A Measuring System for Supervision of the Rail Welding Machine PRSM-4 No. 083

Boris Antić and Dragan Pejić

Abstract—The paper describes a measuring system implemented on the rail welding machine PRSM-4 No. 083. The measuring system monitors and controls all parameters of rail welding procedure in real time. The paper gives an overview of the measurement of all relevant variables, control of the duration of individual welding phases and of the basic options of the command software. The paper describes the most important parts of the measuring block and presents the results of the system exploitation on over 10,000 completed welds on territories of Serbia, Montenegro and Bosnia and Herzegovina during a period of about two years.

Index Terms—measuring system, rail, welding.

I. INTRODUCTION

Most modern railways use continuously welded rails. In this form, the rails are welded together by utilizing the termite reaction or flash butt welding to form one continuous rail that may be several kilometers long. Because there are few joints, this form of track is very strong, gives a smooth ride, needs less maintenance and trains can travel on it at higher speeds and with less friction. Welded rails are more expensive to lay than jointed tracks, but have much lower maintenance costs. The construction and maintenance of railroad tracks on territories of Serbia, Montenegro and Bosnia and Herzegovina are predominantly performed with the use of Ukrainian rail welding machine PRSM-4 No. 083 owned by the Company for Construction, Renovation and Maintenance of Railroads – ZGOP from Novi Sad, formerly part of the Yugoslav Rail company. So far, no data about individual welds were collected. The quality control was carried out aposteriori using x-rays on a random set of completed welds in order to detect possible irregularities and tensions among the fused rails. However, each individual weld was not accompanied with the necessary technical specifications as required by the Law on Traffic Safety. The used welding method involving the melting of metal at the site of the joint is necessarily prone to shrinkage as the heated metal cools. Shrinkage can introduce residual stresses and both longitudinal and rotational distortion. Distortion can pose a major problem, since the final product is not of the desired shape. An analogue system of automatic control realized by the machine manufacturer over 30 years ago was in charge of controlling a part of the welding process. This analogue control system was depending on manual adjustment of set of timers prior to the fusion, demanding constant engagement of experienced and educated staff. This was causing the welding procedure to be both expensive and insufficiently reliable.

There are few papers published dealing with the complex mathematical modeling of the welding processes. In [1] is described one of the developed methods, but with a rather poor performances and no wider field application. A more common approach to the automation of the welding process can be found in the use of expert systems such as described in [2] or published on web sites of welding machine manufacturers such as [3]. It is a straightforward technique used in the measuring system described in this paper as well. With the use of the methods described below all relevant parameters of the welding process were measured and recorded. Whenever the recorded parameters were within set boundaries, the weld was proclaimed to be successful. Otherwise it was dismissed and cut back again in order to repeat the welding process. This is in compliance with the latest standards on rail quality control which aim not only to the final weld quality but to the quality control of the entire welding process as well.

II. MATERIALS AND METHOD

The system for the acquisition of the welding parameters consists of a measuring block, a display, a communication block, sensors installed on the welding machine and a command software installed on a laptop computer (fig. 1).

![Figure 1. Blocks of the measuring system](image)

The measuring block is located in the power module of the welding machine and it receives all the measured signals necessary for monitoring and control of the welding process. In arc welding, the voltage is directly related to the length of the arc, and the current is related to the amount of heat input. The measuring block measures a welding AC
voltage 0 - 500 V (voltage of the prime of the power transformer), a welding AC current 0 - 5 A (obtained from the current measuring transformer 600/5 A), a DC voltage from an analogue velocity regulator 0 - ±150 V, and a DC current 4 - 20 mA (output of the pressure transmitter 0 - 100 bar). Beside these analogue quantities, the block also receives 12 digital signals from timer relays indicating beginning or end of one of the welding phases (warming up, compression, melting, crowding, etc.) The switch states of all relays are reported to the commanding laptop. The computer monitors and displays all measured welding parameters and generates reports on weld soundness.

