CHAPTER – 5

Welding Signature Analyzer Software for Online/Offline Analysis

Introduction

The WSA is designed to operate in two modes namely online mode and off line mode. In online mode, that is used for monitoring the online voltage signature and current signature their instantaneous values are recorded in the computer. In off line mode, recorded samples are retrieved from the memory and statistical parameters are obtained for defect identification and quality evaluation. Software used in the welding signature analyzer is Window XP, version, Office 2003, visual Basic Version -6 and DAQ Bench Run time software and a newly developed software package. Sampling rate and recording duration can be varied by using the newly developed software package. In off line mode the data can be retrieved for statistical investigation for defect identification and quality evaluation.

5.1. Online Mode of Operation of WSA

The block diagram representation of online mode of operation of SWA is shown in fig.5.1.1

![Block diagram representation of online mode of operation of WSA](image-url)
In online mode, the current and voltage transducers collect the online arc current and arc voltage then they feed to Data Acquisition card for processing. DAQ-2010 card has a built in PLX IOP 480 PCI controller, which, controls the CPU loading because the online arc current and voltage is directly transferred to the computer memory without host CPU intervention. DAQ Bench software is used for recording the weld voltage and current samples and using Direct Memory Access (DMA) method the instantaneous values of weld voltage and current signatures are monitored over a specified period in the Industrial computer [49]. The online weld data processing diagram is shown in fig 5.1.2

![Block Diagram of online mode data processing](image)

Fig. 5.1.2 Block Diagram of online mode data processing

Bus mastering (Bus mastering is a feature supported by bus architectures that enables a controller connected to the bus to communicate directly with other devices on the bus without going through the CPU) provides the fastest data transfer rate on PCI-bus. Sampling rate of DAQ-2010 is 2Mega samples per second and it has 14 bit resolution.
5.2 Offline Mode of Operation of WSA

In offline mode the stored samples are retrieved from the buffer memory and its signature and statistical parameters are obtained using the newly developed software package for obtaining statistical parameters are shown in fig.5.2.1. The software package is used to view the arc current and arc voltage signature at any desired duration and its statistical parameters obtained instantaneously. The weld samples may be analyzed in two ways namely micro analysis and macro analysis. In micro analysis the samples are analyzed for period of 5 seconds at a sampling rate of 1000 samples per second. In macro analysis the samples are analyzed for period of 30 seconds at a sampling rate of 1000 samples per second [48].

![Diagram of statistical parameters obtained from recorded data]

Fig.5.2.1 Statistical parameters obtained from recorded data
5.3 Statistical Parameters and their Significance

A cause of variation that is not random and does not occur by chance is "assignable”. An assignable cause is an identifiable, specific cause of variation in a given process or measurement.

In the welding, defects are assignable causes and it is possible to identify the type of fault. Online arc current and arc voltage sample are collected in the Welding Signature Analyzer at any desired rate of samples per second. In this work the samples are collected at a rate of 1000 samples per second and the total of sixty thousand current and voltage samples are subjected to statistical investigation for identifying good and defect part of the weld nugget. Software package has been developed using Visual Basic and Microsoft Excel for viewing the online signature and to compute the statistical parameters such as correlation co-efficient, Measures of central tendency, Measures of relative dispersion and Normal Distribution Curve and Test of Significance (Chi-Square Test) also conducted on the statistical parameters [49].

5.3.1 Correlation Co-efficient [CC] (r)

Correlation co-efficient measures the strength of a linear relationship between the two variables. The correlation co-efficient is a number between -1 and +1 that measures the perfect linear relation between two variables such as arc current and arc voltage. Electric arc can be struck with higher voltages but one cannot make use of this because of safety hazard. As per Factories Act., any person working in an industry can handle only 24 volts. It is not safe to handle voltage above 24V. However, for welding, even though it makes use of Open Circuit Voltage (OCV) of the order of 75V to 90V volts, once the arc starts the arc voltage comes down to 24 volts.
The open circuit voltage exists until the arc strikes. Once arc is struck, the voltage is only around 24V.

The correlation is computed as

\[
    r = \frac{\sum_{i=1}^{n} (X_i \cdot Y_i) - n \cdot \bar{X} \cdot \bar{Y}}{(n-1)S_x S_y}
\]

Where \( n \) is the number of observation, \( \bar{X} \) is the mean arc current, \( X_i \) is the instantaneous arc current, \( \bar{Y} \) is the mean arc voltage and \( Y_i \) is the instantaneous value of arc voltage. \( S_x \) is the standard deviation of arc current and \( S_y \) is the standard deviation of arc voltage.

