An Approach to Best Welding Practice : Part – XVII

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"AN APPROACH TO BEST WELDING PRACTICE: Part XVII" is the Seventeenth Detail Part of **"AN APPROACH TO BEST WELDING PRACTICE"** which was written as a General and Overall approach to the subject matter.

AN APPROACH TO BEST WELDING PRACTICE: Part XVII is particularly focused on the Process Quality Aspects by using Selected Key Indices, calculating the values of the Indices for different Joint Profiles, setting up upper and lower limits for acceptance, monitoring and controlling to ensure desired Process Quality. In fact, this is a lengthy process to develop and as each and every step is connected with each other for cross references, none can be eliminated. I have divided it into four distinct Parts

I. WELDING PROCESS QUALITY / WELDING PROCESS EFFICIENCY

- Parameters,
- Basic Influencing Factors
- Data – Tables, Charts

II. WELD DEPOSITION / CALCULATION OF WELD VOLUME

- Geometrical Configurations of weld Sections
- Formula and Calculations
- Weld Metal Deposition by Different Processes

III. COMPUTERIZED DATA PROCESSING

- Use of Excel Format for Data Storage
- Formulae and Calculations

IV. STATISTICAL PROCESS CONTROL

- Deciding Control Parameters
- Deciding Upper and Lower Control Limits
- Procedure to collect Process Data
- Calculations for Validation

This is a Working Guideline for Planning Engineers, Welding Co-ordinators, Quality Managers and Inspectors working in an Engineering Fabrication Plant using welding as the main manufacturing process.

WELDING PROCESS QUALITY / WELDING PROCESS EFFICIENCY

- Parameters,
- Basic Influencing Factors
- Data – Tables, Charts

PROCESS QUALITY IN WELDING

- QUALITY IS THE CUSTOMER SATISFACTION ACHIEVED THROUGH PRODUCT FEATURES AND FREEDOM FROM DEFICIENCIES – J.M. JURAN
- QUALITY IS THE FITNESS FOR USE OR PURPOSE - J.M. JURAN.
- CONFORMANCE TO PRODUCT SPECIFICATIONS – EDWARD DEMING

An Analytical Approach to Quality of Product and Process

In welded fabrication, manufacturing industries, the general term quality refers to the two complementary categories of quality of design and quality of conformance. Whereas quality of design focuses on how the product design meets consumer requirements, quality of conformance is concerned with whether the quality produced and provided to the consumer meets the intended design. Improving produced quality of conformance via defect prevention and improving quality of conformance delivered to the customer via inspection.

All manufacturing processes are imperfect and have an associated non-conformance rate. Manufacturers seeking to achieve higher quality of conformance have a wide range of options to choose from. It is again a matter of concern whether the selected process can produce the desired effects of Product Quality and at the same time with minimum cost comparative to other processes. Of course, if the Process Quality can be measured and monitored effectively then such apprehensions can be minimized.

There can be two methods of achieving these two objectives:

- improving Product Quality of conformance via defect prevention; and
- improving Quality of Process Conformance.

A number of Indices can be designed to measure and monitor Process Quality. Again, such indices will depend upon other factors which are also to be measured and monitored for optimum values. The Critical Indices with the formula for calculations are listed in **Table 1**.

Table 1 : Indices for determination of Welding Process and Product Quality

SL. NO.	INDEX	FORMULA
1	Penetration index	PI = (p / t) x 100 [%]
2	Convexity index	CI = (r / w) x 100 [%]
3	Spattering index	SI = (S / Dr) x 100 [%]
4	Spattering rate	S = (Felect or Fwire) - Dr
5	Deposition rate	Dr = 3.6 x (Mfcp - Micp) / tarc
6	Deposition efficiency	De = Dr / (Felect or Fwire) x 100 [%]
7	Electrode feed rate	felect = 3.6 x (Miel - Mfel) / tarc.
8	Wire feed rate	fwire = 60 x (p xø2xfwirex ?) / 4

Where:

1. p = the weld penetration [mm],
2. t = joint thickness [mm],
3. r = bead reinforcement [mm],
4. w = bead width [mm],
5. S= spattering rate [kg/h],
6. Dr = deposition rate [kg/h],
7. Felect = covered electrode fusion rate [kg/h],
8. felect = wire feed rate [m/min],
9. Miel = initial mass of the covered electrode, before welding [g],
10. Mfel = final mass of the covered electrode, after welding [g],
11. tarc = arc duration time [s],
12. Fwire= wire fusion rate [kg/h],
13. Ø = wire diameter [mm],
14. fwire =wire feed rate [m/min],
15. r = steel density (7.85 x 10-3 g/mm^3),
16. Mfcp = final mass of the test plate, after welding [g],
17. Micp = initial mass of the test plate, before welding [g] and
18. De = deposition efficiency [%].

