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High-Frequency Invertor Welding Machine – Advantages of New Technology

Abstract: The article presents advantages of inverter welding machines having a high operating frequency of 10kHz and compares conventional AC 50Hz welding machines as well as inverter welding machines having an operating frequency of 1 and 10 kHz. The article presents research results obtained within a currently implemented project of Programme of Applied Research (PBS3/B4/12/2015).

Keywords: invertor welding machine, high operation frequency

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Introduction

Resistance welding is one of the primary methods used when joining thin-walled elements of metal structures in all industries including the automotive industry, civil engineering, electrical engineering, aviation and the production of household equipment.

The technology of resistance welding has been known for almost 139 years, when in 1877 (almost by chance) Elihu Thomson made the first welded joins. Until today, the technology has been used and developed. It should be noted that the efficiency of the very process (welding technology) is not high, amounting to, depending on the type of a welding machine type (AC/DC welding power source) and its design (cross-sections and the reach of arms/ conductor rails [1]), only between ten and twenty percent. The efficiency of resistance welding can be compared to that of steam locomotives (Fig. 1) [2]. Both the need of using the steam technique (steam locomotives) and welding resistance technology were necessitated by the final effect. In the case of steam locomotives, the final effect was a so-called *towing power* of up to 3 thousand tons (i.e. 60 freight cars, 50 tons each), whereas in the case of welding, the final effect was the joining of sheets/plates (several millimetres in thickness)

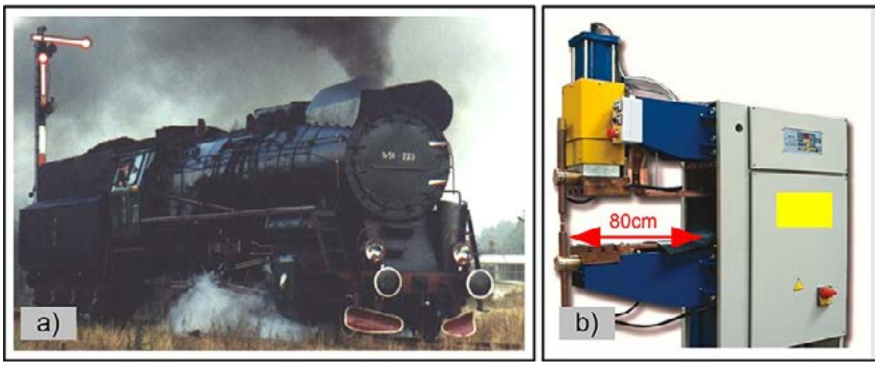

Fig. 1a) The heaviest Polish steam locomotive Ty51-223, (weight of 190 tons) made in 1957 by H. Cegielski-Poznań Company (towing power of 3,000 tons, thermal efficiency of 10% [2]; 1b) spot resistance welding machine, welding current ~25kA, weight 750kg, electric efficiency of 10% [3]

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by melting the material within a fraction of a second and obtaining a weld nugget having a diameter of between ten and twenty millimetres. Such an increase in efficiency is even difficult to imagine. In spite of an unimpressive efficiency, resistance welding continues to be successfully used in spite of alternative and competitive joining methods such as laser welding, riveting or adhesive bonding.

The common use of resistance welding results from three primary, both practical and economical, advantages, i.e.:
- no need for using filler metals,
- short process duration (welding current flow time of ~200ms),
- low cost of energy needed for making one joint (0.1 US cent) [4] [5].

The above-presented data concern the overlap welding of 1mm thick sheets used, among others, in the automotive industry. The popularity of resistance welding results directly from the necessity of making many joints when producing a car body (depending on the car type, between 3,000 and 5,000, mostly overlap welds) [6]. In the automotive industry, most of the car body joints are made using mobile welding machines, either by suspended manual machines or machines fixed on a robot arm. In both cases, the weight of the welding machine is important as it affects the mobility of devices (welding machines) and the efficiency of production, directly influencing the economic aspects of welding processes.

