Welding equipment with improved digital control

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Abstract: *This paper presents the results of the hardware and software development of a Tungsten-Inert-Gas (TIG) arc-welding equipment. First the attributes and application potentialities of the welding process are summarized in brief, then the requirements are presented which were set at the beginning of the development. Finally we present the realized 80C552 microcontroller based central controlling unit, and give a detailed description of the operation modes.*

Keywords: welding, TIG-welding, digital control, microcontroller

1. Introduction

In this paper we introduce the results of the collective development process which were started in 1997 among the **Budapest Polytechnic - Institute of Automation** (former Kandó Polytechnic - Instiute of Automation) and a well known Hungarian welding equipment manufacturer.

The aim of the development was to shape up welding equipments that are competitive in the world-market.

The above mentioned company and its predecessor has been manufacturing welding equipments for more than three decades. In our collective work, their team was responsible for the weld-technological, the mechanical and the power-electronics design.

At the Budapest Polytechnic - Institute of Automation we have been concerning ourselves for the last three decades within developing and training of microprocessor and microcontroller based controlling units, and has been solving various problems in the field of process-control and automation. In the collective work our team was responsible for the hardware and software design of the microcontroller based central controlling unit.

2. The method of TIG-welding

Gas Tungsten Arc Welding (GTAW) is frequently referred to as TIG (Tungsten Inert Gas) welding. TIG welding is a commonly used high quality welding process. TIG welding has become a popular choice of welding processes when high quality, precision welding is required.

In certain fields of welding TIG is the exclusively used method. It became widely used with the spread of high-alloyed steels (e.g. stainless steels) and light metals which are widely used e.g. in the aircraft-industry.

TIG welding goes for slow welding method, because its melt-down power is low. However faster welding methods could not displace TIG, because of the strength and solidity of the TIG-welded joints. Modern TIG current-sources are capable of generating special current-waveforms. This feature improves the quality of the welded joints, and multiplies the application potentialities.

In TIG welding an arc is formed between a non-consumable tungsten electrode and the metal being welded. Inert or slightly reducing gas is fed through the torch to shield the electrode and the molten weld pool (see Figure 1).

The generally used shielding gas is argon. It has several advantages:

- It is rare-gas, so it does not react with metals, even at high temperatures.
- It prevents from contact between the weld-pool and the atmosphere, thereby there is no oxidation, and alloying is not possible with impurities.
- Its ignition voltage is low, so the arc remains highly stable.

As it mentioned argon is the mostly used shielding gas, although productivity and quality benefits can be gained by using mixtures of argon and helium or argon and hydrogen. Helium is generally added to increase heat input (increase welding speed or weld penetration). Hydrogen will result in cleaner looking welds and also increase heat input however hydrogen may promote porosity.

The TIG welding process may be used on thin sheet material without the addition of a filler metal (autogenous TIG welding). Alternatively, when working on thicker sheet or when joining dissimilar materials, a separate wire filler metal is added into the arc region where it is melted and directed by the welder into the molten weld pool.

TIG welding is suitable for manual, mechanized and automatic (orbital) operation. At manual welding, the operator points the tungsten electrode in the direction of welding and uses the arc to melt the base material along the joint, ahead of the molten weld pool. The filler metal is generally added at the leading edge of the advancing weld pool.

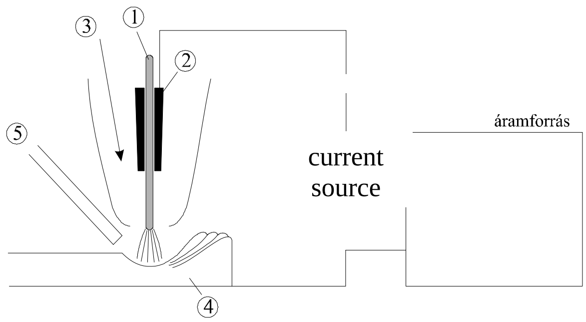

Figure 1

1-Tungseten electrode
2-Gripper of the welding-torch
3-Shielding gas
4-Work-piece
5-Filling-rod

Both Direct Current (DC) and Alternating Current (AC) may be used with TIG welding. The choice is depending upon the type of the material to be welded.

