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UML approach to design of the control of MIG/MAG welding process `(draft version)`

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Abstract

Purpose In many branches of industry e.g. machine, building, food, ship's, chemical and the like for joining metal elements a welding is use. The challenge is to assure the good and repeatable mechanical properties of the connection and cutting down the cost of operation. This can be achieved using modern equipment and smart welding technologies.

Design/methodology/approach Terminology and notation of UML (*unified modelling language*) can be adopted to design and improve the control system of MIG/MAG welding process. UML is supported by all major CASE (computer aided system engineering)tool vendors. Designing UML diagrams on computer screen is supported with CASE software e.g. Rational Rose (2007) and Visual Paradigm (2007).

Findings The main advantage of UML is that it reveals gaps and inconsistencies in the specification of requirements, at very early stages of the design of any system.

Research limitations/implications Weak point of computer aided design process is high cost of computerised design equipment, trained staff and software.

Practical implications Many companies switch from paper blueprints to digital representation of future product.

Originality/value Software engineering methodology and UML diagrams are used in areas beyond computer science. UML notation helps to describe and understand functions, services and activities of any system, regardless of its physical nature.

Keywords MIG/MAG welding, UML aided welding

Paper type Research paper

1 METHODOLOGY AND MOTIVATION OF USING UML

UML models may describe architecture and behavior of actual MIG/MAG system and its future design. UML models have high level of abstraction and they are independent of physical nature used of technology. Designer has possibility to verify his ideas using UML models on high level of abstraction, without building physical prototype. He may identify and eliminate (early in design process) main risks of the project failure, delay or over-budgeting.

The design process of MIG/MAG welding system

The development process is set of partially ordered steps, which leads to desired target. Sequential approach always fixes project status before switching from one discipline specific design tool to another. Then special arrangement is needed to exchange project data between used tools. A typical design process may be presented as a sequence of:

- early design phase, which include requirements elicitation (inception) and conceptual design (elaboration). Off-line simulation may be used for testing of the design,
- building (construction) phase, which includes detailed design, HiL simulation and prototyping, as well as implementation and testing,
- deployment (transition) of achieved solution.

Early design phase: elicitation of requirements

Design starts when need of new or improved solution came into sight. During elicitation of requirements, behaviour of the system is defined and criteria of consumer satisfaction are set. This may be influenced with development strategy of a company. The goal of elicitation of requirements is to describe what the system should do and (which seems to be equally important) to agree with customer on this description. This is an important job, as consumer satisfaction is one of main objectives of the design.

Take in Figure (1)

Use case diagram describes how the system may be used by user and how the MIG/MAG system interacts with external actors (operator, technologist, welding arc phenomena). Use cases capture subsystem functionality as seen from the point of view of end user or domain expert and help to understand how the system should work. Use case icon is an ellipse.

Preparing use case diagrams is an important job, as original problem description may be incomplete and some requirements may conflict with others. When ready, user should verify if all needed functionality of the future system is included in use case diagram and if all actors do communicate with respective use cases.

Describing actor and system interactions in scenario

Scenario is a textual description or set of messages in natural language, describing the sequence of actor and system interactions. It describes details of use case functionality The example of **scenario 1** may be as follows:

1. *Operator fits the welded pieces on Weld Positioner,*
2. *Then he chooses the suitable welding program (welding parameters are set here) from the computer database and sets trajectory for welding gun.*

3. *Then the automated welding process is started: small piece of free end of welding wire is cuted, gas supply and welding power supply is turned on, welding gun is positioned at starting point of welding trajectory, feeding of welding wire is started*
4. *Welding arc ignition procedure starts*.

More detailed **scenario 2** will include setting up welding parameters, e.g.

1. *arming the welding station in: electrode wire about the required diameter and the kind, into the cylinder with the needed kind of protective gas,adjusting the intensity by flows of shielded gas. The rate of flow of shielded gas usually has permanent value and it should be controlled with sensor of the rate of flow,*
2. *of placing the running light voltage of the power source. Depending on an applied source of power setting the tension can take place by hand or by a computer program via the driver,*
3. *adjusting dynamics of the power source. Setting dynamics can take place in modern sources by a computer program via the driver,*
4. *placing the distance of the end of the sleeve passing the electricity on to the electrode to welded material. While welding set the distance of the end by holding an arrangement of steering is carrying the sleeve out with arm of the robot.*
5. *placing electrode wire to the initial feed speed. Setting with wire feed speed while welding will supervise the computer.*
6. *placing the speed welding. In the process of the welding the speed of beading is realized by the arm of the robot.*

Set of parameters should be remembered for the given completion of the process of welding. The parameters constitute the base for creating the welding protocol. After finishing the preparatory sequence the welding station is ready to begin the process of welding.