Until Today

Before presenting the primary advantages of a high-frequency inverter welding machines, the conventional technology based on AC welding machines having a frequency of 50 Hz is worth mentioning. Because of their relatively low price and long service life, such machines are still in use. However, in addition to the above-presented unquestionably favourable advantages, it is necessary to take into consideration technological aspects, including that of adjustment. The shortest time interval during which it is possible to adjust a device is the time of one period (cycle) of device (welding machine) operation. In AC welding machines having an operating frequency of 50Hz, this time amounts to 20 ms. However, the stabilisation and adjustment of welding current requires considerably longer time, i.e. a minimum of 5 periods/cycles [7]. Often, this time is excessively long in terms of technologies requiring welding times amounting to between ten and twenty milliseconds, e.g. when welding materials characterised by high heat conductance (aluminium or copper alloys). In such situations, the technology imposes specific conditions concerning the value of welding current, which should be sufficiently high, yet the time of welding current flow should be relatively short (between ten and twenty milliseconds). In such cases, the use of inverter welding machines, characterised by significantly shorter primary operation times (1 ms / 0.1 ms) is particularly favourable.

The recent trends as regards the use of welding machines by foreign automotive concerns involve production lines equipped entirely with inverter welding machines. The present standard of internal transformation frequency amounts to 1 kHz [8]. The recent years have seen successful efforts aimed to increase the operating frequency of inverter welding machines (10 kHz and higher).

Advantages of Inverter Welding Machines

Generally, both power and technological advantages resulting from the use of inverter welding machines (1 kHz) if compared with AC 50 Hz welding machines (power frequency) [7] [9][10] are presented below. Power-related advantages include:
- symmetric load of the three-phase supply network,
- higher value of power coefficient (0.7 or higher),

– significantly lower hazard related to electromagnetic field emission.

Technological advantages are the following:
– improved quality of welds resulting from increased process dynamics (short welding times – below 20 ms),
– obtainment of greater joints without the risk of expulsion or crack formation,
– increased technological versatility, resulting from significantly shorter adjustment times (several ms),
– possibility of joining hard-to-weld materials,
– reduced HAZ,
– extended service life of electrodes.

New materials, welding machine elements and components, the development of control systems used in power electronics as well as the development of micro-processing systems and software programmes, offer new possibilities improving the properties and efficiency of resistance welding processes. Presently, all the above-presented elements coincide.

Advantages of Increased Internal Transformation Frequency of Inverter Welding Machines

An increase in internal transformation frequency enables the further improvement of the process (technology) as well as makes it possible to obtain the following additional advantages:

1. The element of key importance in the welding machine (advantages visible particularly in terms of manual and suspended welding machines) is the transformer. The weight and volume of the transformer should be as low as possible. The reduction of these parameters is possible by increasing the operating frequency. An increase in frequency from 1 kHz to 10 kHz enables the reduction of the weight and volume of the transformer at least 2-3 times, thus increasing the mobility of moving elements of welding machines and reducing power losses. The reduction of the material consumption index and the supporting structure of the manual welding machine and of the robot, decrease production costs and times of welding machines. For instance, the weight of a transformer (welding current of 15kA) used in an AC (50 Hz) welding machine amounts to approximately 60 kg, in a DC (1 kHz) inverter welding machine – 25 kg, whereas in a DC (10 kHz) inverter welding machine ~7 kg. The transformer itself is powered by the inverter located outside the moving (mobile) part of the welding machine, yet such a configuration leads to the reduction of transformer weight. Figure 2 presents the size and weight of transformers used in AC (50 Hz) welding machines (Fig. 2a), DC (1 kHz) inverter welding machines (Fig. 2b) and DC (10 kHz) inverter welding machines (Fig. 2c). The figure clearly illustrates the decreasing weight and sizes of transformers.

2. Appropriately faster control than that used previously could lead to a technological breakthrough as to the improvement of welded joint quality, particularly as regards the elimination of the highly unfavourable and, at the same, dynamic phenomenon of liquid metal expulsion from the weld nugget. The issue of expulsion has not been solved since the invention of welding. Due to their overly slow influence on the welding process, solutions and technical resources available today are unable to entirely tackle the problem of expulsion, i.e. the primary disadvantage of resistance welding, which, because of technical reasons, cannot be controlled on a follow-up basis). Presently,