DC welding is used with steel, copper, nickel, titanium, molybdenum and their alloys.

AC is needed for the welding of aluminium and its alloys, magnesium and its alloys and aluminium-bronze. The surface of these metals always contain an oxide-skin, that can only be broken up with alternating polarity because of their much higher melting-point. The frequency of the alternating welding current is 30-200 Hz,

Arc-ignition is usually a special procedure. The conventional contact-type arc-ignition can be used at DC welding, which means that first the tungsten electrode is contacted to the work-piece, then it is pulled away forming the electrical arc. This method cannot be used at AC welding, because the arc blows out in every semiperiod.

At AC welding and in demanding cases of DC welding, the arc is formed with short (1 μs), high-voltage (approx. 5 kV) pulses applied between the electrode and the work-piece. These pulses are capable forming arc in the Argon gas even at the distance of 10-15 millimeters, ionizing the arc core and facilitating the current source to drive current through the arc. At AC welding the high-voltage pulse is necessarily have to be synchronized in phase to the frequency of the current source. This procedure is referred to as high frequency ignition.

TIG welding technology requires the modification of the welding-current suitably to the segments of the welding.

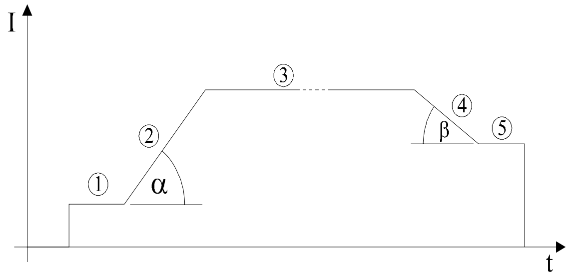

Figure 2

Segments of the welding (see Figure 2):

1: **Start Current.** Its value is usually lower than the welding-current. It facilitates the stable arc-ignition, and precise positioning of the welding-point.

2: **Current upgrade.** The current continuously increases with adjustable slope until it reaches the value of the welding current.

3: **Welding current.** This is the current, that permanently exists, and ensures the acceptable welding quality.

4: **Current downslope.** At the end of the welding procedure an adjustable slope current decrease is needed. Otherwise a crater is formed at the tail of the weld.

5: **Finish current.** Also referred to as crater-filling current. The welder finishes the weld at this phase. Its value is usually lower than the welding-current.

Modern TIG welding equipments are capable of modulating the welding-current. This means that the welding current varies between a higher and a lower value, with adjustable frequency (0.5-5 Hz) and duty cycle (see Figure 3). This method is referred to as slow pulse-welding. This facilitates the easy control of the quality of the weld (welding penetration depth, welding width, amount of the heat-input and rate of the distortions).

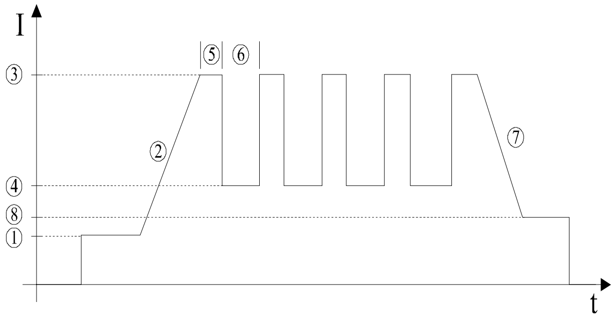

Figure 3

1-Start current
2-Current upgrade
3-Upper welding current
4-Lower welding current
5-Duration of the upper current
6-Duration of the lower current
7-Current downslope
8-Finish current

Modern TIG welding-equipments have to meet the following requirements:

- Continuous adjustment facility of the welding current,
- Both DC and AC operation,
- Both continuous-welding and slow-pulse-welding operation,
- Excellent arc-ignition capability,
- Easy handling and parameter adjustment facility,
- Communication capability between the welder and the welding-equipment (e.g. remote control via the torch),
- Suitability for the conventional Shielded Metal Arc Welding (SMAW), which is among the most widely used welding processes. SMAW is frequently referred to as manual welding, stick welding, consumable electrode welding or covered electrode welding.

