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High-Performance System for Simultaneous Multielement Resistance Welding

Abstract: The article presents initial results related to a newly developed system enabling the quasi-simultaneous welding of elements requiring high dimensional tolerances. The above-named system was developed in response to a new market demand for elements made in very short production cycles. A response to such a demand is an innovative solution including a digital system enabling the switching of welding current with a flexible frequency of even up to 10 kHz. The above-named solution makes it possible to control welding current in individual branches of equipment so that the welding power source is not able to notice a break in the welding process and all of the welds are formed at the same time with the precise definition of the current path.

Keywords: resistance welding, quasi-simultaneous welding system

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Introduction

An ongoing research project discussed in the article will lead to the development of a high-performance system for simultaneous multielement resistance welding. For many years, the ASPA company has been developing and supplying welding machines for various purposes. The company operates both in Poland and other European countries. Obstacles impeding market expansion and accessing new customer groups include significant limitations of welding machines resulting from their insufficient precision and effectiveness, particularly when taking into consideration the fact that the inspection/examination of weld quality is possible only after the completion of the welding process [1]. As a result, welding process efficiency can be low, particularly in terms of multielement welding or the welding of elements having non-standard shapes and dimensions. At the same time, increasing demands concerning the precise and effective welding of metal elements, observed primarily in industrial sectors imposing restrictive requirements concerning the quality of manufactured elements (car parts, household equipment), call for the continuous improvement in product quality and implementation of new technological solutions [2]. In response to the above-presented issue, an innovative welding technology has been developed, aimed to eliminate welding imperfections, control the ongoing welding processes on a continuous basis and introduce related corrections automatically. The essence of the technology under development involves the application of an additional electronic system which will switch current between individual branches of the tool squeezing

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all elements (to be/being welded) at the same time. The foregoing will lead to the generation of welding microcycles, the frequency of which will be restricted within the range of 10 Hz to 10 kHz, as the case may be. Such a solution will make it possible to reduce welding current to the current of a single weld, maximise the simplification of the tool design (lack of additional moving elements), form all welds at the same time (which, e.g. in the case of improper contact during the initial arrangement of the elements in the tool will be corrected during the welding process when the elements are squeezed against one another) and make many welds within one production cycle.

Welding in micro-cycles and the overview of the current state of the art

Multielement or multispot welding machines, making joints within one cycle, are not commonly used in industrial practice because of the lack of explicitly defined contact between elements being welded [3], which, in turn, precludes the precise definition of welding current at all spots simultaneously. One of possible solutions can involve the application of servomotors on each station with the electrode unit so that the machine performs a sequence of movements using these actuators, with which it subsequently squeezes each element being welded and performs the separate welding of each element. However, the above-named solution is characterised by two significant disadvantages, i.e. it makes the design of the tool considerably more complicated, substantially increasing its cost. In addition, long kinematic chains connected with the application of servomotors reduce the accuracy of element positioning during the welding process. Some solutions enable the simultaneous welding of two elements to the base element, yet it entails double welding current, affecting parameters of the welding machine and significantly increasing its cost. In addition, the control of the ongoing welding process is impeded and the process is accompanied by the expulsion of liquid metal in welded areas triggered by excessive squeezing force at the final stage of the process. The above-named problem can be eliminated by the application of a precise proximity sensor and a decrease in squeezing force at the final stage of the welding process. However, the application of the above-named system is rather difficult in relation to "traditional" welding tools, composed of complicated squeezing/clamping systems.

European patent application EP0597214 [4] is concerned with a multipoint welding system provided with a separate current loop with a separate transformer for each element subjected to welding. However, such a design solution is very expensive as a separate welding controller, separate transformer and separate power supply leads must be each used in relation to each electrode unit. As can be seen, the above-presented application is, in fact, one welding system composed of many complete welding machines placed in one housing.

Another solution concerning a resistance welding machine is presented in document no. DE20218655U1 [5]. The device presented therein contains an electronic system and pairs of keying electronic elements (including tracks, thyristors or IGBT transistors or contactors) used to switch current flowing through individual branches of a multi-point welding machine. However, the solution requires the use of a pair of electronic elements to eliminate the leakage of current by other welding branches (not performing the welding process at a given moment) as the system performs the welding of each element separately, switching between individual elements subjected to welding after the making of a weld. Because of non-simultaneous welding, the above-presented solution entails welding-related inaccuracies, which, in turn, requires the additional compensation of the non-simultaneous squeezing of individual elements against one another.

