



INSTANTANEOUS ENERGY AND POWER.

SIS-ISO/TR 18491:2019

3.1 arc energy

E

product of welding voltage and current divided by travel speed of welding Note 1 to entry: The often-used term “heat input” is more correctly the arc energy modified by an arc efficiency factor.

Review notes made by Swedish group according to 3.1 Arc energy.

Heat input is an established name for Energy divided by length.
Keep that and use the established Q but with index 1 to indicate that it is with the “efficiency factor” 1. E is in general physics used for energy.
Energy divided with something is another entity.
Do not use “Instantaneous energy”. A normal linguistic interpretation of that would rather be power than heat input with Efficiency factor 1 with limited low pass filtering

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3.3

instantaneous energy

IE

welding energy determined by summing the product of current and voltage measurements made at rapid intervals which capture brief changes in the welding waveform

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3.4 instantaneous power

IP

welding power determined by averaging the product of current and voltage measurements made over time at rapid intervals which capture brief changes in the welding waveform

Fact check, see next slide!

IEC Electrotechnical standard. (IEC 60050-)

Symbol p

en

instantaneous power

for a two-terminal element or a two-terminal circuit with terminals A and B, product of the voltage u_{AB} between the terminals and the electric current i in the element or circuit

$$p = u_{AB} \cdot i$$

where u_{AB} is the line integral of the electric field strength from A to B, and where the electric current in the element or circuit is taken positive if its direction is from A to B and negative if its direction is from B to A

Note 1 to entry: The direction of electric current is as defined in [131-11-29](#).

Note 2 to entry: In circuit theory the electric field strength is generally irrotational and thus $u_{AB} = v_A - v_B$, where v_A and v_B are the electric potentials at terminals A and B, respectively.

Note 3 to entry: The coherent SI unit of instantaneous power is watt, W.

IEC electrotechnical standard.

Symbol

p

en

instantaneous power (n -terminal circuit)

sum of the instantaneous powers relative to the $n - 1$ pairs of terminals when one of the terminals is chosen as a common terminal for the pairs

Note – The instantaneous power is independent of the choice of the common terminal.

Examples that are totally wrong, in ISO TR

3.3

instantaneous energy

IE

welding energy determined by summing the product of current and voltage measurements **made at rapid intervals which capture brief changes in the welding waveform**

Fact check: can only be captured by calculating a mean value based on an instantaneous product. (Average)

$$Q = \eta \cdot \frac{1}{v} \cdot \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} u(t) \cdot i(t) dt \approx \eta \cdot \frac{1}{v} \cdot \frac{1}{n} \sum_{t_i}^{t_n} U_{t_i} I_{t_i}$$

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Table 1 — Symbols of terms used

Abbreviations and symbols	Term	Unit
I	Arc welding current	A
L	Length of a run	mm
U	Arc voltage	V
v	Travel speed	mm/s
E	Arc energy	kJ/mm
IE	Instantaneous energy	J
IP	Instantaneous power	J/s

Formula (1) provides the arc energy using arc welding current and arc voltage.

$$E = \frac{U \times I}{v} \times 10^{-3} \quad (1)$$

Formula (2) gives the arc energy using instantaneous energy.

$$E = \frac{IE}{L} \times 10^{-3} \quad (2)$$

Formula (3) gives the arc energy using instantaneous power.

$$E = \frac{IP}{v} \times 10^{-3} \quad (3)$$

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7.4 Instantaneous energy or instantaneous power

Measurement of instantaneous energy or instantaneous power should utilize a welding power source or external meter that is capable of calculating and displaying energy or power. Both the sampling rate and the calculation rate should be sufficient to capture the changes in the welding waveform (typically, a sampling rate at least 10 times the frequency of the wave form is used). When using external meters, the same guidelines as 7.2 and 7.3 apply. These meters are often identified by the terms “true energy”, “true power”, or “power factor”. Meters identified by the terms “kVA”, “DC power”, or “average power” do not generally meet these requirements.

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7.2 Arc voltage

The voltage values should be measured as close to the arc as practical in order to prevent the measurement error due to voltage drop in the welding cables.

NOTE The voltage measurement is affected by cable size, length, and connection quality and has to be taken into account during measurement.

The position of the connectors shall be recorded in the WPQR to provide consistency of the measurement during production. The first one should be connected to the earth clamp on the work piece and the second one should be connected as described in Table 2.

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7.3 Welding current

Measure the welding current using a shunt or a clamp meter on a straight portion of the welding cable. The current measurement should include all earth-connection cables or current lead cables, if multiple earth-connection cables or current lead cables are used. It is inaccurate to measure the current intensity on a single cable and multiply by the total number of cables, or to mix the earth-connection cables and current lead cables in one measurement.

For measurements of arc welding current below the recommended range of the clamp meter, the cable may be looped through the clamp, in which case the measured value is divided by the number of loops.

Internal discussions regarding use of the nomenclature “instantaneous”

A large, red, hand-drawn style 'X' is superimposed over the word "instantaneous".

instantaneous

A red octagonal stop sign with a black border. The text is white and centered.

Stop
use the
“ i “
word

Chat GBT Ai

Instantaneous power is the power at any given moment in time.

In an AC or DC circuit, it is defined as the product of instantaneous voltage and instantaneous current through the element ¹.