(Ref : Arc Welding Process Selection through a Quality and Costs, Ashish Thakur, Hagos Gebrelibanos and Tadesse Gabrey)

Establishing the validity of such indices require experimentation and tabulation of Primary and Secondary Data over a wide range of joints welded through commonly used welding processes on a widely used base metal. But, before analyzing each Index for their utility the contributing factors for optimum values need discussing.

The System based Contributing Factors are :

I. Current Density

II. Electrode Efficiency

III. Shielding Gases

IV. Electrode Extension and Contact Tip to Work Distance (CTOD)

V. Operating Factor.

I. CURRENT DENSITY

Current density is defined as the ratio of current employed with a particular electrode diameter by its current carrying cross-sectional area. It varies with the wire feed speed. If the wire feed speed is low, then the current density will be low, and vice versa. From this basic fact it can be concluded that:

- In the short-circuit mode of metal transfer lower current density is applied to a given electrode.
- In globular, axial spray transfer or the more advanced pulsed spray metal higher current density is associated with the higher energy modes of metal transfer. Once the current for a given GMAW solid or metal-cored electrode will reach a maximum density level no additional current can be carried by the electrode. In other words, the electrode has reached its maximum current density.

This phenomenon is shown for 0.035” (0.9 mm) diameter solid wire in the Graphs (**Fig. 1**) above. It can be seen that the

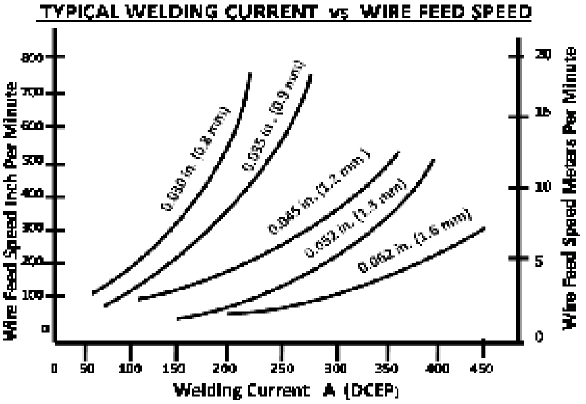

Fig. 1

current is relatively linear up to approximately 200 ampere, but as the current reaches just beyond 210 ampere, the rise in current becomes exponential. At approximately 280 ampere [720 ipm (18.3 M/min.) wire feed speed], the electrode reaches its maximum current density. The electrode at this point becomes saturated with current and no more current can be added to the electrode. The maximum current density for a given electrode diameter is same as the concept of current saturation.

This is applicable to all diameters and material types of electrodes used for GMAW. Once the electrode reaches its maximum current density, the saturation point, any added wire feed speed will provide a higher deposition rate with no increase in current.

II. ELECTRODE EFFICIENCY

Electrode efficiency is ratio of the weight of electrode that actually ends up in the weld deposit to the original weight of the electrode expressed as a percentage. Spatter levels, smoke, and slag formers affect the electrode efficiency in GMAW.

- GMAW-S, short-circuit transfer, shielded with an argon + CO_2 gas blend, will typically operate with an electrode efficiency equal to or greater than 93%. Shielded by 100% CO_2, the electrode efficiency will range from 90 to 93%. Typically, CO_2 increases spatter levels to some extent, and argon blends are typically useful in reducing, but not completely eliminating, spatter.
- STT, a dynamically controlled form of GMAW-S, will attain electrode efficiencies of 98% .
- Globular transfer is associated with higher spatter levels that affect electrode efficiency. The efficiency of globular transfer can vary from 85 to 88%, when shielded with 100% CO_2. Under argon blends the efficiency may vary from 88 to 90%.
- Axial spray has a higher electrode efficiency. This higher energy mode of metal transfer is associated with electrode efficiencies of 98%.
- The electrode efficiency for GMAW-P varies depending upon the welding application and the sophistication of the power source. Generally, the efficiency factor applied for GMAW-P is 98%, like that for axial spray, but there may be the need for a higher travel speed application that requires shorter arc lengths. High speed pulsed spray transfer types of applications generally introduce higher spatter levels. This necessarily reduces the electrode efficiency to some lower value.