These were the main requirements which were set at the beginning of our development. The end-product has been a new, high performance welding equipment family. These types have easy structure and a stable, well-controllable current source, which is improved with an up-to-date digital central controlling unit.

3. Central controlling unit

The control of the technologic process required the evaluation of discrete inputs and outputs as well as analog inputs, and the power stage required a Pulse-Width-Modulated (PWM) drive signal. Considering these requirements, the aim was to set up such microcomputer controlling unit, which can reliably operate even in an industrial environment. Our prior developments confirm, that the PCB 80C552 type of microcontroller manufactured by Philips Semicondutors company is suitable for building industrial microcomputer control units. This microcontroller has several on-chip integrated peripheries. Analog to digital converter, PWM output, asynchronous serial interface, several counters and timers and the well organized interrupt structure jointly facilitate the easy hardware structure and its reliable operation.

Figure 4 shows the simplified block-scheme of the controlling unit.

The Central Processing Unit (CPU) consists of the microcontroller and a program memory, which is expediently an EPROM with 32 kbytes capacity. Address latch is necessary to decouple the address and data signals of the memory.

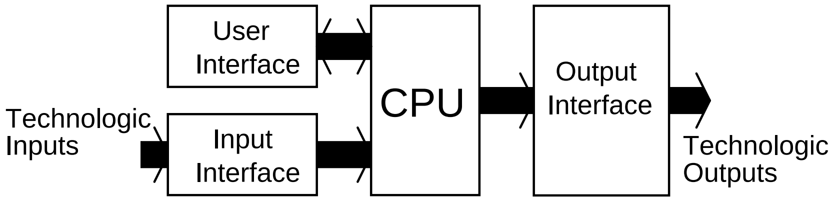

Figure 4

The detailed structure can be investigated on Figure 5, which is extended with the realization of the input and output interfaces.

As can be seen, relatively a few input and output lines are necessary for the control of the welding equipment, so every input and output function could be realized via the ports of the microcontroller, memory mapped peripheries were not required.

The user interface consists of the switches for setting the operation mode and the potentiometers for setting the welding parameters. Selection of the operation mode is available with three pieces of “3 $\rightarrow$ 1” Jacksley-switches that are connected into a 3×3 matrix. Galvanic isolation elements are not used, because these circuits are on the same printed circuit board with the CPU, and pure galvanic isolation is achieved with the plastic cover of the pots and switches.

The microcontroller has only eight analog inputs, but the welding has nine adjustable parameters, so two of the potentiometers are multiplexed into one input of the analog to digital converter.