The formula for instantaneous power is $p = v \times i$, where p is the instantaneous power, v is the instantaneous voltage, and i is the instantaneous current ¹.

The instantaneous power changes with time since the values of instantaneous voltage and instantaneous current change from instant to instant ¹.

The unit of measurement for instantaneous power is watts ¹.

Average power, on the other hand, is defined as the average of instantaneous power over one cycle ¹.

It is measured in watts and denoted by upper case letter P ¹. The formula for average power is $P = \frac{1}{2\pi} \int_0^{2\pi} p d\omega t$, where p is the instantaneous power and $d\omega t$ is an infinitesimal element of time ¹

Chat GBT Ai

Instantaneous energy is the time rate of flow of energy past a given point of an electric circuit ¹. In alternating current circuits or direct current with variations, energy storage elements such as inductors and capacitors may result in periodic reversals of the direction of energy flow ¹. The SI unit for instantaneous power is the watt ¹

Ai source 1 Wikipedia.org, 2 IEC electrotechnical Vocabulary, 3 thespruce.com, 4 khanacademy.org, 5 Si units.org

The Swerim paper-report

Definitions

Symbol	Term	Unit	Waveform	Illustration	Arithmetic mean (rectified)	Root mean square
I	Current	A	Constant		a	a
U	Voltage	V	Sinus		0,637 · a	0,707 · a
i(t) and u(t)	Instantaneous values	A and V	Square edge		a	a
v	Welding speed	mm/s	Triangular		0,5 · a	0,577 · a
Q	Heat input in welding	kJ/mm	Sawtooth		0,5 · a	0,577 · a
P	Real power	W or J/s				
S	Apparent power (= $U_{RMS} \cdot I_{RMS}$)	VA				
There are different ways to calculate the mean values for current, voltage and heat input*:						
<i>Arithmetic mean value</i>		The arithmetic mean value of current or voltage is calculated based on averaging (rectified) instantaneous values of current. Similar for voltage. Meters can be either analogue or digital.				
		$I_m = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} i(t) dt \approx \frac{1}{n} \sum_{t_1}^{t_n} I_{t_i} = \frac{ I_{t_1} + I_{t_2} + I_{t_3} + \dots + I_{t_n} }{n}$				
<i>Root mean square</i>		The true Root Mean Square (RMS) is calculated based on the root of the averaging of the square of instantaneous values of current. RMS calculates the equivalent direct current (DC) value of an AC waveform, i.e. the equivalent DC current that would correspond to the same heating on the same load. This mean value is therefore sometimes called the effective value. Indicated RMS is based on the arithmetic mean but multiplied with a factor depending on wave shape (for sinus wave the factor is 1.11)				
		$I_{RMS} = \sqrt{\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} i^2(t) dt} \approx \sqrt{\frac{1}{n} \sum_{t_1}^{t_n} I_{t_i}^2} = \sqrt{\frac{I_{t_1}^2 + I_{t_2}^2 + I_{t_3}^2 + \dots + I_{t_n}^2}{n}}$				

The Swerim paper-report

Heat input

The heat input is based on the arc power divided with the travel speed (this is the same as arc energy per weld length) multiplied with an arc efficiency factor.

The most correct way to calculate the heat input is based on instantaneous values of current and voltage. Use of instantaneous values is important especially when the shape of current and voltage varies with time such as in short arc welding, pulsed arc welding or any other controlled waveforms.

In TR 18491 the heat input can also be calculated based on arithmetic mean values of current and voltage but only if the current and voltage are fairly constant (as in TIG welding or MIG/MAG welding using spray arc).

Heat input based on instantaneous values

$$Q = \eta \cdot \frac{1}{v} \cdot \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} u(t) \cdot i(t) dt \approx \eta \cdot \frac{1}{v} \cdot \frac{1}{n} \sum_{t_i}^{t_n} U_{t_i} I_{t_i}$$

Heat input based on arithmetic mean values

$$Q = \eta \frac{U_m \cdot I_m}{v}$$

** Since most modern measuring devices uses analogue to digital converters, calculations are expressed as sums rather than integrals. For high accuracy in measurements the sampling frequency should be at least 10 times the highest frequency in the measured arc signals.*

Example deviation according to the Swerim paper-report

Example of deviation between arithmetic and root mean square measurements

Table 1: Example of deviation between different ways to calculate the average values in MAG and SAW welding

	Current			Voltage			Arc power				
	Mean*	RMS	Diff*	Mean*	RMS	Diff*	Inst*	IxU of Mean	Diff Mean to Inst	IxU of RMS	Diff RMS to Inst
	A	A	%	V	V	%	kW	kW	%	kW	%
MIG/MAG											
Short arc	121	130	7	19.1	19.8	4	2.27	2.32	2	2.52	14
Pulsed arc	85	149	75	24.2	25.0	3	2.77	2.05	-26	3.72	34
Spray arc	185	186	1	30.2	30.3	0	5.59	5.60	0	5.64	1
SAW											
DC+	706	707	0	27.2	27.2	0	19.17	19.20	0	19.23	0
Balanced AC	464	485	5	30.5	31.0	2	14.13	14.14	0	15.01	6
Unbalanced AC 75% +2V	726	754	4	32.9	33.2	1	24.44	23.90	-2	25.03	2

* "Mean" refers to arithmetic mean, "Diff" is the difference between RMS and mean

What shall be done!?

Do it again and do it right!