Parallel activities

Activity diagram (fig. 2) is used to visualise parallel activities and to show sequence of internal states. It is well suited to describe set of sequential and parallel actions when preparing the welding gun to work in MIG/MAG welding mode. Short horizontal or vertical thick lines are used for synchronisation of actions.

Take in Figure (2)

2 Observing main parameters of welding process

The welding process can be evaluated basing upon the analysis of signals which accompany such a process. While welding, the data related to the process course are provided in electric, optical and sound signals [1,2,3,4].
Optical and sound signals are complicated and complementary. They entail a well-developed measuring circuit. A complex analysis of such signals must be performed elsewhere so as to get the data indispensable for controlling the quality of the welding process. Current and voltage signals occurring in the course of welding constitute the base for an evaluation and control of the welding process.A dynamic characteristic curve of the welding arc, as shown in Fig. 3, was applied for the ongoing control of the MAG joint under production [1].

Take in Figure (3)

This curve allows one to evaluate the course of the welding process. The vertical axis represents the voltage value during the welding operation U, whereas the horizontal one – the welding current I. The constant power lines are found from formula /1/

$$P = U^{*} I = \text{const.} \qquad /1/$$

On Fig. 3, the point A shows the shorting occurring between the electrode and the material under welding, caused by a metal droplet. At point B, the metal dropping from the electrode under melting passes to the molten pool. Within the segment from B to C occurs not only a spacing, but also arc burning which takes place between the interrupted droplet neck and the electrode end. From C to D, the arc glows. The arc heats up the electrode end and causes the wire to melt. At point D, the volume of the droplet under formation increases. In turn, an increase in the droplet size brings about a reduction in the arc length. At shorting, the voltage value decreases down to a few volts. This state is represented at point A. The described course of the process is repeated in cycles. In order to enhance the chance of analyzing the process by means of the dynamic arc characteristic, the voltage and welding current were recorded at discrete time intervals and shown on the Fig. 3. The space between successive samples is Δt. The duration time of the process between the starting and the ending points can be found from formula /2/:

$$T = (n-1) * \Delta t \qquad /2/$$

where n gives the number of points on the characteristic - from the starting point to the ending point.

Experimental data used to prove theoretical dynamic current-voltage characteristic of the welding arc.

The investigation on the process of arrangement of runs and beads was carried out by means of the welding parameters as specified in scenario 2. While arranging padding welds, instantaneous control voltage and welding current values were measured. All measured results were recorded during the welding process. Fig. 4 shows the recorded dynamic characteristic curves of the welding arc and the pad welding results. The characteristic curve shape allows to distinguish several states 18A, 18B, 18C, 18D of the process. On the characteristics is laid the average power value $\underline{P}$. Its value was determined according to formula /1/ basing upon the measured average values of voltage and welding current.

Take in Figure (4)

An evaluation of the welding process was carried out by comparing the appearance of the padding weld with the recorded arc dynamic characteristic. Basing upon the visual control of padding weld N18, one can state that segment 18A-18B is correct. Segment 18C-18D of the padding weld exhibits some defects, and cannot be used. The electrode wire feeding rates were as follows: 18A - 24 mm/s; 18B – 84 mm/s; 18 C 145 mm/s; 18 D 205 mms.
In the example as analyzed in Fig. 4, cases 18A and 18B represent the state of metal passage through the welding arc in shorting conditions. This state is correct provided that the maximum instantaneous shorting power does not exceed the pre-set power value Pgr , and the electrode wire feeding rate does not exceed the limiting value of Vgr. In the case 18B - the control system may increase the feeding rate of electrode wire until Pgr ≤ 5 kVA. An increase in the electrode wire feeding rate causes an increase in the current value which directly influences the fusion penetration. So as to maintain a constant penetration depth, the welding rate Vs should be increased. This control is aimed at keeping a constant linear welding as expressed in /3/:

$$E = (U*I)/Vs = const \qquad /3/$$

A correction is of significance, especially when metal sheets are welded. Technological formulae to express, respectively, the effect of current parameters upon the penetration depth and the effect of the penetration depth on the welding rate should be determined experimentally. In a system which can keep the average power $\underline{P}$, the control occurs through the time control of the short-circuit current pulse. At shorting, the duration time of the short-circuit current time should not cause any increase in power in excess of Pgr. The maximum value of the shorting time is to be found from formula /2/ by making use of the recorded 18NB characteristic [Fig. 2].

This time can control the current conduction through transistors in the power system of a welding current source.

In Fig. 2, case 18C. shows porosity – a welding defect. The instantaneous voltage values at the stage of arc burning are by 10V higher than the average voltage in the course of welding. In this stage of the process, the maximum current exceeds 600 A. Instead, case 18D in Fig. 2 presents the state of spattering. Voltage dispersion in the arc burning phase exceeds by 15V the average welding voltage value. Instantaneous current values exceed 800 A. At such a current value, two voltage levels occur. One amounts to 7-10 V, the other to 11 -15 V. Those values are time delayed. The time of delay is of an order of a few to a dozen or so milliseconds. In the characteristic one can notice a 'crook' accompanied by a sound effect – 'shots'.

