

New Code Requirements for Calculating Heat Input

Welders, inspectors, and engineers should be aware of the changes to QW-409.1 of ASME IX regarding waveform-controlled welding

BY TERESA MELFI

Welding waveforms are used to limit distortion, weld open roots, and to control HAZ properties. Waveform control is essential for common processes like uphill GMA pulse welding. Power sources that support pulsing (GMAW-P, GTAW-P, etc.) are the most common waveform-controlled power sources. Those marketed as synergic, programmable, or microprocessor-controlled are also likely to support waveform-controlled welding.

The correlation between heat input and mechanical properties is blurred when heat input is calculated using current and voltage readings from conventional meters. This includes external meters and even those located on the welding power source. It's not that the meters are incorrect — in fact, most are calibrated and tested to NIST standards. Rather, the inaccuracy involves the means of capturing and displaying the data.

Conventional DC meters display average voltage and average current. Conventional AC meters display RMS values. To accurately indicate the energy input to a weld, the voltage and current readings must be multiplied together at very rapid intervals that will capture brief changes in the welding waveforms. This frequency is in the order of magnitude of 10,000 times per second. Specialized meters are required to accomplish this.

Revisions to ASME Section IX provide a new method of calculating heat input that allows comparison of the heat input from various welding power sources and various welding waveforms. This will allow production welding to take place with a welding procedure specification (WPS) that specifies either conventional or waveform-controlled welding, which is sup-

ported by a procedure qualification record (PQR) using either conventional or waveform-controlled welding.

Calculating Heat Input

Many welding codes use the equation shown in Equation 1 to calculate heat input. Because the welding process (GMAW, SAW, etc.) is an essential variable, a process or efficiency factor is not included in the heat input calculation. The new equations that will be in the 2010 edition of ASME Section IX are shown in Equations 2 and 3, either of which gives equivalent results. Both equations are shown because some welding power sources and meters display energy values, and others display power values.

$$\frac{\text{Voltage} \times \text{Amperage} \times 60}{\text{Travel Speed (in./min or mm/min)}}$$

Equation 1: Traditional heat input equation, ASME Section IX QW-409.1 (a).

$$\frac{\text{Energy (Joules)}}{\text{Weld Bead Length (in. or mm)}}$$

Equation 2: New heat input equation for meters displaying energy measurement (Joules), ASME Section IX QW-409.1 (c)(1).

$$\frac{\text{Power (Joules/s)} \times \text{Arc Time (s)}}{\text{Weld Bead Length (in. or mm)}}$$

Equation 3: New heat input equation for meters displaying power measurement (Joules/s or W), ASME Section IX QW-409.1 (c)(2).

Three examples from GMA welding are shown in Fig. 1. The axial spray waveforms are essentially constant, and the difference between the measurement methods is minimal. For the two waveform-controlled procedures, there is an error between the measurement methods that can be in a positive or negative direction. It is clear from the significant differences why a new measurement method is needed.

Changes in ASME Section IX

ASME codes and standards have a long history, now in their 125th year. The rules for welding were removed from the construction codes when ASME Section IX was published in 1941. ASME Section IX has become a global standard, referenced by the ASME construction codes, owners, engineering firms, and other fabrication and construction codes.

The ASME IX Standards Committee has subcommittees that address procedure and performance qualifications, materials, general requirements, and brazing. More than three years ago, a task group was formed to work on issues surrounding welding with complex waveforms from microprocessor-controlled power sources. The first result of this group's work will be a change to the measurement and calculation method for heat input.

QW409.1 is the main Section IX variable that deals with heat input. Currently, there are two ways to calculate heat input. Method (a) is the traditional heat input equation shown in Equation 1. Method (b) is a measurement of the volume of

TERESA MELFI is with The Lincoln Electric Co., Cleveland, Ohio. She is chair of the AWS A5B Committee on submerged arc welding, a member of the AWS A5 Committee on filler metal specifications, a member of ASME Section IX, including the materials subgroup and a working group on advanced waveform welding, and is the U.S. delegate to the International Institute of Welding commission that covers pressure vessels, boilers, and pipelines.