As an example. If 100 lbs. (45 kg) of 0.035" (0.9 mm) diameter electrode is used on a particular job with GMAW-S process, then the effective amount of electrode that will be expected to end up in the welds will be:

EE x (lbs. Electrode)
= 0.93 x 100 lbs.
= 93 lbs.

NOTE: The calculation assumes no loss of material due to wire clipping.

III. EFFECTS OF SHIELDING GASES ON GMAW PROCESS

Shielding gases respond in different ways under the heat of the arc. The flow of current in the arc and its magnitude has a profound effect on the behavior of the transferred molten droplet. Three basic criteria are useful to understand the behavior and the properties of shielding gas:

- The chemical reactivity of the shielding gas with the molten weld puddle
- Ionization potential of the gases used.
- Thermal conductivity of the shielding gases used.

Inert Shielding Gases

Argon and helium are the two inert shielding gases used for protecting the molten weld pool. In order to become a conductive gas, that is, a plasma, the gas must be ionized. Different gases require different amounts of energy to ionize, and this is measured in terms of the ionization energy – eV.

- For argon, the ionization energy is 15.8 eV.
- Helium, on the other hand, has an ionization energy of 24.6 eV.

Thus, it is easier to ionize argon than helium. For this reason argon facilitates better arc starting than helium.

Again, the thermal conductivity, or the ability of the gas to transfer thermal energy, is the most important consideration for selecting a shielding gas. High thermal conductivity levels result in more conduction of the thermal energy into the workpiece. The thermal conductivity also affects the shape of the arc and the temperature distribution within the region resulting different Penetration pattern.

Argon has a lower thermal conductivity rate — about 10% of the level for both helium and hydrogen. The high thermal conductivity of helium will provide a broader penetration pattern and will reduce the depth of penetration. Gas mixtures with high percentages of argon will result in a penetration profile with a finger-like projection into the base material, and this is due to the lower thermal conductivity of argon.

Reactive Shielding Gases

Oxygen, hydrogen, nitrogen, and carbon dioxide (CO_2) are reactive gases. Reactive gases combine chemically with the weld pool to produce a desirable effect.

Carbon Dioxide (CO_2) is inert at room temperature. In the presence of the arc plasma and the molten weld puddle it becomes reactive. In the high energy of the arc plasma the CO_2 molecule breaks apart through a process known as dissociation. In this process, free carbon, carbon monoxide, and oxygen are released from the CO_2 molecule. This occurs at the DC+ anode region of the arc. At the DC- cathode region, which is invariably the work piece for GMAW, the released elements of the CO_2 molecule undergo the process of recombination. During the recombination process higher energy levels prevail and cause the deep and broad penetration profile that characterizes the use of carbon dioxide.

Hydrogen (H_2) in small percentages (1-5%), is added to argon for shielding stainless steel and nickel alloys. Its higher thermal

Table 2 : Ionization Properties of Argon and Helium

SL.NO.	FUNCTION	ARGON	HELIUM
1	Ionization Potential a. Arc Initiation b. Arc Stability	15.8 ev Good Good	24.6 ev Poor Poor
2	Thermal Conductivity (cal./sq.cm/cm p C/s)	0.406/10000	3.32/10000
3	Density Relative to Air	1.38	0137
4	Cleaning action	Good	Poor

Table 3 : Shielding Gas Selection Guide

CO_2	ARGON + CO_2	ARGON + O_2
Higher Fume Levels	Lower Fume Levels	Lowest Fume Levels
Deeper Penetration	Shallower Penetration	More Rounded Penetration
More Violent or Inconsistent arc transfer	Smoother Arc Transfer	Smoother Arc Transfer
Lower Cost	Higher Cost	Highest Cost
Higher Spatter	Lower Spatter	Lowest Spatter
Less Radiated Heat	More Radiated Heat	Most Radiated Heat
Less Attractive Beads	More Attractive Beads	More Attractive Beads
Pulse Welding NOT Possible	Pulse Welding Possible	Pulse welding Possible
Spray Transfer NOT Possible	Spray Transfer Possible	Spray Transfer Possible

conductivity produces a fluid puddle, which promotes improved toe wetting and permits the use of faster travel speeds.