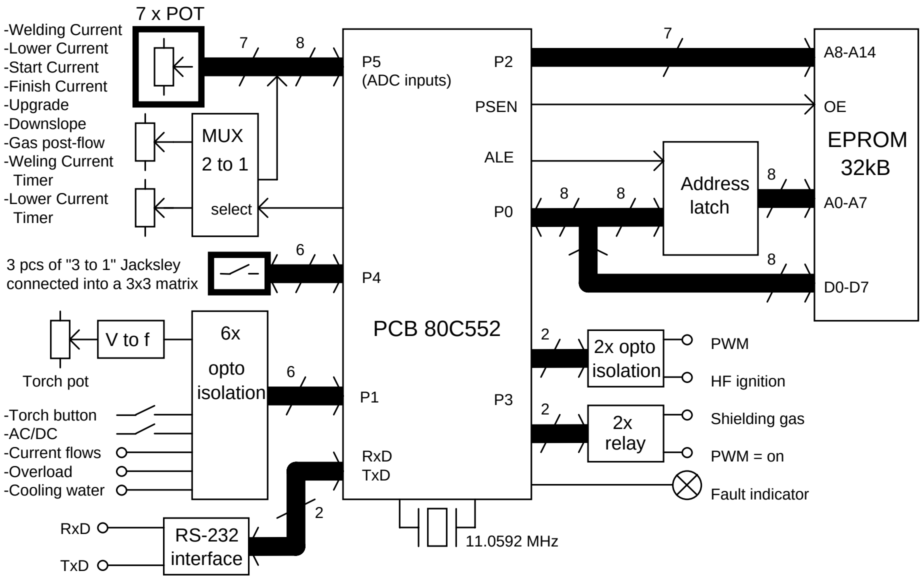

Figure 5

The technologic inputs and outputs of the welding equipment are interfaced to the CPU either via optical isolators or via relays, ensuring the galvanic isolation, meeting the safety regulations

Remote control of the value of the welding current is available via the welding-torch. The signal of the torch-potentiometer is converted to pulses by a Voltage-to-Frequency Converter, and this signal is connected to the counter input of the microcontroller also via galvanic isolation.

The microcomputer unit has an optically isolated asynchronous serial interface as well, meeting the EIA recommended standard RS-232-C. This interface facilitates the using of a standard personal computer for troubleshooting and parameter checking at the first startup and at further check-inspections. The internal software of the welding equipment has a TEST-mode, which does not require any other host software, only a standard RS-232-C terminal, or a PC with a running terminal-emulation software, which can be found either in the prior as well as in the present PC operation system packages.

The test mode facilitates:

- checking the state of the operation mode switches,

- checking the values of the potentiometers,
- checking the state of the technologic inputs,
- and setting the state of the technologic outputs,

4. User Interface

The realized TIG-welding equipment has to be operate in eight different operation modes which will be described later in detail.

Figure 6 shows the control panel of the welding equipment.

The welding method can be selected with the **"TIG/SMAW selector switch":**

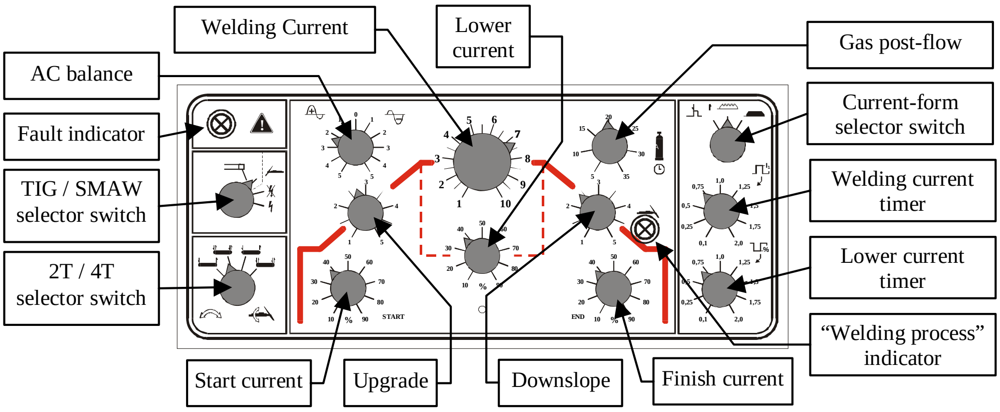

Figure 6

- consumable electrode manual welding (SMAW),
- TIG welding with high frequency ignition,
- TIG welding without high frequency ignition.

The operation of the user-control can be selected with the **"2T/4T selector switch":**

- 2T mode without remote control,
- 4T mode without remote control,
- 2T mode with remote control of the current via the torch pot,
- 4T mode with remote control.

2T mode is called two-tact mode, which means that the welding current flows only when the torch button is kept down. 4T mode is the four-tact mode, which requires a sequence of operation of the torch button. The first push starts, the second stops the current flow.