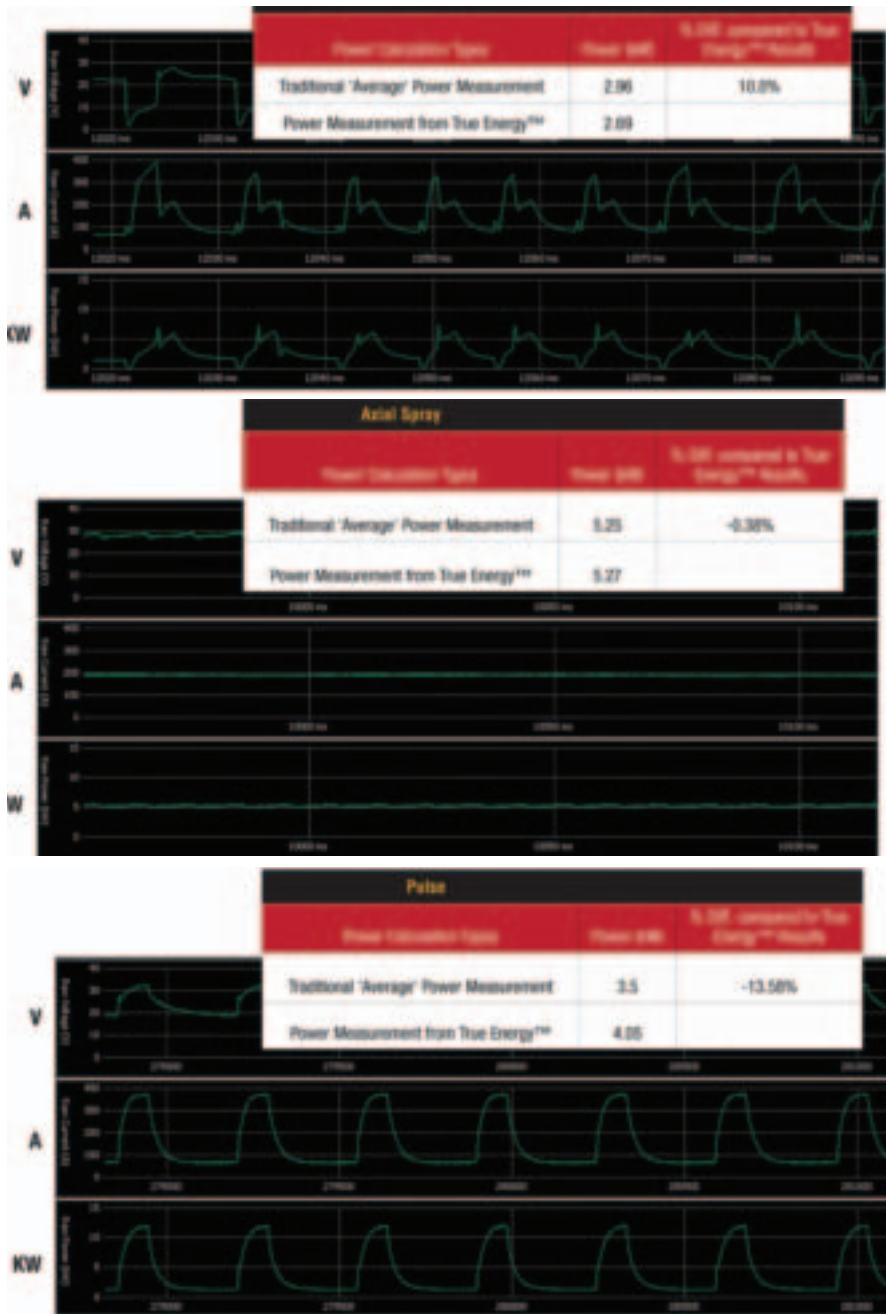


Fig. 1 — Heat input differences calculated using Equation 1 vs. Equation 2.

weld metal deposited. A new method (c) is added in the 2010 edition, which includes Equations 2 and 3.

Any of the methods can be used when welding following procedures that are not waveform controlled. When welding following waveform-controlled procedures, only methods (b) or (c) are permitted. With these methods, it is possible to determine the compliance of a production weld made using a waveform-controlled welding procedure to an existing qualified procedure, even when the procedure qualification was performed using nonwaveform controlled welding. An appendix to ASME Section IX has been provided to

guide users through these code changes. The appendix provides guidance with new procedure qualifications, existing qualified procedures, and comparing heat inputs between waveform-controlled and nonwaveform-controlled welding. ASME Section IX does not mandate separate performance qualifications for waveform-controlled welding.

How to Comply with ASME Code Changes

To use method (c) of the code, a reading of energy (Joules) or power (Joules/s)



Fig. 2 — With the proper software installed, access to the energy reading entails pressing the menu option “Display Energy.”