Description of the ASPA solution

The above-presented inconveniences were eliminated by the implementation of a new invention involving the application of an additional electronic system switching current between individual branches of a tool squeezing simultaneously all of the elements subjected to welding. The foregoing leads to the generation of welding micro-cycles, the frequency of which is restricted within the range of 10 Hz to 10 kHz (as the case may be). Such a solution enables the limitation of welding current to the value of one weld current, the simplification of the tool by eliminating additional moving elements, the simultaneous formation of all of the welds (which, e.g. in the case of improper contact during the initial arrangement of the elements in the tool will be corrected during the welding process when the elements are squeezed against one another) and the making of many welds within one production cycle.

Measurements of the test welding system

A new welding method involves the interchangeable flow of welding current through elements subjected to welding, combined with the simultaneous squeeze of two or more elements. The aim of the above-presented approach is aimed at the performance of multi-element welding as well as the controlling of current flowing through all of the elements subjected to welding (at the same time). Assumedly, the foregoing should enable the implementation of the new method making it possible to perform a welding cycle involving the smaller number of mechanical elements, which, in turn, should favourably translate into the accuracy of the positioning of elements being welded. The above-named effect was obtained by the interchangeable switching of high-power IGBT transistors in a measurement cycle. The entire measurement cycle was defined from

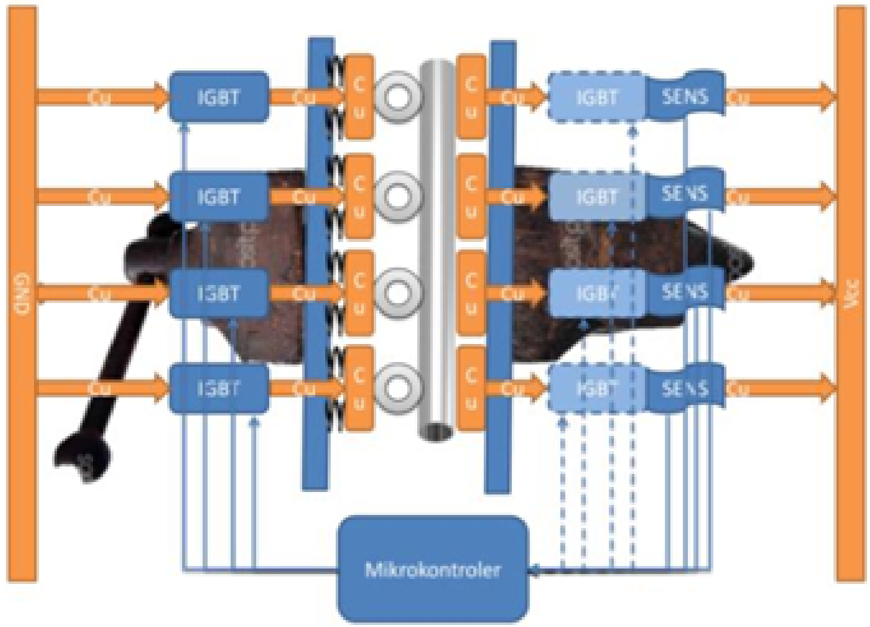

Fig. 1. Conceptual diagram of the testing system (made only for two lines)

Table 1. Welding sequence

Cycle time / Number of cycles	1 ms	3 ms	5 ms	10 ms	20 ms	40 ms	50 ms
10	34, 38, 42			41			7
20	8	9, 35, 39, 43	10	11	12		13
30	14	15	16, 36, 40, 44	17	18	19	
50	20	21	22, 45	23	24	25	
100	26	27	28	29			
200	30	31	32				
300		33					

the external controller level and consisted of a number of switching cycles and the time of the performance of one cycle. After the initiation of a welding cycle, only one transistor was on. After the time equal to the half of the cycle (time) the transistor was switched off, whereas the other transistor was switched on. The above-named cycle was repeated for a definite number of times (Fig. 1). The testing method is presented in Table 1.

