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The Use of Video Systems in the Automatic Evaluation of Electrode Wear in a Robotic Spot Resistance Welding Station

Abstract: The assessment of the consumption of electrodes used in resistance welding processes is an important issue significantly affecting the quality of welded joints. The article presents an individually developed station integrating an industrial robot, a video system, a columnar sharpener and a "Smart Light" lamp. The elements of the station, i.e. sensors and the video system were selected in view of their use in the lot production of welded structures. The developed and optimised system enables the automatic evaluation of the consumption of spot resistance welding attachments. In turn, tested and implemented decision-making algorithms enable the performance of welding processes with the permanent monitoring of the quality of the above-named attachments and the assessment of their further sharpening possibility during the production process.

Keywords: robotic spot resistance welding, consumption of electrodes

Introduction

Electrode wear constitutes a crucial issue when making components subjected to spot resistance welding [1-4]. In today's manufacturing systems, the process of electrode sharpening (aimed to constantly maintain the predefined diameter of an electrode) is usually based on the use of automated milling stations integrated with welding robots. The process of sharpening is not complicated technologically, yet the key issue is the determination of the moment when an electrode (because of its considerable shortening) can no longer be used in welding processes. In most cases, systems are programmed to perform a preset number of electrode milling operations, the exceeding of which is followed by the manual or automatic replacement of electrodes (even when a given electrode is not significantly shorter). The frequency of milling operations depends on many factors. In relation to materials being welded, process parameters, the chemical composition of an alloy electrodes are made of and the presence of anticorrosive coatings on plate/sheet surfaces, the repair of the electrode work surface may be necessary after between ten and twenty or after hundreds of welding cycles. Particular attention should be paid during the welding of sheets made of galvanised steels. The layer of zinc protecting the material being welded against corrosion

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diffuses in copper, leading to the formation of brass on the surface. The above-named phenomenon leads to an increase in temperature in the contact between the electrode and the material being welded, which, in turn, results in the reduction of electrode service life. In such a case, the frequency of repair milling operations should be increased. A similar situation takes place when welding plates made of weldable aluminium alloys.

The article presents an original solution (system) involving the continuous and automatic measurement of the electrode height during the welding process. The system makes it possible to use a set of caps (in welding processes) until they wear out entirely (when electrodes reach an overly low height, i.e. the distance between the work surface and the cooling channel precludes the obtainment of a proper joint).

Issues in electrode diameter measurements

The model video system verifying the usability of spot welding caps should be composed of two subsystems, i.e. the system responsible for the inspection of the diameter of the cap work surface (to determine the moment when repair milling becomes necessary) and the system tasked with the inspection of the cap height

(to determine if the cap can be subjected to repair milling or should be replaced). Both subsystems can be installed in production stations, yet their use depends on a number of external factors. In cases of electrode diameter measurements it is necessary to pay attention to the following (potential) problems (Fig. 1):

– misalignment – sometimes, as a result of backlash in the pressure system, caps are misaligned when touching each other. Usually, the above-named situation does not preclude the obtainment of a proper weld, yet it significantly complicates video measurements of diameters (Fig. 1a).

– deviation in work surface flatness – caps exposed to considerable operating cycles (hundreds of welds made without the milling of the electrodes) can lose the flatness of the work surface. Usually, in the tip area such caps become spherical, which significantly complicates diameter measurements (Fig. 1b).

– deviation in roundness – work surface of new caps has the shape of a circle having a predefined nominal diameter. During operation, the work surface often becomes deformed, e.g. adopts the oval shape (Fig. 1c), which nearly precludes the precise measurement of a dimeter on a single video measurement basis.