Fig. 3 — The real-time energy is continuously incremented while welding, and the final energy is displayed until the next arc start.

must be obtained using a meter that captures the brief changes in a welding waveform and filters out extraneous noise. The simplest place to obtain this is from the welding power source. Many power sources that output pulsing waveforms will display these readings, although some might require software upgrades to enable this. Details and software upgrades for Lincoln Electric’s Powerwave “M” series and several other models are available free of charge at www.powerwave

Assist Chart for ASME IX QW-409.

PQR qualified with:	Qualifies for welds produced with:
Non-waveform controlled welding using conventional volt and ammeters and QW-409.1(a)	<ul style="list-style-type: none"> • Non-waveform controlled power supply using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c).
Non-waveform controlled welding using instantaneous energy or power and QW-409.1(c)	<ul style="list-style-type: none"> • Non-waveform controlled power supply using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c).
Waveform controlled welding using instantaneous energy or power and QW-409.1(c)	<ul style="list-style-type: none"> • Non-waveform controlled power supply using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c).
Waveform controlled welding using conventional volt and ammeters and QW-409.1(a) (qualified prior to 2010 code change)	<ul style="list-style-type: none"> • Non-waveform controlled power supply using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled power supply which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c). <p>Note: In some cases, it might benefit the user to append a PQR to show the heat input calculated using instantaneous power or energy. This can be done by welding a simple bead on plate using the same parameters (mode or program, voltage, current, etc) as were used in the procedure qualification. Utilizing either a welding power source or external meter that displays instantaneous energy or power, the heat input may be calculated per QW-409.1(c) based on those readings.</p>



Fig. 4 — The heat input is calculated by taking the final energy value and dividing it by the length of the weld.

software.com. For a power source that doesn't support the display of energy or power, external meters are available. A meter with demonstrated accuracy in this application is the Fluke® 345 Power Quality Clamp Meter.

With the proper software installed, it is simple to access the energy reading — Fig. 2. In the setup menu, enable the option to “Display Energy.” When an arc is started, the energy value will begin to increment. The value will continue to increase, showing the real-time energy put

into that weld — Fig. 3. When the welding stops, the final energy value will be displayed until welding resumes again. This value represents the amount of energy that went into that weld, from arc start to arc stop.

To calculate the heat input, the final value is simply divided by the length of the weld — Fig. 4. In this case, the heat input would be 22.3 kJ/3.6 in., or 6.2 kJ/in.

A detailed matrix has been developed showing how a PQR qualified with either waveform or nonwaveform-controlled

welding may be used to support welding with waveform or nonwaveform-controlled procedures and QW-409.1(a) or QW-409.1(c). This can be downloaded from www.lincolnelectric.com.

Summary

The ASME Section IX welding and brazing standard is widely used by public agencies and private companies concerned about the safety and integrity of welds. Just as specifications change when new materials are developed, ASME Section IX has changed to recognize modern welding waveforms. The changes involve the measurement of energy or power made at very rapid intervals, and the use of these to calculate heat input. These code changes establish the relationship between heat input across a range of power sources and welding waveforms.

Welders, inspectors, and engineers should be aware of the new ways to calculate heat input. While no code can guarantee good workmanship, these changes make it easier for welders to use waveforms that help improve their welds. The new method will allow flexibility in the way one compares the heat input used in procedure qualification and in production welding. ♦

QW-408.12 A change of more than 5% in the flow rate of one or more of the following: shielding gas, trailer shielding gas, backing gas, and plasma-removing gas.

QW-408.13 A change in the position or orientation of plasma-removing gas jet relative to the workpiece (e.g., coaxial transverse to beam).

QW-408.14 A change in the oxygen or fuel gas pressure beyond the range qualified.

QW-408.16 A change of more than 5% in the flow rate of the plasma-arc gas or powdered metal feed gas recorded on the PQR.

QW-408.17 A change in the plasma-arc gas, shielding gas, or powdered metal feed gas from a single gas to any other single gas, or to a mixture of gases, or vice versa.

QW-408.18 A change of more than 10% in the gas mixture composition of the plasma-arc gas, shielding gas, or powdered metal feed gas recorded on the PQR.

QW-408.19 A change in the nominal composition of the powder feed gas or (plasma-arc spray) plasma gas qualified.

QW-408.20 A change of more than 5% in the plasma gas flow rate range qualified.

QW-408.21 A change in the flow rate of the orifice or shielding gas.