The form of the welding current can be selected with the **“Current type selector switch”:**

- spot welding,
- continuous welding without modulation,
- continuous welding with slow pulse modulation.

There is an other switch, that is not the part of the Control Panel. This switch selects the current type to either AC or DC. It connects directly to the power stage, and only an accompanying signal is fed into the control unit via an optical isolator. In the case of DC welding the HF ignition can be turned off after the arc is stably formed.

The welding parameters can be set with ten potentiometers, whereof nine connects directly to the control unit, these are:

- **Welding Current pot.** It sets the permanent value of the welding current, or in the case of pulse modulation it sets the higher current value. It has no function when remote control is used.
- **Lower Current pot**. In slow pulse welding it sets the lower current value between 10 and 90 percent of the welding current.
- **Start Current pot.** It sets the start current value between 10 and 90 percent of the welding current.
- **Current Upgrade pot.** It sets the duration of the linearly increasing segment from 1 to 5 seconds.
- **Current Downslope pot.** It functions as the previous one, but it affects the linearly decreasing segment.
- **Finish Current pot.** It sets the finish current value between the 10 and 90 percent of the welding current.
- **Welding Current Timer pot.** It has two functions: at slow pulse welding it sets the duration of the higher current segment (0.1 to 2 seconds), at spot welding it sets the duration of the current flow from 0.5 to 10 seconds (the scale is multiplied by five).
- **Lower Current Timer pot.** It sets the duration of the lower current segment (0.1 to 2 seconds).

- **Gas Post-flow Timer pot.** After the blow-out of the current the shielding gas flows until a specified time, which can be set from 5 to 35 seconds.

The 10th pot sets the **AC balance**, and connects directly to the power stage. Its function is to remove the DC component from the current in the case of AC welding.

5. Technologic I/O

The technologic inputs are (see Figure 4):

- torch button, which gives the start and stop signals,
- signal from the AC/DC selector switch,
- signal from the power stage, indicating if the current flows,
- overload failure signal from the power stage if the internal temperature reaches a critical value,
- signal from the power stage, indicating if the cooling water flows.

The technologic outputs are:

- PWM signal to the power stage,
- high frequency ignition signal,
- signal to the shielding gas injector,
- failure indicator.

6. Operation modes

Mode-1 (see Figure 7)

Consumable electrode manual welding (SMAW) with continuous current. There is no pulse modulation and there is no button on the special torch of the SMAW. Output signals are immediately active after switching the “TIG/SMAW selector switch” into SMAW mode. 2T and 4T mode, and spot-welding do not make sense. Shielding gas and high frequency ignition is not necessary.

If the internal temperature reaches a critical value, and overload failure occurs, then an immediate downslope starts. Restarting is possible after the recovery from the failure with turning the “TIG/SMAW selector switch” into TIG state then back to SMAW state.

Mode-2 (see Figure 8)

Consumable electrode manual welding (SMAW) with slow pulse modulated current. Similar to the previous mode, but the current varies between a preset lower and higher value.

Mode-3 (see Figure 9)

TIG welding with 2T operation and continuous current. Pushing the torch-button starts the shielding gas flow, and after 0.2 seconds of gas pre-flow the other outputs are activated. If the gas is flowing in the moment of pushing the torch-button, then the pre-flow time is zero. The current starts with the “start value”, and increases linearly by the “upgrade value” until reaching the welding current value.

The current turn-off starts with releasing the torch button. It decreases linearly by the “downslope value” until reaching the “finish value”, then blows out.

High frequency ignition is active during the whole AC welding sequence, but it must be turned off after the arc forming in the case of DC welding.

Mode-4 (see Figure 10)

TIG welding with 2T operation with slow pulse modulated current. Similar to the previous mode, but the current varies between a preset lower and higher value.

Mode-5 (see Figure 11)

TIG welding, 2T operation of spot welding. Similar to Mode-3, but the current flows only for a specified time determined by the “welding current timer” potentiometer, then downslope and current turn-off starts. If the operator releases the torch button before the time-out, then an immediate downslope starts.