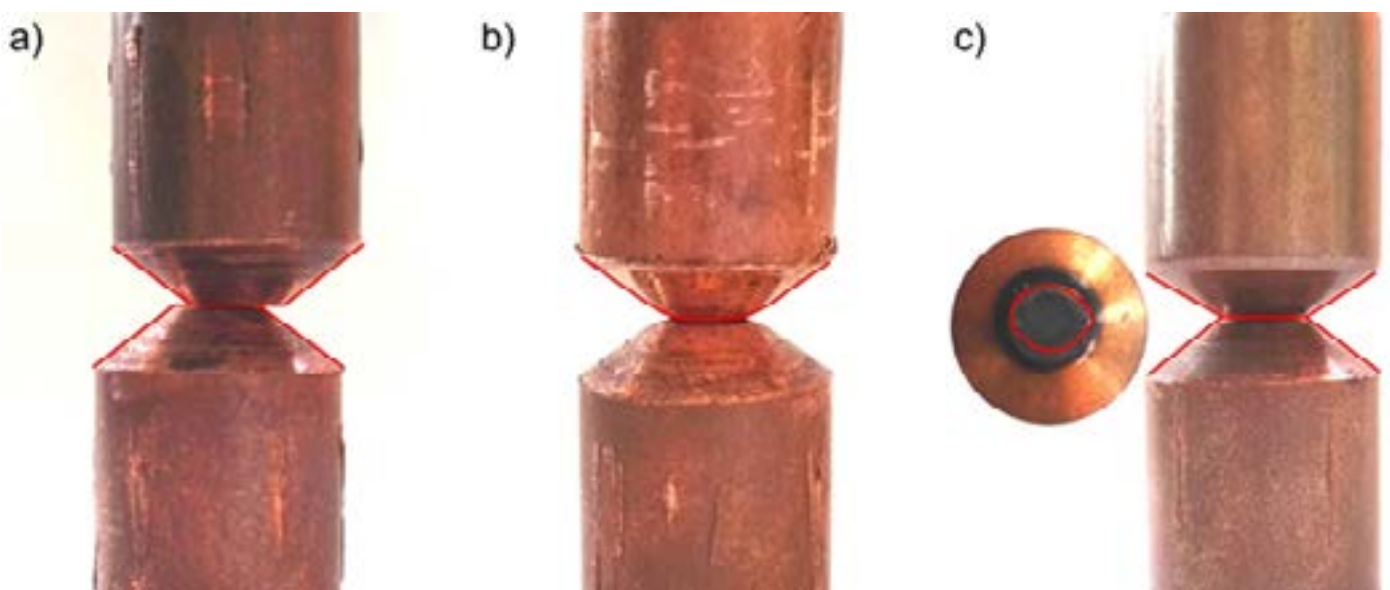– hardening – during welding, electrodes

Fig. 1. Cases complicating the video measurement of the electrode diameter: misalignment (a), deviation in work surface flatness (b), deviation in roundness (c)

undergo hardening and are subjected to the above-named diffusive phenomena. As a result, it is not possible to precisely and repeatedly determine the moment when the replacement of electrodes becomes necessary.

– additional measurement time – measurement of the diameter of an electrode performed using a dedicated video system does not last longer than 5 seconds (including the time necessary for the tongs to reach the object, leave the object and reach the diagnostic position). The aforesaid time should be multiplied by the frequency of checks (affecting the precise determination of a moment when the application of the milling procedure becomes necessary). In production conditions, time is a factor directly affecting the costs of manufacturing. If the programme provides for the stoppage of the robotic station for production breaks (e.g. to exchange or replace an element), this time could be used for diameter measurements. If the operating efficiency of the robotic station is optimised, it is necessary to asses both technological and economic aspects of checks.

The above-named factors were taken into consideration and subjected to practical verification, the remainder of the study focuses on measurements of cap heights.

Video systems

Video systems enable the automation of the inspection procedure in relation to various components. The verification of elements is based on the analysis of single parts and determination of their workmanship. The analysis of images includes the recognition of colours, the calculation of specified areas, the counting of elements, text recognition and the reading of bar codes. If an irregularity is detected, the system rejects an element being examined and generates an appropriate report.

The operation principle of the system involves the recording of light reflected against an element being tested. The recording is performed by a camera with an appropriately selected and adjusted optical object lens. An obtained image is sent to a computer and subjected to analysis based on tests previously defined by the software developer. The tests make it possible to determine the conformity of an element being tested with a previously adopted model. An inspection-based result defines whether a given part is proper; related information can be read out by the user or sent to the controller.