QW-408.22 A change in the shielding gas type, gas pressure, or purging time.

QW-408.23 For titanium, zirconium, and their alloys, the deletion of one or more of the following:

- (a) shielding gas
- (b) trailing shielding gas
- (c) backing gas

QW-408.24 For gas-shielded processes, the maximum moisture content (dew point) of the shielding gas. Moisture control may be by specification of shielding gas classifications in SFA-5.32.

QW-409 Electrical Characteristics

(10) **QW-409.1** An increase in heat input, or an increase in volume of weld metal deposited per unit length of weld, over that qualified. The increase shall be determined by (a), (b), or (c) for nonwaveform controlled welding, or by (b) or (c) for waveform controlled welding. See Nonmandatory Appendix H.

(a) Heat input [J/in. (J/mm)]

$$= \frac{\text{Voltage} \times \text{Amperage} \times 60}{\text{Travel Speed [in./min (mm/min)]}}$$

(b) Volume of weld metal measured by

(1) an increase in bead size (width × thickness), or

(2) a decrease in length of weld bead per unit length of electrode

(c) Heat input determined using instantaneous energy or power by

(1) for instantaneous energy measurements in joules (J)

Heat input [J/in. (J/mm)]

$$= \frac{\text{Energy (J)}}{\text{Weld Bead Length [in. (mm)]}} \quad \text{[in. (mm)]}$$

(2) for instantaneous power measurements in joules per second (J/s) or Watts (W)

Heat input [J/in. (J/mm)]

$$= \frac{\text{Power (J/s or W)} \times \text{arc time (s)}}{\text{Weld Bead Length [in. (mm)]}} \quad \text{[in. (mm)]}$$

The requirement for measuring the heat input or volume of deposited weld metal does not apply when the WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic or P-No. 10H material is solution annealed after welding.

QW-409.2 A change from spray arc, globular arc, or pulsating arc to short circuiting arc, or vice versa.

QW-409.3 The addition or deletion of pulsing current to dc power source.

QW-409.4 A change from AC to DC, or vice versa; and in DC welding, a change from electrode negative (straight polarity) to electrode positive (reverse polarity), or vice versa.

QW-409.5 A change of ±15% from the amperage or voltage ranges in the qualified WPS.

QW-409.6 A change in the beam current of more than ±5%, voltage of more than ±2%, welding speed of more than ±2%, beam focus current of more than ±5%, gun-to-work distance of more than ±5%, or a change in oscillation length or width of more than ±20% from those previously qualified.

QW-409.7 Any change in the beam pulsing frequency duration from that qualified.

QW-409.8 A change in the range of amperage, or except for SMAW GTAW or waveform controlled welding, a change in the range of voltage. A change in the range of electrode wire feed speed may be used as an alternative to amperage. See Nonmandatory Appendix H. (10)

QW-409.9 A change in the arc timing of more than ±1/10 sec.

QW-409.10 A change in amperage of more than ±10%.

QW-409.11 A change in the power source from one model to another.

PQR qualified with:	Qualifies for welds produced with:
<p>Non-waveform controlled welding using conventional volt and ammeters and QW-409.1(a)</p>	<ul style="list-style-type: none"> • Non-waveform controlled welding procedure using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c).
<p>Non-waveform controlled welding using instantaneous energy or power and QW-409.1(c)</p>	<ul style="list-style-type: none"> • Non-waveform controlled welding procedure using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c).
<p>Waveform controlled welding using instantaneous energy or power and QW-409.1(c)</p>	<ul style="list-style-type: none"> • Non-waveform controlled welding procedure using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c).
<p>Waveform controlled welding using conventional volt and ammeters and QW-409.1(a) (qualified prior to 2010 code change)</p>	<ul style="list-style-type: none"> • Non-waveform controlled welding procedure using conventional volt meters and ammeters and QW-409.1(a). • Non-waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure displaying instantaneous energy or power measurement and QW-409.1(c). • Waveform controlled welding procedure which does not display instantaneous energy or power measurement using external meters that display instantaneous power or energy measurements and QW-409.1(c). <p>Note: <i>In some cases, it might benefit the user to append a PQR to show the heat input calculated using instantaneous power or energy. This can be done by welding a simple bead on plate using the same parameters (mode or program, voltage, current, etc) as were used in the procedure qualification. Utilizing either a welding power source or external meter that displays instantaneous energy or power, the heat input may be calculated per QW-409.1(c) based on those readings.</i></p>