A positive value of for the correlation implies a positive association i.e. large values of arc current tend to be associated with large values of arc voltage and small value of arc current tend to be associated with small values of arc voltage.

A negative value for the correlation implies a negative or inverse association (large values of arc current tend to be associated with small values of arc voltage and vice versa).

By virtue of constant voltage source the value of correlation co-efficient is always strong negative value. Positive value indicates the welding power source behaviour is abnormal and is not suitable for welding as well as dangerous to the welding personnel.

**Interpretation of Correlation Co-efficient**

The correlation coefficient is always between \(-1\) and \(+1\).

The closer the correlation is to \(+1\) or \(-1\), the closer to a perfect linear relationship

- \(-1.0\) to \(-0.7\) strong negative association
- \(-0.7\) to \(-0.3\) weak negative association
- \(-0.3\) to \(+0.3\) little or no association,
- \(+0.3\) to \(+0.7\) weak positive association
- \(+0.7\) to \(+1.0\) strong positive association
5.3.2 Measures of Central Tendency

There is always a tendency of individual observations contained in any set of data (arc current and arc voltage) to cluster or centre around a specific value which is the central value. This peculiar characteristic of the data is referred to as central tendency.

A measure of central tendency is a single value which is used to represent an entire set of data.

It is a typical value to which most of the observations fall closer than to any other value.

There are mainly three principal measures of central tendency which are widely used in statistical analysis. These are arithmetic mean, median and mode.

The relation between these three measures depends on the shape of frequency distribution. In a symmetrical distribution, the values of mean, median and mode are the same.

Mean: The sum of a set of data divided by the number of data.

Median: The middle value or the mean of the middle two values, when the data is arranged in numerical order.

Mode: The value (number) that appears the most. It is possible to have more than one mode, and it is possible to have no mode.

5.3.3 Measures of Dispersion

Measure of dispersion is to express the variability characteristic of the welding current and voltage signature data. In this work the measure of absolute dispersion is calculated and the data is expressed in the same unit of measurement in which the original data are recorded in the welding signature analyzer.
There are several terms that describe the dispersion or variability of the data around the mean are: Range, Variance, Sample Standard Deviation, Population Standard Deviation and Coefficient of Variation.

**Range:** Range is the difference or spread between the highest and lowest observations. It is the simplest measure of dispersion. It makes no assumption about the central tendency of the data.

**Variance:** Variance is the measure of variability about the mean. It is calculated as the average squared deviation from the mean. The sum of the deviations from the mean, squared, divided by the number of observations (corrected for degrees of freedom).

The (population) variance of a random variable is a non-negative number which gives an idea of how widely spread the values of the random variable are likely to be; the larger the variance, the more scattered the observations on average.

Variance gives an impression of how closely concentrated round the expected value the distribution is; it is a measure of the 'spread' of a distribution about its average value.

The formula of Variance is $\sigma^2 = \frac{\sum(X - \mu)^2}{N}$

**Sample Standard Deviation (SSD):** The sample standard deviation (usually represented by S) measures the variability of data in a sample. It is easy to compute (compared to a population standard deviation) because it is based on a small and manageable sample.

The formula of SSD is $S = \sqrt{\frac{1}{(n-1))}\sum(X - \bar{X})^2$.

**Population Standard Deviation (PSD):** The population standard deviation (often represented by the Greek letter sigma) is measures the variability of data in a population. It is usually an unknown constant.
The formula of PSD is \( \sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{N} (x_i - \mu)^2} \)

**Calculation of Standard Deviation (SD):** The standard deviation (SD) is the square root of the variance. 

\( \sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2} \)

SD is the square root of the average squared deviation from the mean.

SD is commonly used due to the same units as the mean and the original observations.

SD is the principle calculation used to measure dispersion of results around a mean.

**5.3.4 Coefficient of Variation (CoV)**

The absolute measures of dispersion of the welding signature current and voltage data are generally inadequate to facilitate comparison of two or more sets in terms of their variability.

If the mean of two more sets of data are the same, comparison between such sets of data is possible directly in terms of variance or standard deviation.

