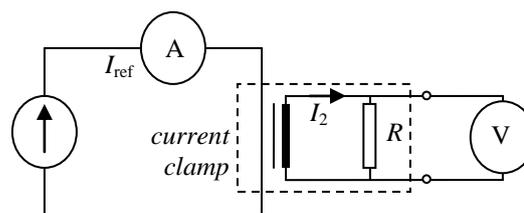

Fig.1: Electrical circuit – measurement set-up

In the experiment we used Metrel A1033 AC current clamps with bandwidth 40 Hz to 5 kHz, current range up to 1000 A. The terminating resistor was customized to obtain current-to-voltage ratio of approx. 10 A/V. The diameter of the conductor was 6 mm, which is 9 times smaller than the inner section of clamp with diameter of 54 mm. The relatively big difference in diameters allowed us to study the non-uniformity of the system sensitivity to geometry with more contrast. Reference AC, I_{ref}, in the conductor was set to rms value of 2.5 A. To obtain a stable sinusoidal waveform with low distortion, reference current was generated with Zera MT3603 current amplifier. This module is a part of the system for power testing with accuracy class 0.05%. Current range of the MT3603 extends from 4 mA to 12 A.

Reference current I_{ref} was measured by a true RMS Agilent 34411A amp-meter with specified error limit of better than 0.26 % at 2.5 A. Another multimeter of the same type was selected to measure the AC voltage drop across the stable termination resistor R at the clamp output with specified error limit of better than 0.12 % at 0.25 V.

For clamp positioning relative to conductor, an industrial robot Epson Scara G3-351S-L was used with repeatability below 0.01 mm in all three axes and in orientation. The robot was controlled by custom software, programmed in Labview.

3. EXPERIMENTAL WORK

To optimize the positioning resolution and the measurement time on the other hand, the clamp circular cross-section was divided into 21x21 positions of the clamp relative to conductor in both directions. This resolution has been found to be sufficient, because smooth current

gradients can be clearly observed (see Fig.3) as oppose to random scatter, which would be present otherwise.
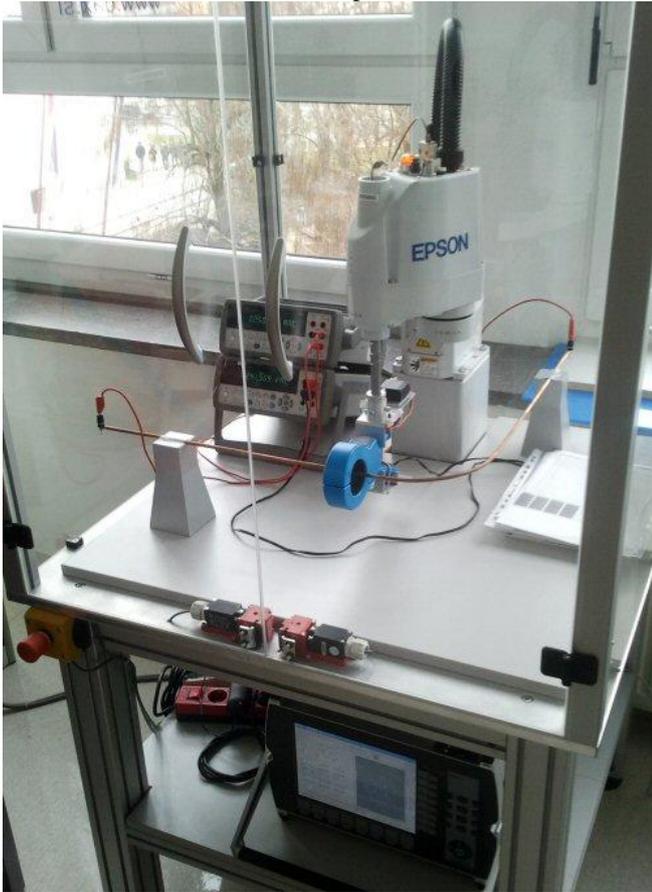