The numerals in the individual spaces represent the numbers of elements subjected to welding. Specimens no. 0–6 were welded as trial specimens, therefore the current waveform was not recorded in relation to these specimens. In addition, the IGBT transistors at the specimens did not switch properly because of an error in the external controller programme. The empty spaces represent the lack of measurements because of programme-related limitations (extension of controller functionality during subsequent tests). The current waveforms were recorded using a dedicated TECNA tester with an external Rogowski loop.

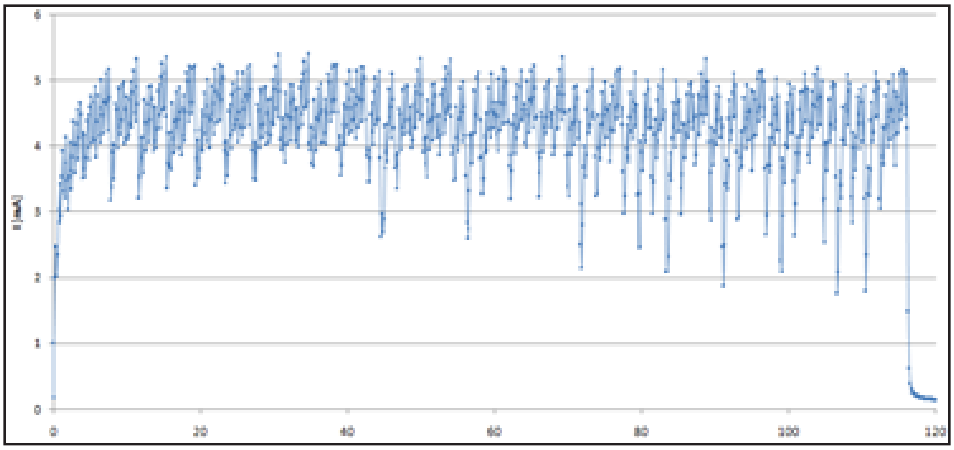

Fig. 2. Exemplary current waveform for specimen 44; the measurement was performed for one IGBT transistor

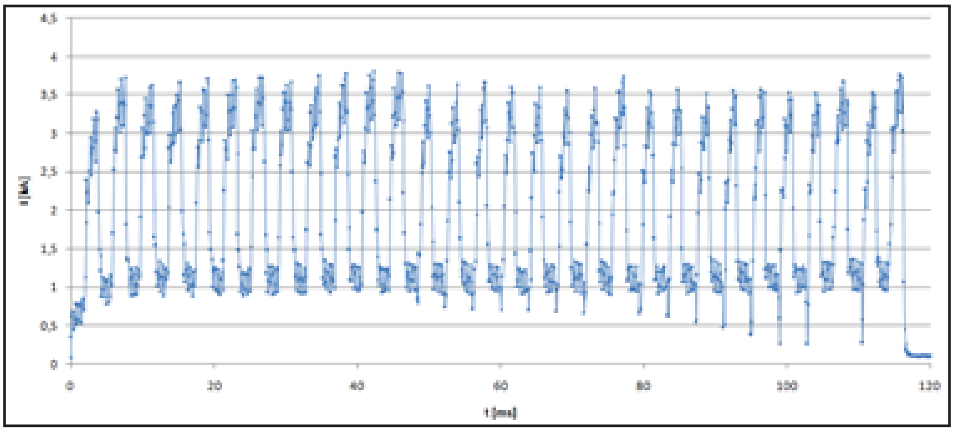

Fig. 3. Exemplary current waveform for specimen 44; the measurement was performed for one IGBT transistor