Video system design

A typical video system is composed of a part tasked with the acquisition of images (digital camera, stand and lighting) and an analytical part responsible for the transmission and processing of images (computer with a controller and software). The system presented in the article consists of a SmartCamera BVS SC (Balluff) (Fig. 2a), enabling the preparation of any test schedules, the video inspection of various parameters and the extensive management of results (including their transmission to the controller or user interface) [5]. The device integrates a camera having a resolution of 1.31 MPx and a computer featuring an operating system in one housing, combining the part responsible for image acquisition with the analytical part, thus considerably simplifying the system structure. The assessment algorithm is programmed using the computer and the Ethernet interface. The computer is needed only at the programming stage as the camera works autonomously during operation, performing operations via an integrated graphic processor and operating memory. Images are recorded using an FL-CC5024A-2M object lens (Ricoh) having a focal length of 50 mm. The proper image inspection is inextricably tied to the proper lighting of an element. The above-named application involves the use of a ring-shaped BAE LX-VS-RI100 illuminator provided with infrared LEDs (Balluff) (Fig. 2b).

Fig. 2. SmartCamera Balluff BVS with an object lens (Ricoh) [6] (a), camera installed in the robot stand along with the ring-shaped lighting system (b)

The arrangement of the diodes in the ring-shaped configuration enables the uniform lighting of electrodes and prevents the casting of undesirable shadows. In addition, a diffusive plate (invisible in Figure 2) eliminates disturbant light reflections (reflected against the metallic surface).

Principle of electrode wear measurement performed using the video system

The above-presented video system constitutes a part of the automated system responsible for the spot welding process. The system is composed of a spot welding robot (FANUC R2ooiA welding manipulator) and a milling machine shaping the work surface of electrodes (in order to restore the original geometry of electrodes). However, the mechanical treatment of electrodes results in the reduction of their height. Video inspections are performed to measure the wear of electrodes in order to determine the necessity of their replacement.

The camera has been programmed via the BVS Cockpit user interface in the browser (Fig. 3). The interface also enables process monitoring on a real-time basis. The algorithm of electrode wear is based on electrode height measurements performed when the welding tongs are pressed against each other (Fig. 3). If a measured value is higher than the limit (specified by the technologist), electrodes need to be subjected to sharpening (milling). If sharpening is considered insufficient, the system generates a message about the necessity of electrode replacement. If analysis is concerned with electrodes characterised by different geometry, it is necessary to change the model in the algorithm. It is important that in each measurement the distance between the electrodes and the camera remains the same.

Image inspection results are made available to the industrial robot controller using specific I/O digital outputs. As a result, the welding

Fig. 3. User interface (BVS Cockpit) with the algorithm of electrode wear assessment

head is moved to the milling machine station or the station is stopped until the replacement of a worn-out part. The tongs of the robot welding machine in the diagnostic position are presented in Figure 4. Analysis results can also be sent to the PLC using an Profinet Ethernet interface. It is possible to view the history in the interface console along with ongoing inspection.
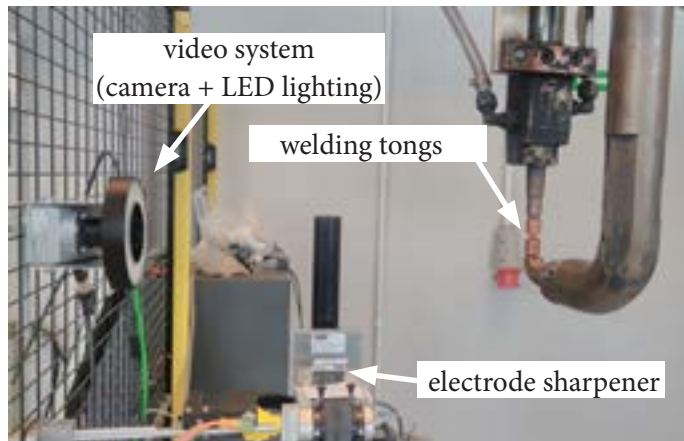

Fig. 4. Testing station: welding tongs, electrode sharpener and the video system

Integration of station elements

The above-presented elements of the station were appropriately integrated. Figure 5 presents the schematic interaction of the measurement system.