Fig.2: Measurement set-up: robot, test current clamp, two multimeters and stable AC current source at the bottom
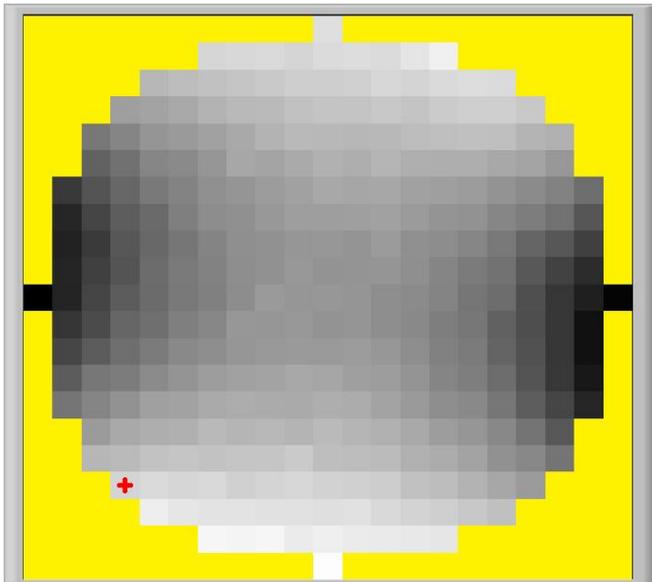

Fig.3: Current homogeneity of the current clamp; different pixels show different values of a measured current at different conductor positions

At each planar point an average of 20 readings were taken. The lowest average values are obtained at the ends of clamp jaws (at the opening). In Fig.3, these values are coloured in black, while the highest are coloured in white. At 2.5 A, the difference between maximum and minimum value of measured rms current value was 7.5 mA or 0.3 %. Standard deviation of the measurements, which could also be taken as a measure of spatial non-uniformity amounted only to 507 µA.

After each point, clamps were moved, so that conductor was positioned in central point to check for reproducibility. Central point current scatter is shown in Fig.4. Standard deviation of this measurement was found to be 33.1 µA, which is small compared to spatial non-uniformity of 7.5 mA or even 507 µA.
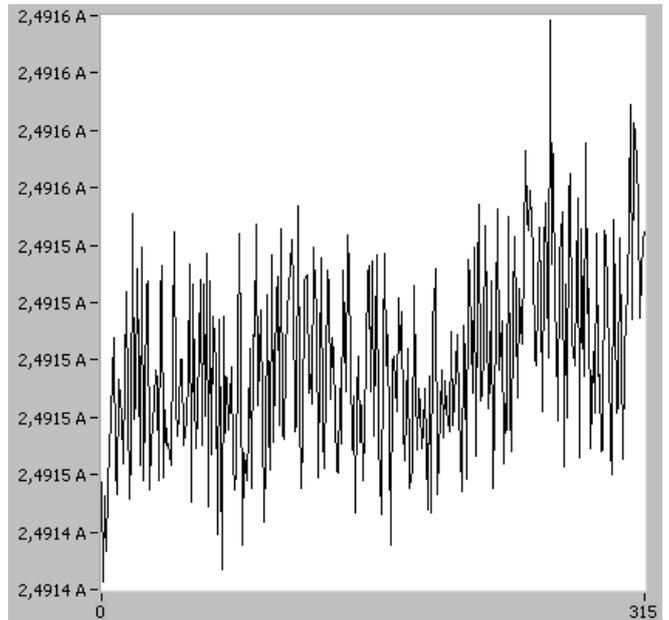

Fig.4: Stability of a central point, measured after each position of a current profile; vertical axes: current in amps; horizontal axes: number of consecutive measurement