In both cases - 18C and 18D, the control system should either reduce the electrode wire feeding rate or interrupt the welding process.

3 Describing the MIG/MAG process with state diagram

Statechart diagram (Fig. 5) is used to describe behavior of the MIG/MAG process. Statechart shows all states the system may go through during its life, rather than states described by single scenario.

Each state represents a named condition during the life of an object e.g. slowWelding as 18A on Fig. 4. System stays in the actual state as long as it satisfies needed condition or until it is fired by some event (e.g. change of wire feeding ratio) to other state. A black ball shows a starting state. The end state (if exists) is shown as black ball in a circle. Lines with arrow (Fig. 5) show possible transitions from one state to another one.

Statechart diagram models behaviour of MIG/MAG system and shows all states the object may go through. Each state represents a named condition during the life of an object. It stays in actual state as long as it satisfies some condition or until it is fired by some event to other state. A black ball shows a start state. An end state (if exists) is shown as black ball in a circle. Transitions (lines with arrow) connect the various states on the diagram. Statechart diagram is very useful to verify functionality of more complicated products. Figure 6 presents subsystem for positioning of arc welding gun. This statechart diagram is prepared with Stateflow [5] software in MATLAB environment. If the gun is in “follow welding path” state, the welding wire if fed into gun (do: feed_wire) and gun moves along welding path (do: move_gun). It finishes if end of trajectory is reached. If welding arc die or if welding wire is pinched, actual state transits to “strike_welding_arc” state or to “tear_of_wire” state, respectively. All exit conditions (here: “exit: move_gun(0)” and “exit: feed_wire(0)”) are fulfilled before leaving “follow welding path” state.

Take in Figure (5)

Take in Figure (6)

Conclusion

The paper describes using UML diagrams to describe MIG/MAG welding process with controled voltage current power supply. If special welding power sources are used, e.g. digitally-controlled inverter welding power source capable of complex, high-speed communication, allowing the system components to digitally communicate faster and more reliably than comparable analog-based systems, using UML diagrams to design control strategy is even more useful.

The modern units features the industry's fastest response time for enhanced arc starting and superior arc control, which results in reduced arc spatter, reduced fumes, and exceptionally smooth arc welding performance. The operator may use constant voltage mode or pulse mode of the power source operation.

Preparing UML diagrams is an extra work, comparing with classic design methodology. But time used is not lost. It is not possible to build UML diagrams if there are gaps or inconsistencies in requirements specification. So problems with requirements are identified and corrected on high abstraction level of UML diagrams. Then statechart and activity diagrams are used to verify behaviour of future system against use cases and scenarios. Verification of behaviour is done before more detailed models are prepared (with CAD/CAM,

On the other hand, even little knowledge of UML languages is sufficient to read and understand most of UML diagrams. This gives opportunity to all members of designing staff, regardless of their speciality, to actively cooperate in conceptual phase of design, when subsystems are defined and technology to build them is chosen. This helps to integrate different technologies in the design.

Later CAD/CAM and CAE tools are used in detailed design of subsystems. Parameters from detail design are used in simulation models. Modelica, MATLAB, SIMULINK and other software is used to build models for virtual and HIL (hardware in the loop) simulation. Simulation is used to tune and verify behaviour of designed product on prototyping stage, before its physical model is prepared.

The Unified Modeling Language provides the means to visualize, document and model software applications before coding. It is independent of any programming language that will be used for coding the final application software. UML represents a collection of the best engineering practices that have proven successful in the modeling of large and complex systems. Many successful attempts have been considered to extend the application of UML to areas beyond informatics. The advantage of UML over other systems analysis tools is that, it reveals gaps and inconsistencies in the requirement's specification at very early stages of the design

Using commercially available CASE packages, UML may greatly improve productivity of the design team by cutting down development time and improving final product quality - in accordance with ISO 9000 standards. The next step should be prototyping of MIG/MAG process controller using MATLAB/Simulink/RTW or Modelica/Dymola environment, dSPACE, xPC, FPGA tools or supported microcontroller hardware, as described in [Uhl T, Mrozek Z and Petko M, 2001].

The UML diagram may be used to design and prototype the control system for welding power supply (for constant or pulsed current) and robot arm movement controller. Control engineer will find it helpful to describe behaviour of system states and to map system logic to embedded processor or FPGA chip.The code which is automatically generated during prototyping the system (described with state diagram) may be targeted to embedded processor used in MIG/MAG control system. This code may be produced with StateflowCoder and RTW [5] and other tools from MATLAB environment, linked with digital library modules (as shown in [10]), so actual welding process data may be effectivly used for on-line control of MIG/MAG equipment.

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