The welding robot performs a specific number of proper spot welds in spite of the advancing wear of the caps (a change in the diameter within the limits of allowed deviations). Once the meter has reached the limit value (estimated on the basis of production-based experience)
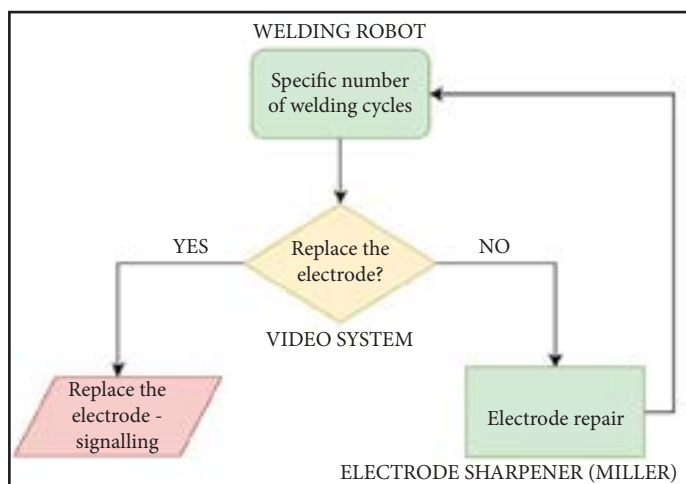

Fig. 5. Schematic operation of the automated electrode wear assessment system

the system sets the welding machine tongs at an appropriate distance from the video sensor, enabling the analysis of electrode wear. A positive result of verification generates an related signal in the control cabinet, activating the sub-programme of electrode sharpening, i.e. the milling of the work surfaces of electrodes. After the performance of the aforesaid procedure, the welding machine returns to the initial position and can perform subsequent welding cycles. If the result of a measurement is negative, the robot stops and the user is informed about the necessity of electrode replacement. The information is provided by the SmartLight signalling column, the sections of which turn red. In each case, measurements are performed before the process of repair, which significantly reduces testing times.

Programing the video system

The inspection programme contains the following functions:
– setting of the camera (Set up camera),
– acquisition of an image (Get image),
– recognition of an element in the image (Find object),
– measurement of predefined geometrical features of an element (Measure object),
– setting of outputs in relation to a negative result (Set Outputs NOK),
– setting of outputs in relation to a negative result (Set Outputs OK).

The tool Set up camera (Fig. 6) enables the selection of a camera, in relation to which a programme is created and makes it possible to set parameters related to image acquisition, e.g. time of exposure, the selection of an image fragment for analysis (Image section) or the mode of camera operation (Trigger mode), i.e. in the continuous mode (continuous) or triggered by the edge (edge). In relation to the installed programme, the operation of the video sensor was defined in the edge mode, activated by a triggering signal provided by the robot controller at the digital input of the camera (channel I/O
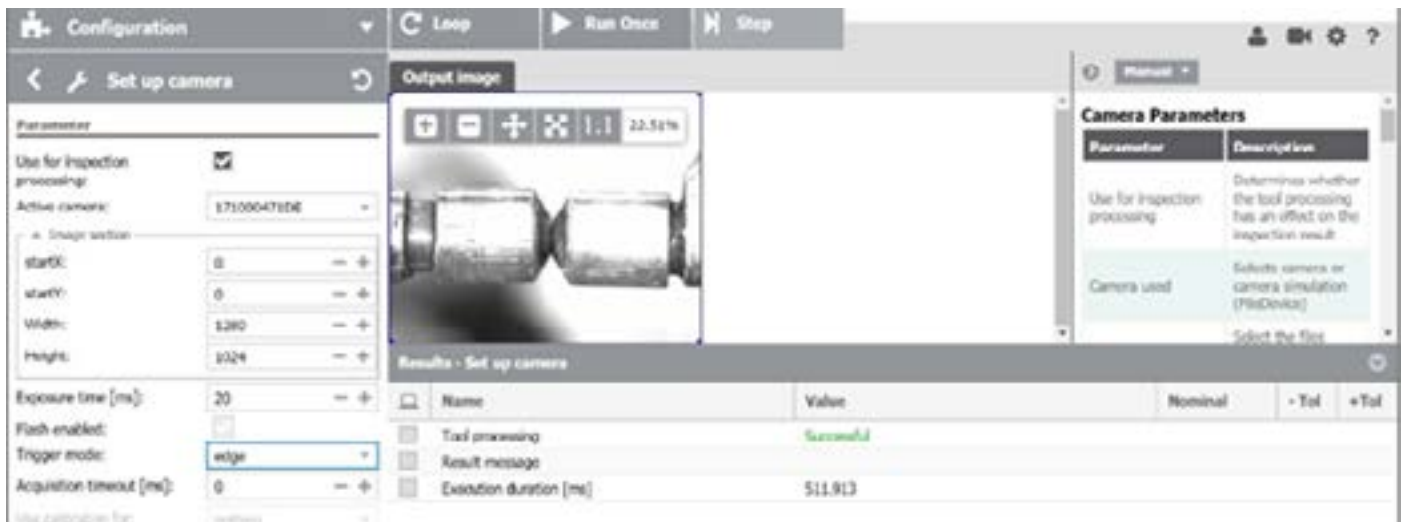
Fig. 6. Interface of video system settings