Mode-6 (see Figure 12)

TIG welding with 4T operation and continuous current. First pushing the torch-button starts the shielding gas flow, and after 0.2 seconds of gas pre-flow the other outputs are activated. The current keeps up the “start value” until releasing the torch button, then increases linearly by the “upgrade value” until reaching the welding current value.

The current turn-off starts with pushing the torch button again. It decreases linearly by the “downslope value” until reaching the “finish value” and keeps up this value until the operator releases the torch button, then blows out.

“Repeat operation” is the specialty of this mode. This means, that the operator has the possibility to change the current from the higher to the lower value or vice versa by pushing the torch button for no longer than 0.2 seconds.

Mode-7 (see Figure 13)

TIG welding with 4T operation and with slow pulse modulated current. Similar to the previous mode, but the current varies between a preset lower and higher value.

“Repeat operation” does not make sense.

Mode-8 (see Figure 14)

TIG welding, 4T operation of spot welding. Similar to Mode-6, but the current flows only for a specified time determined by the “welding current timer” potentiometer, then downslope starts until the finish value. If the operator pushes the torch button again before the time-out, then an immediate downslope starts.

7. Conclusion

This paper summarized the development process whose end-product had been a new, high performance welding equipment family that are competitive in the world-market.

These types have easy structure and a stable, well-controllable current source, which is improved with an up-to-date digital central controlling unit.

After presenting the method of TIG welding, the hardware structure and the operation modes have been discussed.

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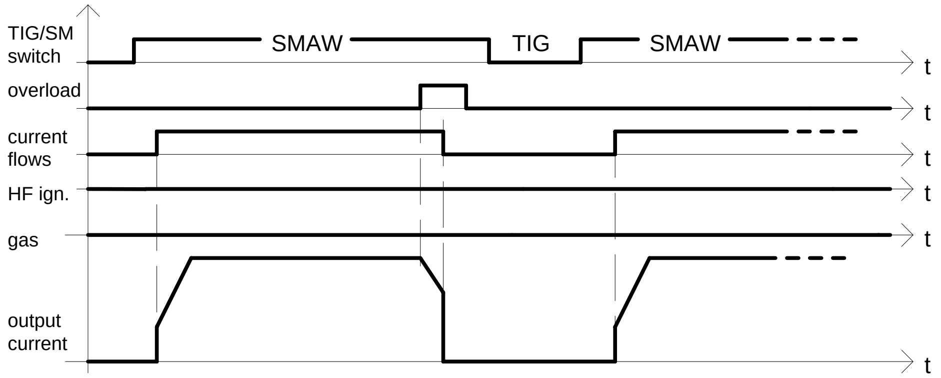

Figure 7 (Mode-1)

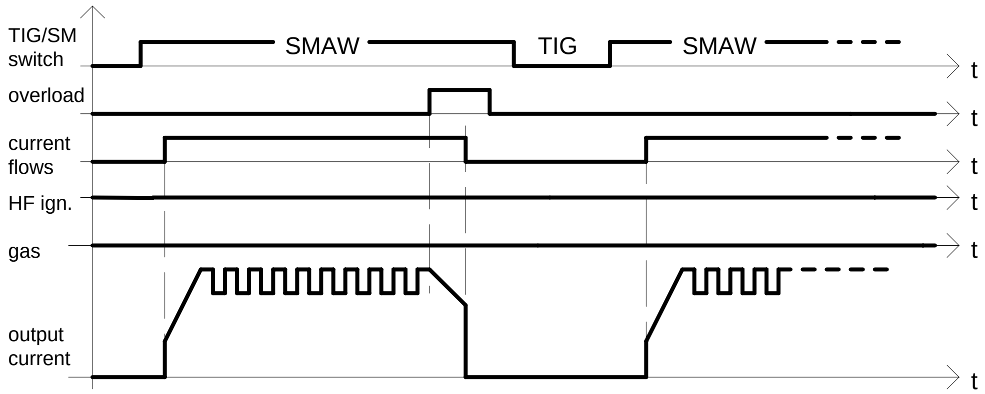

Figure 8 (Mode-2)