All converted analogue parameters and relay states are sent to the commanding software by the measuring block at the rate of 10 times per second. The software calibrates and displays to the operator all measured analogue quantities and the duration of the welding phases. The computer activates a sound alarm and a rotating light in case it detects any of the possible irregularities (encoder does not lean on the rail, rails are slipping during the fusion etc.) Upon welding the computer records all data in an encrypted file on its hard disk. This file is a complete qualitative and quantitative description of the performed weld and can be used to generate a ready-to-print report.

The computer also sends the calculated duration of individual welding phases towards the 7 segment display where they are displayed to the operator outside of the cabin. The operator can therefore inspect the duration of the welding phases and decide whether the weld was performed successfully or not, without entering the control cabin and peering through files on the disk.

A. Measurement of the AC Voltage

The AC voltage ranging from 0 V - 500 V is performed with a measuring chain shown in figure 2. The voltage value is first reduced with the use of 500/9 V measuring transformer in order to adapt it to further electronic processing and to enable galvanic isolation of electronic and power circuits. The RMS-to-DC converter generates a DC output proportional to RMS value of the input AC voltage. It enables a correct conversion of highly distorted input signals commonly occurring in welding processes. The output of the RMS-to-DC converter is brought to a 10-bit ADC wherefrom it is fetched by a microcontroller. On a query from the commanding laptop the converted digital value is sent to the computer in form of an integer number where it is interpreted depending on the voltage calibration curve. The calibration curve is confirmed or altered after a periodic calibration procedure.

B. Measurement of the AC Current

Measuring the AC current in range 0 A to 5 A is performed with a similar measuring chain. A current measuring transformer 600/5 A is used to reduce the current down to several mA and to galvanically isolate electronic and power circuitry. The input buffer converts this small current to a voltage of several volts. This voltage is lead to the RSM-to-DC converter wherefrom the chain continues identically as in the case of the AC voltage. Calibration process determines the interpretation of received digital values and the level of measurement errors.

C. Measurement of the DC Voltage

The DC Voltage from the analogue velocity regulator varies in the range from -150 V to +150 V. The conversion of this voltage to frequency (as shown in fig. 3) was due to the difficulties associated with galvanic isolation of DC signals where the use of transformer in not an option. The output of the Voltage-to-Frequency-Converter (VFC) is a signal whose frequency is proportional to the level of the input DC voltage. Digital impulses are passed through an optical coupler and, hence the electronic circuitry is galvanically isolated from power circuitry.

D. Measurement of the Pressure

In figure 4 is given the circuit for measuring pressure of the hydraulic compression system. The maximum pressure of the hydraulic fluid is 100 bar. The pressure transmitter generates DC current from 4 to 20 mA. Power supply for the used circuit is 12 V so no galvanic isolation was necessary. The transmitter output current is converted to voltage, amplified and lead to the input of an ADC. The calibration procedure defines relation between the pressure, transmitter's current and the ADC output.

E. Measurement of the Slipping of Rail Bars

The welding head holds, melts and crowds two adjacent rail bars during the fusion process. For the quality of the
weld it is critical that the injection force applied to two rails is kept constant while the rails are approaching each other maintaining constant speed. On both sides of the welding head rotating wheels are installed with an incrementing encoder laid directly on the rail bar during the welding. Whenever a slipping of any of the two rails occurs the corresponding encoder counts several impulses indicating faulty situation to the commanding laptop. The laptop than activates the sound alarm and the rotating light to signal the operator that the welding is faulty and should be aborted. Radius of the contact wheel is 100 mm, and the incremental encoder generates 200 impulses per full rotation. This means that the slipping is measured with a sensitivity of 0.5 mm.

F. The Digital Inputs

The 12 digital inputs from relays indicate the beginning and the end of each of the 12 welding phases. Apart from these signals the measurement block sends the increment signals from two slipping encoders and two additional signals set manually by the operator to indicate actual beginning and end of the welding process in case any of the relay times fails to open/close.

Communication between the measuring block and the computer is RS-232. The data acquisition is performed by software written in Delphi 6. Polling of the serial port every 100 ms enables the reception, processing and the display of all 6 welding parameters and the stage of the welding process in real time. Fig. 5 shows an example of the application's main window.