o in the Power connection [7]). When configuring the programme in the continuous mode of camera operation the user can adjust the appropriate brightness and sharpness of images depending on inspection-related needs.

The function Get image downloads an image in accordance with previous settings of the sensor and makes it possible to continue the programme of inspection. The occurrence of errors in the operation of the programme precludes

Fig. 7. Settings of the tool for finding an object (a) and automatic rotation (b)

the further operation of the programme. A recorded image is transferred for further analysis, involving the use of subsequently available functions. The module Find object (Fig. 7a) is used for detecting a specific element in the image. Using the aforesaid module, the operator can identify the position of the object in the image and move (rotate) the object so that a part being tested is always placed in the same position (Fig. 7b). Such a functionality of the programme enables the operation of subsequently available tools in relation to the object itself (not in relation to a recorded image).

The tool can detect various elements in relation to a previously specified model. The module creator enables the user to define features of the model which should be detected in relation to each part being tested and to specify the shape of the mask (Fig. 8a). During programme operation, the function finds a shape most closely resembling a previously programmed scheme. If specific features have not been detected, the result of a test is negative and further inspection is impossible. When defining a model the operator should remember to select features and shapes present in all parts subjected to the test and unique in the downloaded image. An appropriately positioned photograph is transferred to the module Measure object, enabling the measurement of features specified by the programmer, e.g. distances, angles and radiuses. Attributes are defined using the creator (Fig. 8b).
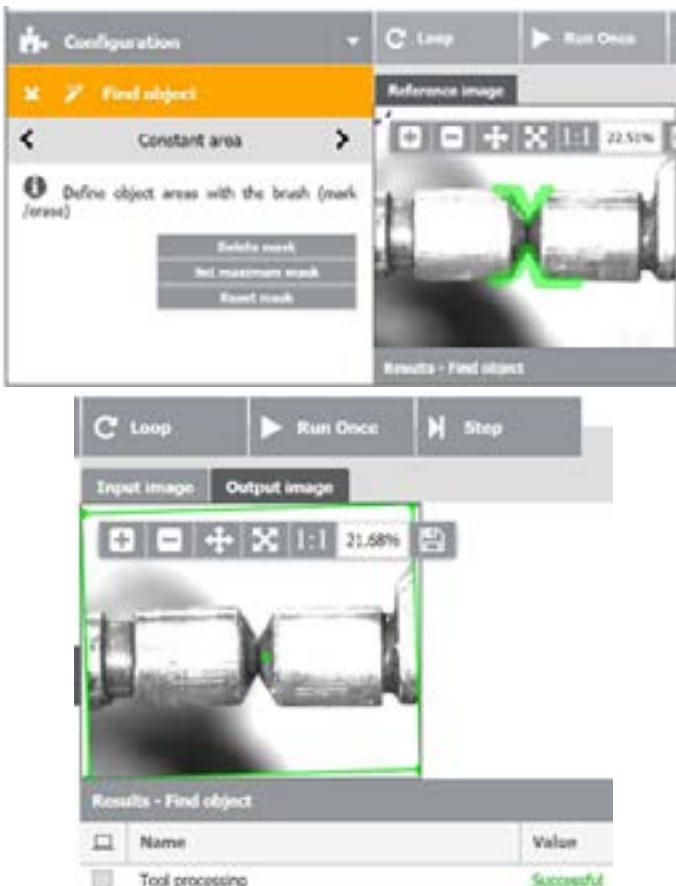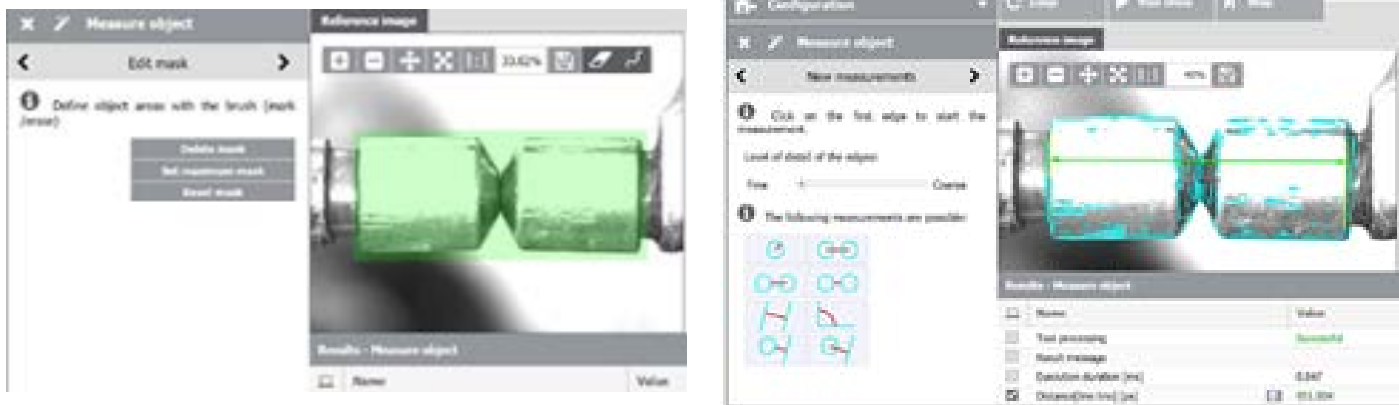
Fig. 8. Measurement of geometrical features of electrodes: setting the mask to determine an area subjected to measurement (a), selection of edges to be measured (b)