IV. EFFECT OF CTWD ON GMAW PROCESS.

Electrode Extension and Contact Tip to Work Distance (CTWD)

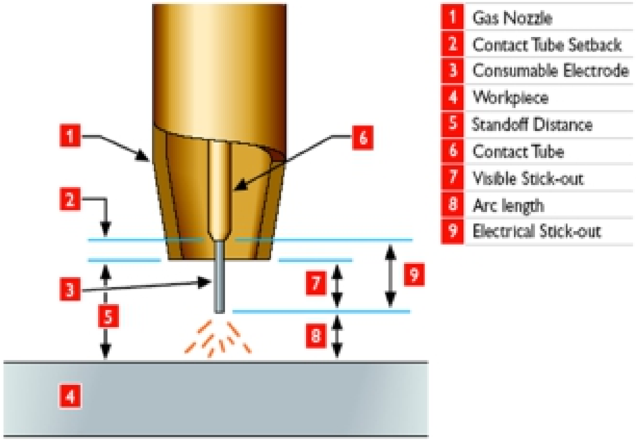

Fig. 2

Contact tip to work distance (CTWD) is a term that lends itself well to the electrode extension for mechanized or robotic welding applications. It is measured from the end of the contact tip to the work piece. In a non-adaptive constant voltage (CV) system the electrode extension or the CTWD acts as a resistor. Varying the length of the electrode affects the current applied to the arc:

- Increasing electrode extension increases the resistance to the flow of current in the electrode, and the current in the arc is decreased.
- Decreasing the electrode extension decreases the resistance to the flow of current in the electrode, and the current in the arc increases. Because the current can vary with an increase or decrease in extension, the consistency of the extension is important to the consistency of weld penetration. It is important to maintain a very steady hand during semiautomatic welding. It is equally as important to establish and maintain the correct CTWD for mechanized or robotic welding.

For short-circuiting metal transfer or GMAW-S, semiautomatic welding, the electrode extension should be held between 3/8"-1/2" (10 – 12 mm). For either axial spray or GMAW-P, pulsed spray metal transfer, the electrode extension should be held between 3/4" – 1" (19 – 25 mm). Maintaining the correct electrode extension is important to the uniformity of the penetration profile along the length of a weld, and it is considered to be an important variable for any GMAW procedure.

V. OPERATING FACTOR

Operator Factor: percent of time that a welder is actually making a useful weld.

Operating factor is the percentage of a welder's working day that is actually spent welding. It is the arc time in hours divided by the total hours worked. A45% (.45) operating factor means that only 45% of the welder's day is actually spent welding. The balance of time is spent installing a new electrode or wire, cleaning slag, positioning the weldment, cleaning spatter from the welding gun, etc.

When welding with solid wires (GMAW) or metal cored welding (MCAW) using the semi-automatic method, operating factors ranging from 45%-55% are easily attainable.

For welds produced by flux cored arc welding (FCAW) semi-automatically, the operating factor usually lies between 40%-50%. The estimated operating factor for FCAW is about 5% lower than that of GMAW to allow for slag removal time.

In semi-automatic submerged arc welding, slag removal and loose flux handling must be considered. A 40% operating factor is typical for this process.

Automatic welding using the GMAW, FCAW, and SAW process, requires that each application be studied individually. Operating factors ranging from 50% to values approaching 100% may be obtained depending on the degree of automation.

- Semi-automatic and automatic plants have higher operator factors
- Field welding / construction work with small welds in scattered locations have low operator factor
- Welding in the flat position has higher operator factor than horizontal, vertical, overhead:
  - Faster travel speed
  - Fewer defects / fewer repairs
  - Use of fixtures, positioners, and handling equipment increases operator factor

Table 4 : Average Values of Operating Factors for Different Welding Processes

Sl. No.	Process	Operating Factor %
1	(SMAW) Shielded Metal Arc Welding	15%-40%
2	(GMAW) Solid Wires or Metal Cored Welding (MCAW)	45%-55%
3	(FCAW) Flux Cored Arc Welding Semi-Automatic	40%-50%.
4	(SAW) Semi-Automatic Submerged Arc Welding,	40%
5	GMAW, FCAW, Automatic Welding	50% - 80 %
6	(SAW) Automatic Welding,	90 % - 100 %

- Slag chipping, electrode changes, moving from joint to joint all reduce operator factor

DUTY CYCLE AND PERMISSIBLE CURRENTS

Duty cycle can be defined as a ratio, as a percentage, of the load-on (generating an arc) time to a specified time of cycle in welding operation. So, Duty cycle (%) = (Arc time) / (Time of one cycle) x 100.