G. The Software

The described measuring system has exceptionally high accuracy in measuring and controlling all welding parameters. Figures 6, 7, 8 and 9 show fiducial errors, where the spans of the measured quantities were used as the specified (fiducial) values.

III. RESULTS

The measuring block samples and measures all relevant welding parameters at a rate of 10 Hz (each 100 ms) thus enabling the quality control of the entire welding procedure and not only of the final weld. This has enabled significant savings in rail deployment since the need for repetitive welding and cutting is reduced to a minimum. Also the possibility of human error is minimized due to the elimination of the random selection of arbitrary weld samples. Each weld is carefully monitored and documented leaving any faults clearly visible and thus guaranteeing higher safety of people in rail transportation.
text editor, the operator can tune the accuracy of the system without any need for the reprogramming of the commanding software.

The operator can zoom in and out and rotate all the diagrams to acquire better insight and spot possible irregularities in the performed weld. The display of all diagrams and graphics is in real time. At the end of the welding the software generates an encrypted report containing: 1) values of all 6 measured analogue parameters during the welding procedure with sampling frequency of 10 Hz, 2) measured and referent duration of all 12 weld phases, including relative discrepancies in percentage, 3) data about the place, rail route segment and weather conditions, 4) data about the type of the rail bar and the quality of the material and 5) in case of a failure - information about the cause.

The encrypted file is small in size and therefore convenient for long term storage of great number of data about completed welds. It can't be manually altered or copied as a new report. The restriction was due to security reasons so no abuse or manipulation with this type of information is possible. This was a necessary precaution to ensure maximum reliability of collected data. Another side-effect is that the management staff of the welding company gained an insight into the actual number of successfully and unsuccessfully performed (repeated) welds.

The encrypted file is used to generate a report in Excel with graphical and tabular representations of all recorded parameters. An example of this report is shown in figure 10.

![Excel report on a performed weld](image)

**Figure 10. Excel report on a performed weld**

The encrypted file is used to generate a report in Excel with graphical and tabular representations of all recorded parameters. An example of this report is shown in figure 10. This report is in compliance with ISO 9001 and has been nominated as the new standard for reporting on soundness of performed welds on the territories of Serbia and Montenegro. The software also has a search engine for faster data mining and reloading of files in order to print out detailed reports and statistically process data.

The software enables the operator to define so called referent welds for various rail types and manufacturers. These referent welds can be reloaded at a later time to be used as a reference. This excludes the need for the trained experts to be present on the filed and constantly monitor the whole process. An arbitrary number of test welds can also be performed should the operator want to adequately warm up and set the welding head performances to match the referent weld.

After several months of system testing and completing over 200 welds the following minimum set of conditions was adopted as sufficient criterion for quality control of the welding process: 1) the difference between the measured and the referent durations of all welding phases must be lower than 4 %, and 2) no slipping of rail bars during the injection phase is allowed.

Based on the gained experience, some of the irregularities occurring during the weld can now be easily explained and prevented, e.g. too large gap between the rail bars prior to melting causes prolongation of the time before the arc appears (the arc current is delayed), unclean and contaminated bar surface is evident through a lower amplitude of the welding current, etc.

During three years of the system exploitation and over 10.000 successful welds not a single malfunction of the measuring system has occurred.

**IV. CONCLUSION**

The presented measuring system enables complete control and monitoring of the welding process in real time and displays all relevant quantities with measurement errors less than 1 % and time resolution of 100 ms. For the first time in the world some welding parameters such as slipping in the crowding phase were put under control. This was achieved with an error lower than 0.5 mm. Efficient and user friendly software gives a unique feeling of comfort to the operator and the welding procedure is completely automated and significantly shortened. The use of the measuring system in praxis has led to a better understanding of the rail welding process and revision of the necessary and sufficient conditions for the welding quality control. The quality control of the process and not only the final product has enabled significant savings and facilitation of rail deployment on the territory of the West Balkan hopefully leading to higher safety in rail traffic in the future.

**REFERENCES**