Mechanics of the robot allowed also checking for sensitivity of angle at which conductor is crossing the clamps, to the current in the secondary coil. Fig.5 shows angularly rotated clamps.
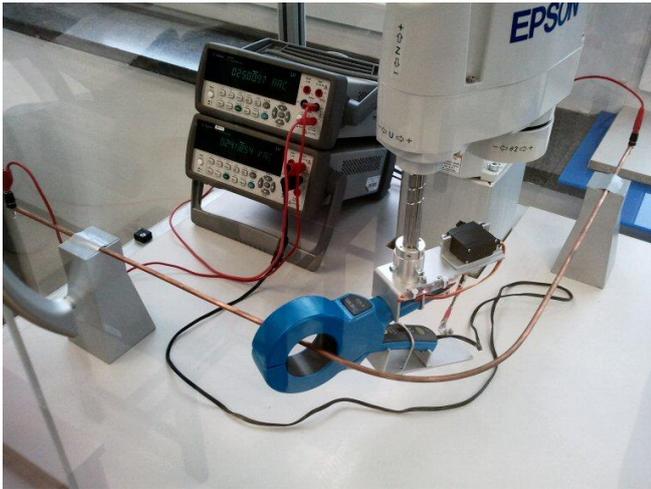
Fig.5: Angularly rotated current clamp

Fig.6 shows a angular profile measured while rotating the clamp between the maximum and the minimum angle values.
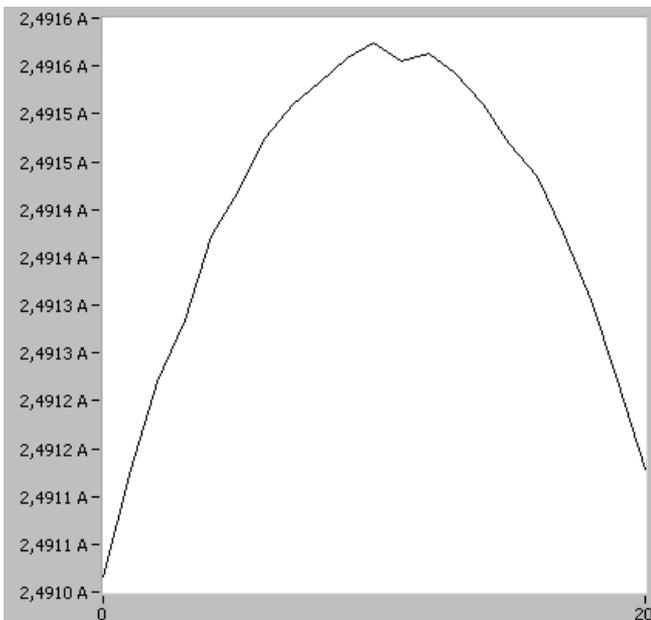

Fig.6: Angular profile of current clamp; vertical axes: measured current; horizontal axes: consecutive number of angle at which conductor crosses the clamp at central point

Fig.6 shows that the angular profile is less pronounced than the spatial profile. The difference between the maximum and the minimum value is 0.56 mA.

Fig.3 and Fig.6 also clearly show a functional dependence, which means that stability of the current source is sufficiently high.

Results also show a large deviation of all measured values from the reference value of current in the conductor. The deviation is in average around 9.4 mA, which is higher than all the profile differences. It needs to be stressed out, however, that this is a systematic error, which is taken care of by calibration or, in this case, by defining the value of terminating resistor more accurately.

4. CONCLUSIONS

The presented work shows an experimental set-up, which is stable enough to measure sensitivity of mutual inductance of current clamp to the position of the conductor, in which the reference current flows. With an appropriate robot, spatial and angular profile can be measured. Results show that spatial differences in measured current amounted to 7.5 mA, which is comparable to deviation of the measured current from the reference current. The angular profile for the particular precision clamp is more than 10 times smaller. The set-up can also be used to investigate the effect experimentally, which enables not only to estimate additional contribution of uncertainty due to positioning profile, but also to tackle the geometry of the clamp windings to lower systematic error.

5. REFERENCES

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