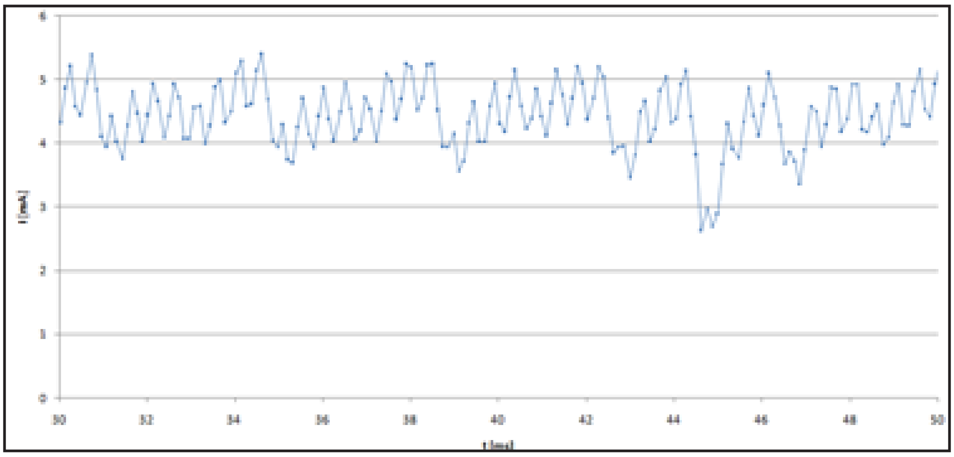

Fig. 4. Current waveform in relation to specimen 10 within the 30–35 ms time window; current fluctuations restricted within the range of 4 kA and 5 kA were triggered by the formation of the weld; the visible decrease below 3 kA was triggered by the transducer sampling when both IGBT transistors were off during switching

The value of mean current in Figure 2 amounts to 3.84 kA. The granularity visible in the diagram was triggered by the changing resistance of the welding area of the element as a result of the weld formation and the heating of the elements subjected to heating.

The same effect can be seen in Figure 3. Mean current per only one element should adopt a value close to 3 kA. Calculations were impeded by the visible concentration of measurement points near 1 kA. The value of power visible in the area results from the relatively high capacity of the gate-transistor emitter connection and the accumulation of current during the shut-down of the transistor and the defect (imperfection) of transducer sampling.

The external controller did not affect the design of the welding machine. The initial moment of IGBT switching was detected by the appearance of voltage on the anode of the welding system.

After the welding of the elements, to determine the strength of the joint, it was necessary to measure the geometry of the specimens. Measurements were performed in accordance with Figure 6.

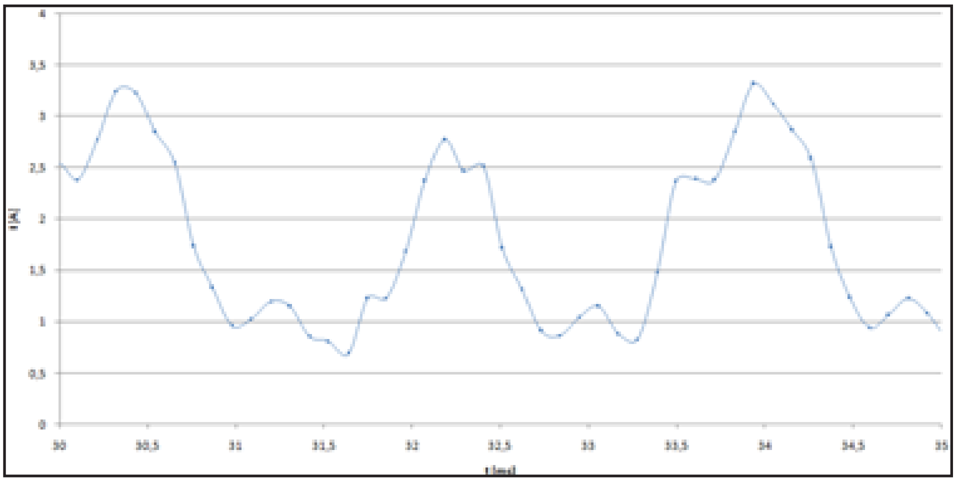

Fig. 5. Current waveform in relation to specimen 44 within the 30–35 ms time window; visible low current values correspond to the shut-down of the transistor; the non-zero value results from the high capacity of the gate-transistor emitter connection