At the initial stage of programming it is necessary to specify an area where selected features can be present. The aforesaid specification is performed using an appropriately modelled mask (Edit mask). The above-named operation is important as it eliminates the detection of improper (e.g. irrelevant) features. Afterwards, it is necessary to define the type of a measurement, e.g. in the case under consideration – the distance between two straight lines and segments (detected by the programme), between which the digital value of a given parameter is to be measured. The selection of an edge should be accompanied by the identification of its type. Using the slide the operator can continuously specify whether straight lines are clear (Fine) or, to some extent, blurred (Coarse). A test result is expressed in pixels. In relation to new and unworn caps their total value amounts to 950 px, which corresponds to a length of 40 mm.

The identification of the critical value in the inspection programme, i.e. the value precluding the further use of electrodes, involved the performance of measurements of worn-out electrodes (welding caps) (Fig. 9) and the empirical determination of the lower tolerance limit Tol at 150 px. Where the value of the height of an element being tested is not restricted within the predefined tolerance range, a test result is recognised as negative. It is also possible to define the upper tolerance limit, thus preventing the system from using improper, i.e. excessively

long, caps. Also in the above-named situation the system will report an error and stop the process of welding.

Verification results are transmitted to the controller of the robot and the signalling column using the Set outputs tool. The aforesaid tool enables the setting of digital signals at specific outputs in relation to obtained results. In the above-presented manner, a result concerning the degree of electrode wear (in the zero-one form) is transmitted to external devices. Information is sent to the robot via a digital output (channel I/O 1 in the camera power supply). A high signal at the output enables the start of the milling system and further operation. In cases of the low signal (being the negative verification result), the robot stops operation until the replacement of electrodes and the subsequent
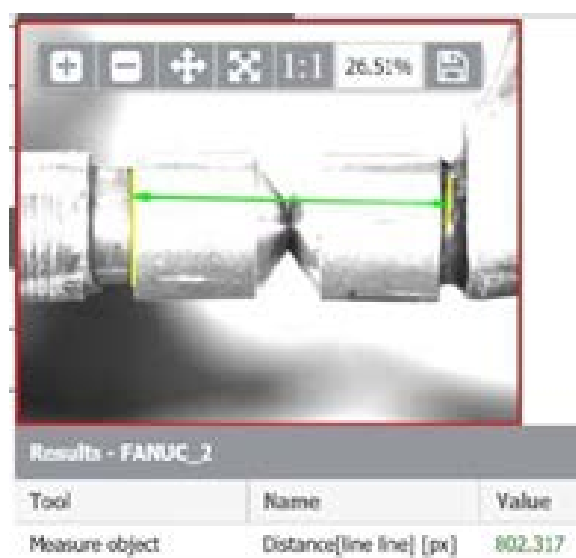