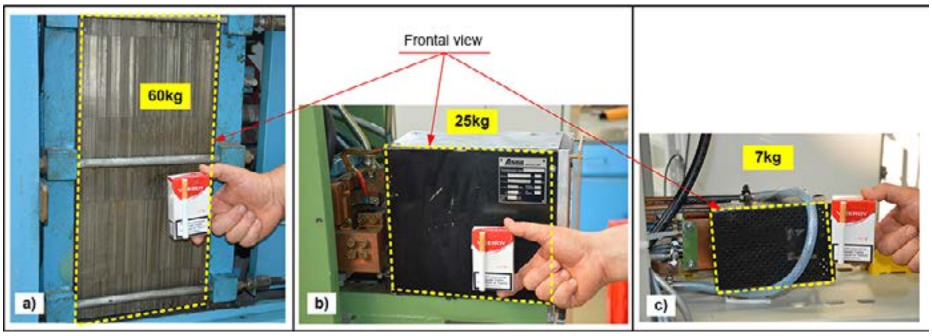

Fig. 2. Sizes and weights of welding machine transformers: a) AC 50 Hz, b) DC 1 kHz (inverter type), c) DC 10 kHz (inverter type)

the results obtained in relation to this area enable the detection of expulsion [11][12], yet the elimination of this expulsion requires further research [13][14]. In addition, the elimination of expulsion and the reduced melting of protective coating materials can minimise the emission of various noxious chemical elements (zinc, iron, manganese, aluminium and titanium) [15].

3. The increased internal transformation frequency translates into a 10-fold more frequent effect on the process, which enables a 10-fold faster control (0.1 ms), (*weld. AC (50 Hz) – 20 ms, DC (1 kHz) – 1 ms, DC (10 kHz) – 0,1 ms*) [16]. The greater operating frequency provides faster adjustment and stabilisation of the pre-set value of welding current and affects the rate of welding current up-slope time (Fig. 3).

4. A shorter current up-slope time (higher dynamics) and higher current stability (lower pulsation) are factors concentrating energy. Higher dynamics and the continuity of the heating of elements being welded concentrate energy, which is favourable as regards the welding of metals and their alloys characterised by high heat conduction, e.g. aluminium or copper. When welding the above named materials, their HAZ should be reduced as much as possible, therefore the time of welding should be short.

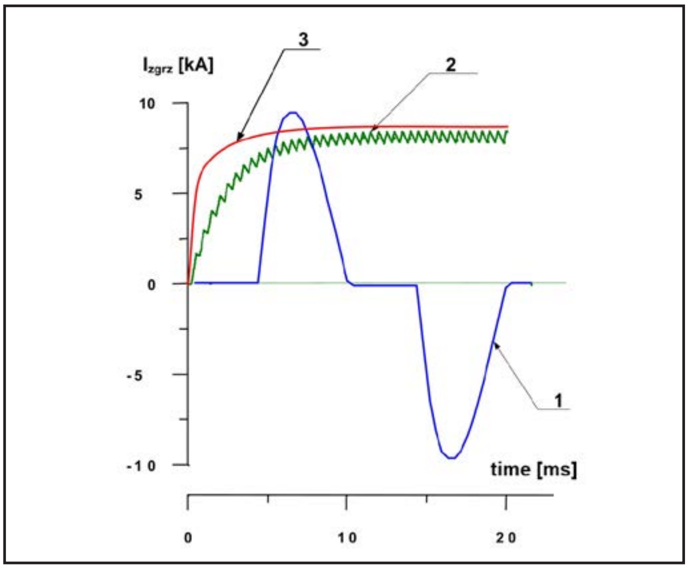

Fig. 3. Welding current waveforms in time:
1) conventional one-phase AC welding machine (50 Hz)
2) DC welding machine with internal frequency transformation (1 kHz)
3) DC welding machine with internal frequency transformation (10 kHz)

Polish Contribution to the Development of Inverter Welding Machine Technologies

The ongoing research is performed as part of the project PBS3/B4/12/2015 implemented within the confines of the 3rd Programme of Applied Research. The project participants include the Silesian University of Technology (Faculty of Electrical Engineering, Department of Power Electronics, Electric Drives and Robotics), Wrocław University of Technology (Faculty of Mechanical Engineering, Department of Materials Science, Resistance and Welding Engineering), Enel PC, Aspa Wrocław, Laska Tychy and Instytut Spawalnictwa as the project leader.

The objective of the project was to develop a DC welding machine with an inverter having transformation frequency higher (10 kHz and above) than that previously used in such devices. The block diagram of the inverter welding machine is presented in Figure 4.