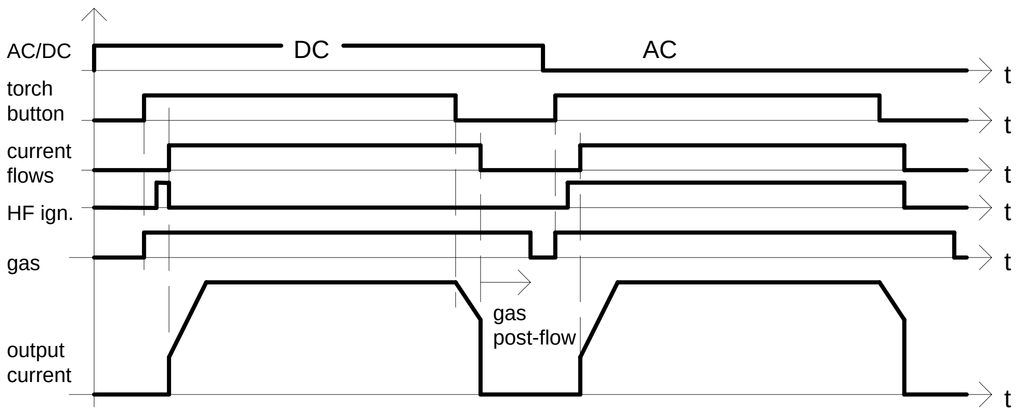

Figure 9 (Mode-3)