The Coefficient of Variation (CoV) is the Standard Deviation (SD) expressed as a percentage of the mean and also known as Relative Standard Deviation (RSD). Formula of CV or RSD is

\[ \% CV = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100 \]

**5.3.5 Measure of Skewness \([S_k]\)**

Skewness refers to the direction in dispersion, departure from symmetry or lack of symmetry in a distribution.

Skewness is defined as asymmetry in the distribution of the sample data values. Values on one side of the distribution tend to be farther from the 'middle' than values on the other side.
For skewed data, the usual measures of location will give different values, for example, mode<median<mean would indicate positive (or right) skewness.

**Skewness Formula** is for univariate data \( Y_1, Y_2, Y_N \), then

skewness formula is \[ S^n_k = \frac{\sum_{i=1}^{N} Y_i^n - \left( \frac{1}{N} \sum_{i=1}^{N} Y_i \right)^n}{\left( \frac{1}{N} \sum_{i=1}^{N} Y_i - \left( \frac{1}{N} \sum_{i=1}^{N} Y_i \right) \right)^{3n}} \]

Where \( \mu \) is the mean, \( \sigma \) is the standard deviation, and \( N \) is the number of data points.

The skewness for a normal distribution is zero, and any symmetric data should have skewness near zero.

Negative values for the skewness indicate data that are skewed left and Positive values for the skewness indicate data that are skewed right.

By skewed left, means that the left tail is long relative to the right tail

By skewed right, means that the right tail is long relative to the left tail

**Guidelines for Interpreting Skewness co-efficient values**

Greater than 1 or less than -1 indicates a highly skewed distribution;

Between 0.5 and 1 or -0.5 and -1 is moderately skewed; and,

Between -0.5 and 0.5 indicates that the distribution is fairly symmetric.

**5.3.6 Measure of Kurtosis [\( K_r \)]**

Kurtosis refers to the degree of peakedness, or flatness, at the top of a distribution.

It is to be understood in relation to a symmetrical distribution.

A distribution whose polygon has a high peak is known as **leptokurtic** distribution.

The one whose polygon has flatness at its top is called **platykurtic** distribution.

A distribution whose polygon does not have a very high peak and is not even too flat at its top is termed as **mesokurtic** distribution.

The **mesokurtic** distribution is also frequently referred to as a normal distribution.
The formula of Kurtosis is \[ (\frac{\sum (X - \mu)^4}{N\sigma^4}) - 3 \] Where \( \sigma \) is the standard deviation,

- The kurtosis of a normal distribution is 0.
- Kurtosis measures the "fatness" of the tails of a distribution. Positive excess kurtosis means that distribution has fatter tails than a normal distribution.
- Fat tails means there is a higher than normal probability of big positive and negative returns realizations.
- When calculating kurtosis, a result of +3.00 indicates the absence of kurtosis (distribution is mesokurtic).
- For simplicity in its interpretation, some statisticians adjust this result to zero i.e. kurtosis minus 3 equals zero), and then any reading other than zero is referred to as excess kurtosis.
- Negative numbers indicate a platykurtic distribution and
- Positive numbers indicate a leptokurtic distribution.

5.3.7 Normal Distribution Curve

Normal distributions model (some) continuous random variables, strictly, a Normal random variable should be capable of assuming any value on the real line, though this requirement is often waived in practice.

For example, height at a given age for a given gender in a given racial group is adequately described by a Normal random variable even though heights must be positive.

A continuous random variable \( X \), taking all real values in the range is \(-\infty \) to \( \infty \) is said to follow a Normal distribution with parameters \( \mu \) and \( \sigma \) if it has probability density function.
The normal Density function is

\[ f(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp \left( -\frac{1}{2} \left( \frac{x - \mu}{\sigma} \right)^2 \right) \]

The Normal Distribution Curve is shown in fig.5.3.1

Empirical Rule: Normal Distributions

✓ 68% of the data fall between mean \(-1\) (std.dev) to mean + 1 (std.dev)

✓ 95% of the data fall between mean \(-2\) (std.dev) to mean + 2 (std.dev)

✓ 99.7% of the data fall between mean \(-3\) (std.dev) to mean + 3 (std.dev)

5.3.8 Z - Score

The Z score transformation is especially useful when seeking to compare the relative standings of items from distributions with different means and/or different standard deviations of the current and voltage samples.