Duty cycle is a major factor in determining the type of service for which a power source is designed. The rated duty cycle of GMAW power sources of constant voltage output is specified as 20%, 40%, 50%, 60%, 80%, and 100%.

The use of a power source in the conditions that exceed the rated duty cycle can cause burning of the power source because of overheating the power source components. Power sources are designed, in an economical point of view, to use under the conditions of intermittent loads where the arc is often turned on and off as seen in usual welding operations. In other words, power sources including their accessories are designed thermally safe, provided they are used within specified rated duty cycles.

Power source manufacturers perform duty-cycle tests under what the pertinent standard defines as usual service conditions. Factors that cause lower than the tested or calculated performance include high ambient temperatures, insufficient cooling-air quantity, and low line voltage. Rated duty cycle (Tr), rated current (Ir), permissible duty cycle (T), and permissible current (I) have the following relationship:

$$Tr \times Ir^2 = T \times I^2 \qquad (1)$$

Based on this relationship, the following formulas are given for estimating the duty cycle at other than rated output (3-1), and for estimating other than rated output current at a specified duty cycle (3-2).

$$T = (Ir / I) \text{ x } (Ir / I) \text{ x } Tr \qquad (2)$$

Example 1: What duty cycle does the use of 300A output make in use of a power source rated at 60% duty cycle at rated current of 350A?

Using equation (2): T = (350/300)2× 60% = approx. 82%.

Therefore, this unit (a non-constant duty cycle type) can be loaded approximately 8 minutes out of each 10-minute period at 300A.

$$I = Ir \;\; (Tr / T) \qquad (3)$$

Example 2: The above-mentioned power source (a non-constant duty cycle type) is to be loaded continuously, thus at 100% duty cycle. What output current must not be exceeded?

Using equation (3):

$$I = 350 \;\; (60/100) = \text{approx. } 270A.$$

Therefore, if operated continuously, the current should be limited to 270A.

The aforementioned equations imply that welding currents exceeding a rated current could be used if the duty cycle is lower than the rated. However, welding currents should not be higher than the rated even if the duty cycle can be decreased. This is because thermal capacity of rectifier elements used in power sources is lower than that of the main transformer; thus, the use of currents higher than the rated can overheat the rectifier elements.

In addition, as defined as

$$H = I^2 R T \qquad (4)$$

Where

H : Joule heat,
I : current,
R : internal resistance, and
T : duty cycle,

Heat of a power source is affected by the internal resistance of the power source, in addition to by current and duty cycle.

This suggests that joints between the components must sufficiently be fastened through maintenance activities to minimize the resistance; if not, a loose joint can cause more heat than the estimated, which may cause overheating of the power source even if the duty cycle and welding current is within the specified.

In order to prevent overheating, duty cycle is specified for welding torches, too, in the same way as for power sources as discussed above. However, unlike power sources, the rated duty cycle of welding torches varies depending on how to use the welding torch: e.g. 80% for CO_2 welding, 60% for MAG welding, and 50% for pulse-MAG welding in use of the same welding torch. This is because radiant heat from the arc to the tip of the torch varies affected by the welding process. The radiant heat becomes higher in CO_2 welding, MAG welding, and pulsed-MAG welding in this order, when other welding parameters are kept constant. Specifications of welding torches indicate the rated duty cycle when used in CO_2 welding, unless otherwise specified.

CONCLUSION

In this part, the author has tried to analyze the Basic Factors which contribute to the Welding Process Quality for consistency, optimum effectiveness and efficiency and of course resulting high productivity with minimum cost.

In the next Part, details of Weld Deposition Rate and Calculations involving Geometrical Configuration of Weld and Weld Volume will be dealt with.