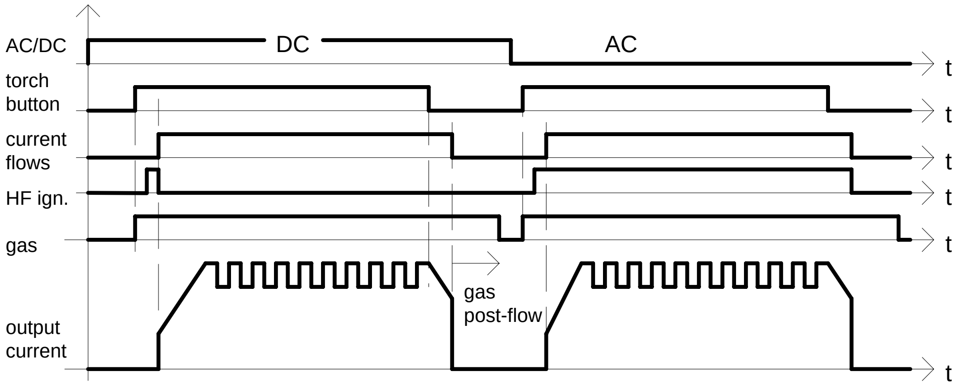

Figure 10 **(Mode-4)**

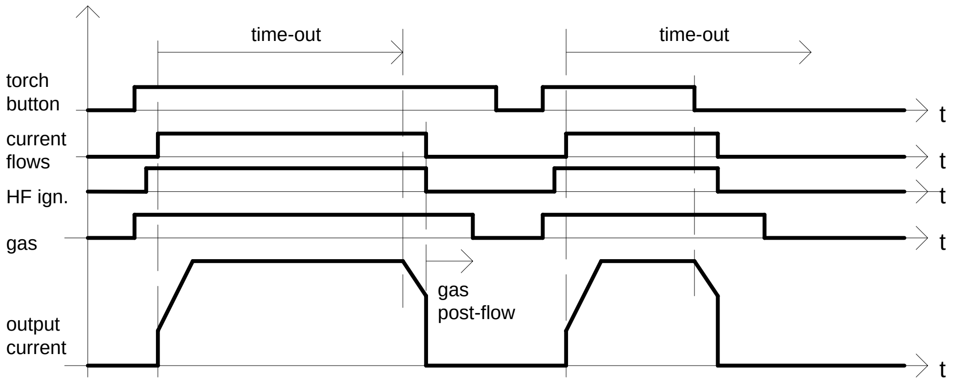

Figure 11 **(Mode-5)**

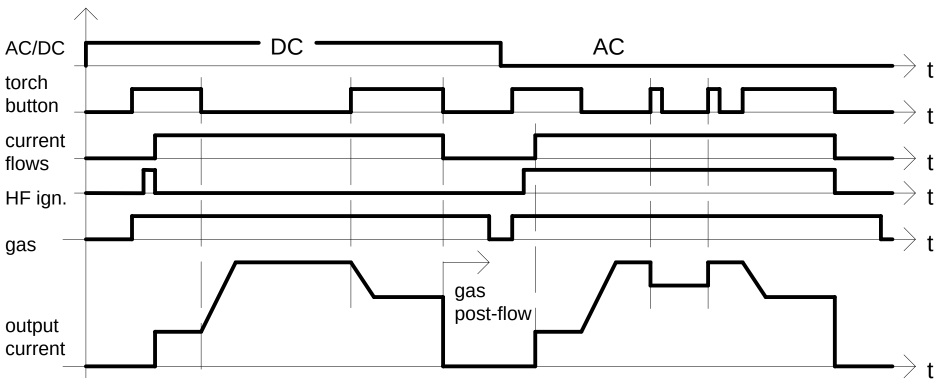

Figure 12 **(Mode-6)**

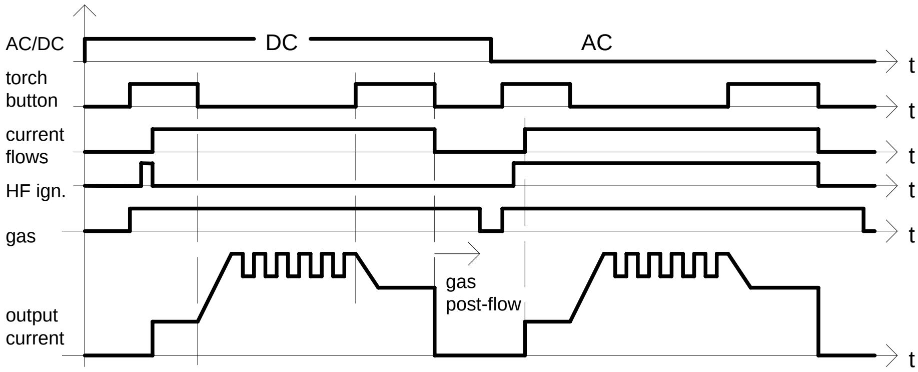

Figure 13 (Mode-7)

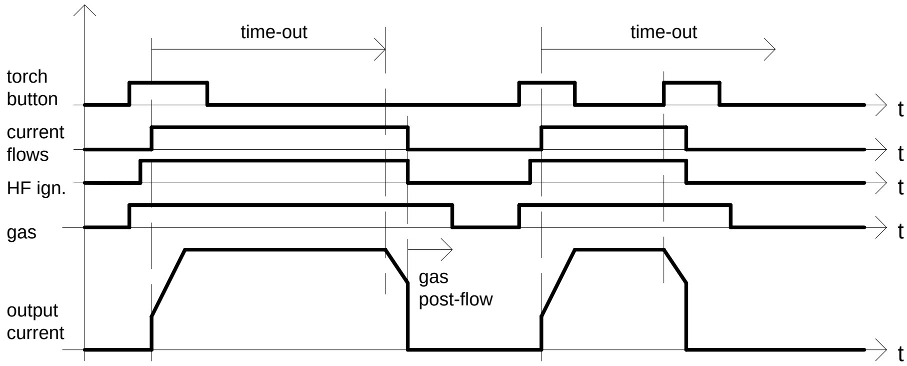

Figure 14 (Mode-8)