The Z score for an arc current and arc voltage indicates how far and in what direction, that arc current and arc voltage deviate from their distribution's mean of the current and voltage samples, expressed in units of its distribution's standard deviation.
Z scores are especially informative when the distribution to which they refer to normal. In every normal distribution, the distance between the mean and a given Z score cuts off a fixed proportion of the total area under the curve.

The number of standard deviations from the mean is called the Z-score.

Z-score can be found by the formula \( \frac{x - \mu}{\sigma} \)

In every normal distribution 0.343 of its total area lies between the mean and \( Z = 1 \)

5.4 Procedure of Monitoring and Recording

The welding machine is connected to the Welding Signature Analyzer for online monitoring and recording the following options available in the main menu.

**Main Window:** The available options are

1. Data logging
2. Load analysis
3. Real time trend i.e. monitoring and recording and Exit the proc

**Run Menu:** In this menu three buttons are available for online recording

1. **Scaling Button:**
   
   \( I_{\text{max.}} \) & \( I_{\text{min.}} \) arc current, \( V_{\text{max.}} \) & \( V_{\text{min.}} \) arc voltage

2. **Set time Button:**

   Sampling rate for data acquisition & choosing path for data logging

3. **Start Button:**

   Once the start button is pressed it initiates the data acquisition process.

   Data acquisition process will stop automatically after storing required data.

   A message will appear stop the entire process. Block diagram and flow chart of Data acquisition process is shown in 5.4.1 and flow chart is shown in fig.5.4.2
Block representation of Data acquisition is explained in fig.5.4.1

Fig.5.4.1 Block diagram representation of Data Acquisition process
Open Start Window

Configure Welding Parameters – Scaling Welding current and welding voltage

Stored in the Local Memory

Scanning Configure Parameters

DAQ 2010 Card

Start Process

DAQ 2010 card starts the Scanning of Data in Channel 1 - Online weld voltage Channel 2 – Online weld current

Data Stored in Direct Memory Axis (DMA) Method

Sampling time over

No

Yes

Stored in the computer Memory

Stop Process

Flow chart representation of Data acquisition process is explained in fig.5.4.2

Fig.5.4.2 Flow chart of data acquisition process in WSA
5.5 Procedure of Offline Analysis

Analysis window is used for calculating Measures of central tendency, Measures of dispersion, correlation co-efficient, Gaussian Normal distribution curve, Short Circuiting Time, Net Burning Time and Data reporting etc. for any desired range of current and voltage samples or any time duration. The block diagram representation of welding data analysis window is shown in fig.5.5.1

![Block Diagram of Analysis Window](image)

- **Analysis Window [Off mode Analysis]**
  - **File Menu**
  - **Load Analysis**
  - **This is used to load the *.DAT file for further analysis.**
    - When click load analysis open file dialog will appear.
    - Choose Appropriate *.DAT file.
    - After choosing the file then the voltage & current Information will be plotted in graph.
  - **File Analysis**
  - **Print**
  - **EXIT**

Fig.5.5.1 Analysis window for analyzing recorded welding data
Analysis Window

Analysis window has three major dialogue boxes namely load analysis, exit and print.

File Menu Load analysis

This is used to load the *DAT file for further analysis in this mode any desired range of data can be analyzed. When the load analysis button is clicked open file dialogue box will appear. By choosing appropriate *DAT file the voltage and current will be plotted in the graph. Then click the run mode the program for obtaining the statistical parameters for a desired range of data.

Exit: Exit from the analysis window and

Print: When click the print in file menu then preview window will appear. Select the appropriate paper size, printer color and etc., and then click the print button to take out the printout either the statistical parameters or its arc current or voltage signature.

Recorded welding signatures analysis operation is shown in fig. 5.5.2 to 5.5.9.

![Fig.5.5.2 Welding current and voltage in the Analysis window](image-url)
Fig. 5.5.3 Properties and Report Generation window

Fig. 5.5.4 Font size and signature’s colour changing window
Fig.5.5.5 Window for selection of time period for analyzing signatures

Fig.5.5.6 Window for selection of statistical parameter
Fig. 5.5.7 Window for viewing signature and its PDD curve

Fig.5.5.8 Window shows the statistical values and PDD curve
5.6 Conclusion

In this chapter software development, statistical parameters and their significance are explained. The method of monitoring and recording and a step by step method of obtaining statistical parameters of the recorded welding signature in micro and macro level of samples using WSA software package is also discussed.