Fig. 9. Measurement of electrodes to identify the upper limit of wear

Fig. 10. Digital presentation of measurement results involving the use of the user interface in the monitoring mode: proper verification (a,b), negative verification (c)

start-up of the machine by the operator. An appropriate system is generated and transmitted to the signalling column. The positive inspection result is signalled by the green colour of the optical signalling device. The negative inspection result, i.e. indicating the necessity of electrode replacement, is signalled by the red flashing light.

Tests of the system

The system was tested using electrodes characterised by various degrees of wear. Figure 10 presents the results of inspection displayed in the BVS Cockpit user interface of the Smart-Camera (in the monitoring mode). The programme properly displayed and detected edges as well as presented results (in px). Figure 10 presents the measurement in relation to one model pair (new caps – Fig. 10a), the pair after one sharpening cycle (Fig. 10b) and one pair of the worn-out electrodes (Fig. 10c). In relation to each set subjected to analysis, the verification result was consistent with the assumptions. In relation to the first two examples, the result
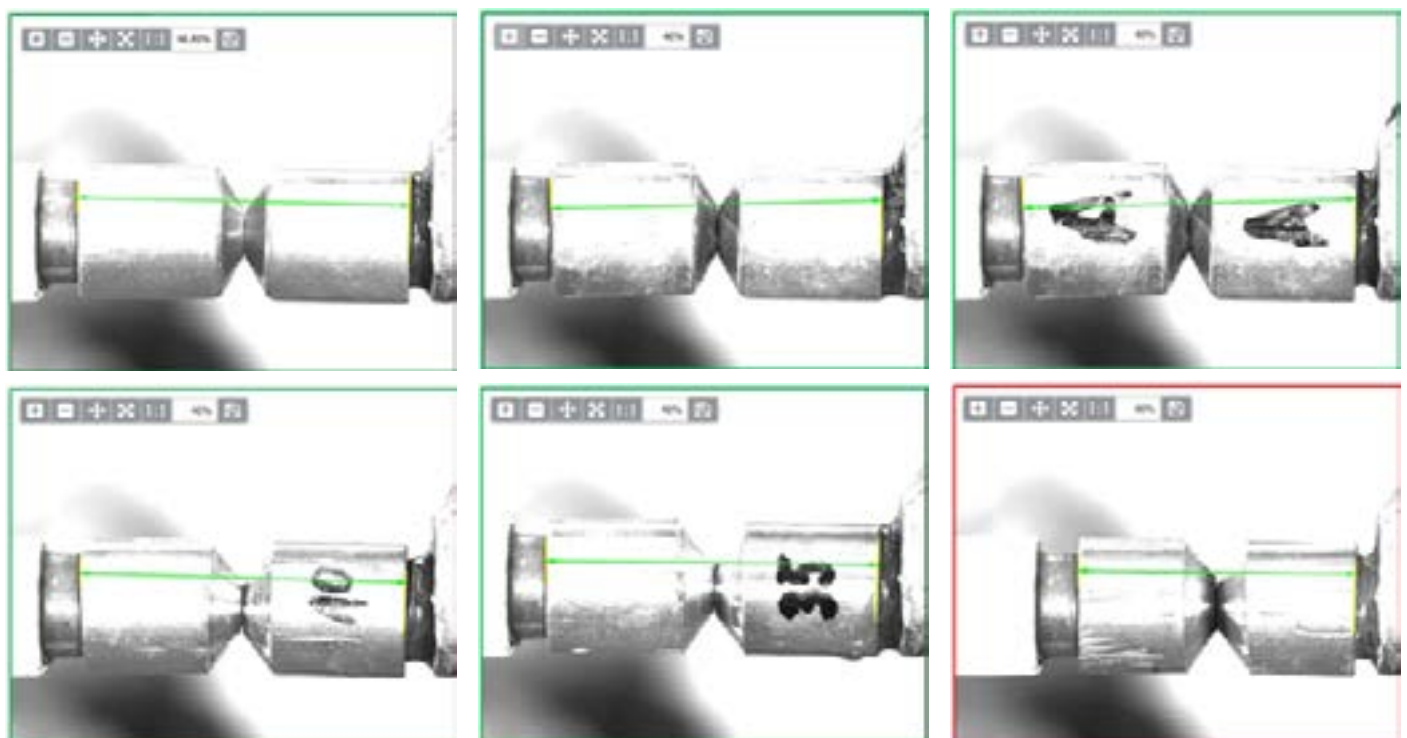