The project-related tests aimed to determine the operational properties of the above named welding machines in resistance welding technological applications, in particular using suspended manual and robot welding stations and

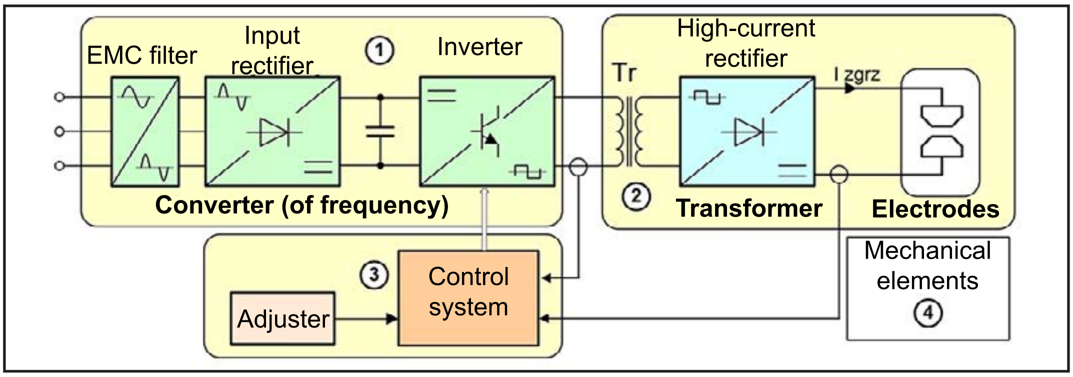

Fig. 4. Block diagram of the welding machine with frequency transformation 50 Hz/10 kHz

having in view the automotive, household appliances, electronic, electrotechnical and medical equipment industries as well as to identify the competitive edge of this inverter welding machines over previously used welding machines.

Presently, the project is being implemented. The project outcome, i.e. the 10 kHz inverter welding station, is presented in Figure 5. The project implementation included the development and production of an inverter, the model system of inverter and welding machine control as well as welding machine transformer. The results obtained were satisfactory; the maximum momentary value of short-circuit amounted to 16 kA of the welding machine system as presented in Figure 5.

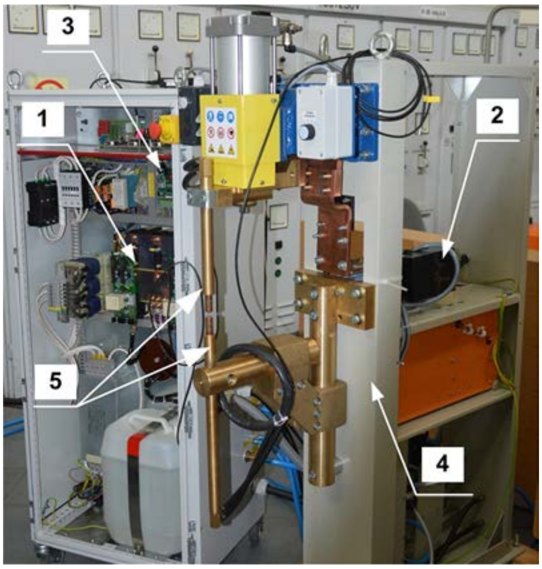

Fig. 5. Inverter welding machine (10kHz) 1) inverter, 2) transformer, 3) control system, 4) welding machine housing, 5) electrodes

Summary

Advantages resulting from the use of higher operating frequency in inverter welding machines greatly contribute to resistance welding technologies. The progress results from the n-fold increase in welding machine operating frequency. In comparison with an operating frequency of 1 kHz, an operating frequency of 10 kHz provides a 10-fold increase in process control frequency, more than a 2.5-fold reduction of transformer weight and volume, greater operating mobility of manual and robot welding stations, lower material consumption index, greater power efficiency and improved quality by reducing the intensity of expulsion.

The joint project resulted in the development of a Polish (model) inverter welding machine (Fig. 3). Polish producers of welding machines do not possess ready solutions characterised by the parameters obtained in the project. The activities aimed to develop the Polish design of an inverter welding machine (10 kHz) meet expectations of Polish producers of welding equipment increasing the competitiveness of solutions offered by Polish companies producing welding machines.

Project PBS3/B4/12/2015 implemented in the years 2015-2017 within a consortium composed of Instytut Spawalnictwa (project leader), Enel PC, Aspa Wrocław, Laska Tychy, Silesian University of Technology (Department of Power Electronics, Electric Drives and Robotics), Wrocław University of Technology (Faculty of Mechanical Engineering, Department of Materials Science, Resistance and Welding Engineering) is financed from the funds of the National Centre for Research and Development (NCBR).

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