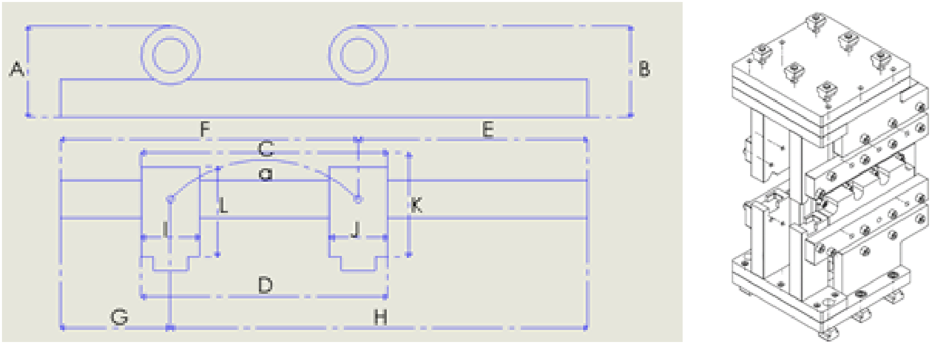

Fig. 6. Schematic diagram of the measurements of the specimen (letter "a" designates the angle between the specimens) and view of the exemplary welding tool (right)

Materials and measurement methods

Materials

The measurements involved elements made of steel SS304, with a circular undercut and four welding projections; the area of the base of each projection amounted to 1 mm2. The elements were welded to the tube made of the same material; the diameter of the tube amounted to 20 mm. The measurements were performed using the following tools/instruments:

- electronic slide caliper PRO IP54, Δ = ± 0.02 mm,
- measuring tape GIANT 8m, Δ = ± 1 mm,
- tester TECNA TE1700C + Rogowski loop of special purpose.

Measurement methods

Because of its vastness, the measurement table was divided into two parts, i.e. from 0 to 25 and from 26 to 45. Information concerning current accuracy measurements by the TECNA tester was not provided by the manufacturer. The results of calculations concerning the angle between the specimens were expressed in degrees. The time of welding presented in the last column corresponds to the welding time specified by the tester.

The designations of the columns are the following:

- A, B, C… – values of individual dimensions in accordance with Figure 1,
- Δ – measurement uncertainty related to the measurements presented in the preceding column,
- α – angle between the elements after welding,
- $I_{śr}$ – maximum current flowing through the specimen,
- Cykle – number of welding cycles,
- t – total time of the welding of both specimens,
- I*t – power flowing through the specimen.

All of the geometric measurements were performed using a PRO IP54 electronic slide caliper. The measurements were performed "by hand", which could generate errors. The measured dimensions were identified on the basis of Figure 6 and compared with the nominal values of the tool.

Differences between the nominal value and the measured dimensions (e.g. dimension C in Figure 6 and the distance between the centres of the elements in the Figure) resulted in the performance of an intermediate measurement. Taking into consideration the width of the elements along with its accuracy [(18±0.1) mm] and the distance between the centres [(85±0,1) mm]m, the values and tolerances were summed up, finally obtaining the distance between the edges (103±0.2) mm. A similar approach was adopted in relation to dimension D; dimensions A and B were compared directly to the nominal value.

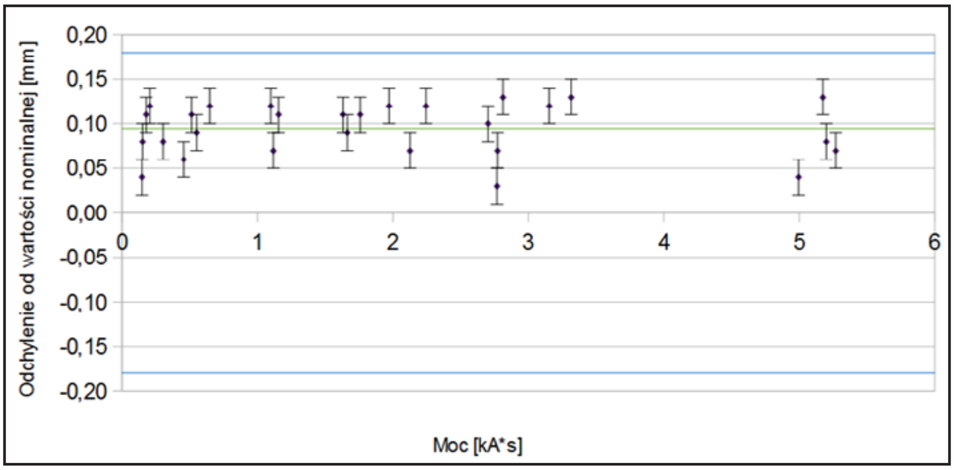

Fig. 7 Difference between the measured and the nominal value for measured specimens in relation to parameter A; the error bars correspond to a slide caliper accuracy of ±0.02 mm; the azure line represents an element workmanship accuracy of ±0.18 mm; the green line represents a mean value of 0.09 mm