Fig. 11. Measurement results in relation to various degrees of electrode wear: new electrodes (a), electrodes subjected to multiple sharpening cycles (b-e), worn-out electrodes (f)

was positive, i.e. the measured values amounted to 952 px and 931 px respectively. In cases of the worn-out electrodes, the measured value amounted to 786 px, which translated into the negative test result. The operation of the signalling column was proper during each measurement.

Figure 11 presents images of exemplary electrodes along with identified edges and analysis results recorded in the automatic mode. Figure 11a presents model (new) electrodes; the pairs presented in Figure 11b – e were subjected to multiple sharpening cycles, whereas the pair presented in Figure 11f was consumed entirely (worn-out). The test results were consistent with the actual condition, which was confirmed by related verification measurements.

Analysis of results

The tests of the video system involved the analysis of external factors affecting the verification measurements of the electrodes and the operation of the entire integrated station. One of such parameters is the proper and constant lighting of tested objects. Figure 12 presents the exemplary analysis of unworn electrodes, in relation to which the value of height beyond the upper tolerance limit was identified. The above-presented problem resulted from the improper

Fig. 12. Example of the wrong identification of an edge resulting from improper lighting

detection of edges of elements indispensable for the proper identification of height, which in turn resulted from the inappropriate lighting of the object subjected to analysis. It should be emphasized that in terms of the video system and lighting applied in the tests, ambient light did not affect images being recorded. It is important to provide the proper and uniform lighting of the system. Furthermore, the aforesaid lighting should remain unchanged in time.

Another factor affecting the proper performance of measurements is a constant distance between electrodes in the diagnostic position and the video sensor. A change in a position in relation to the camera during the acquisition of an image generates errors when verifying the element in accordance with the previously adopted model. It is recommended to check an image being recorded before the start-up of the system and perform calibration to eliminate the effect of the above-named factor in measurements. It is also necessary to adjust sharpness and brightness parameters by appropriately adjusting the object lens, thus enabling the obtainment of an image as similar to a previously programmed model as possible. It was noticed that vibration generated by the industrial robot affected adjacent elements, including the housing to which the video system was attached. The very recording of images by the video camera was not accompanied by nor did it reveal any interference, yet in terms of longer operation or the exposure of the housing to vibration generated (also) outside the station, the moving of the sensor in relation to the welding gun in the diagnostic position could trigger problems with the proper analysis of a recorded image.

Conclusions

– The tests involved the development of a fully functional system assessing the wear of electrodes. The above-named system was composed of a FANUC industrial robot, an automatic electrode sharpener and a video system (a Balluff BVS smart camera).

– The BVS Cockpit user interface (integrated in the smart camera), enabling the preparation of any test schedule based on available tool libraries, was used to develop an algorithm aimed to assess the wear of electrodes on the basis of electrode height measurements.

– Test results concerning the wear of electrodes were visualised using the SmartLight signalling column. Positive evaluation results led to the cleaning of electrodes (milling performed using the sharpener), whereas negative evaluation results led to the replacement of electrodes.

– The communication interfaces were used to connect the video system with the welding robot (via the controller) and with the signalling device acting as the user interface, thus enabling the elimination of the computer from the industrial station. The welding robot was appropriately programmed, in accordance with the previously adopted system flowchart.

– The tests and measurements performed using the robotic station enabled the assessment of the proper operation of the system in the actual work environment.

– The test results obtained in relation to the sets of electrodes subjected to analysis were consistent with the actual condition. In addition, the tests enabled the identification of factors affecting the quality of recorded images. When implementing the above-presented solution in the production environment, the aforesaid factors should be minimised or, possibly, eliminated. It was ascertained that the use of the video system could significantly reduce pre-weld preparation time and increase the efficiency of the spot welding process itself.

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