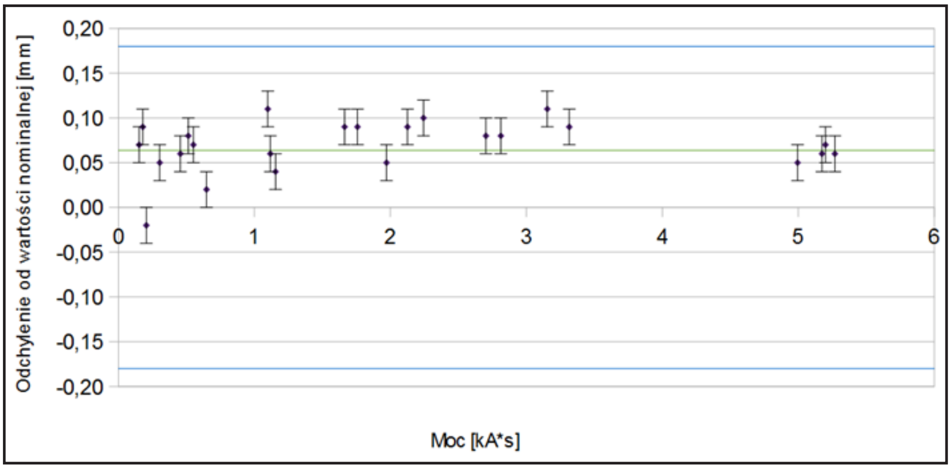

Fig. 8 Difference between the measured and the nominal value for measured specimens in relation to parameter B; the error bars correspond to a slide caliper accuracy of ±0.02 mm; the azure line represents an element workmanship accuracy of ±0.18 mm; the green line represents a mean value of 0.06 mm

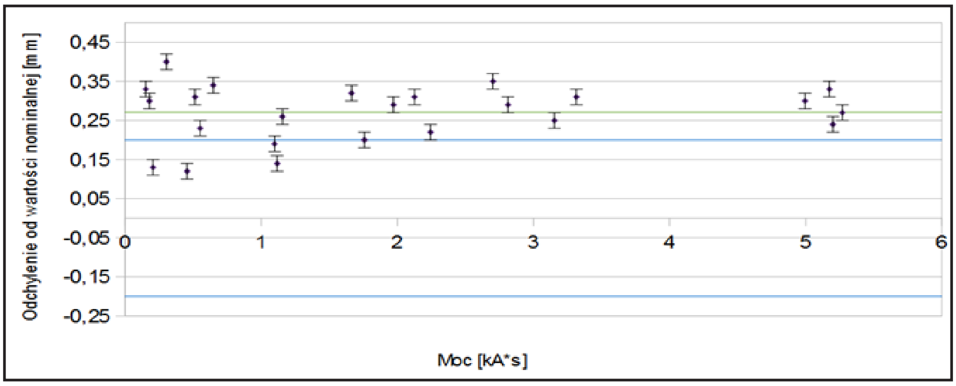

Fig. 9 Difference between the measured and the nominal for measured specimens in relation to parameter C; the error bars correspond to a slide caliper accuracy of ±0.02 mm; the azure line represents an element workmanship accuracy of ±0.2 mm; the green line represents a mean value of 0.27 mm

Measurement results

Table 2. Results of geometric measurements of specimens 0–45.
[Download table](#)

Missing dimensions were designated with the symbol of "-". Nominal values A, B, C, and D were red out of Figure 12; A=B=(32±0.18) mm, C=D=(103±0.2) mm. The results from Table 2 are presented in Figures 7–11.

Analysis of results

The above-presented results were analysed in respect of theoretical obtainable accuracy resulting from tool workmanship tolerance and element quality tolerance (see related diagrams). In relation to dimension D, the nominal dimension of the tools was affected by a fabrication error of 0.2 mm in relation to the nominal value (see the mean value of results). In relation to angle α, the element was not tolerated in assumptions, yet the general tolerance amounted to +/- 2°.

The obtained results compared with those typical of the classical design tool are not presented because of ongoing works and confidential agreements with the Customer, for whom the classical tool was made.

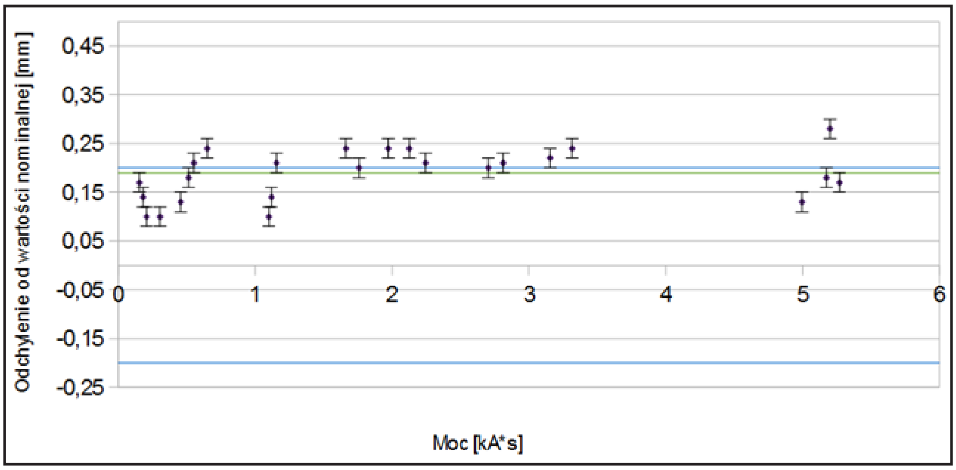

Fig. 10 Difference between the measured and the nominal value for measured specimens in relation to parameter D; the error bars correspond to a slide caliper accuracy of ±0.02 mm; the azure line represents an element workmanship accuracy of ±0.2 mm; the green line represents a mean value of 0.19 mm

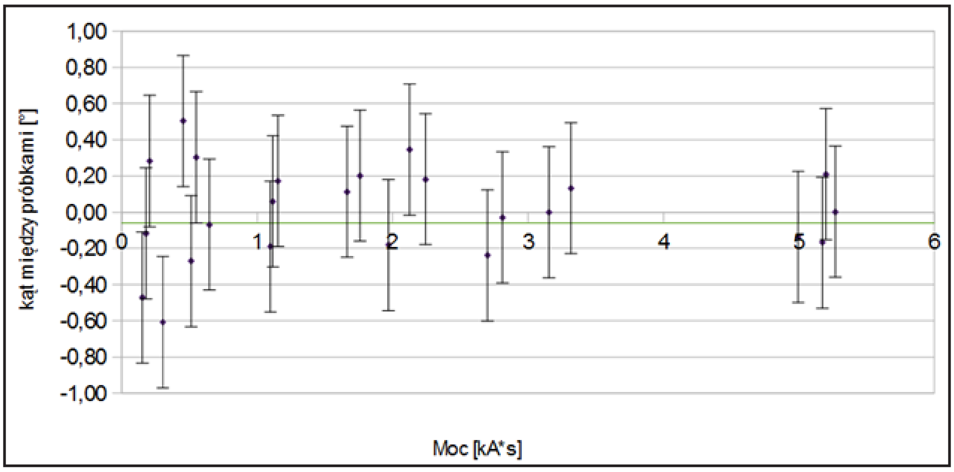

Fig. 11. Difference between the measured and the mean value in relation to the calculated values of angle α; the green line represents a mean value of -0.059; the error bars correspond to the error calculated using the total differential

The proposed conceptual solution only consisted of 5 parts per welding line and did not contain any moving elements. In turn, the classical tool was composed of 43 parts per welding line. Both from the tube side and from the side of the element being welded it is necessary to use flexible mechanisms to compensate dimensional imperfections resulting from projection welding. Such an approach makes a significant difference as regards the service life and development costs of the tool (in terms of both design and fabrication laboriousness).

The only element creating problems in the above solution is the additional impedance of the IGBT transistor in the welding circuit, responsible for the lacking possibility of stabilising welding current using the classical welding power source. The above-presented system is a subject of patent proceedings PL423282.

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