

# STUDY OF WELD COMPONENT FATIGUE LIFE IN RANDOM ENVIRONMENT

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**Abstract** - Fatigue life of a welded component in the random vibrational environment has been carried out in this work. To do so, initially collecting random inputs from the source, requires data acquisition system (DAQ) with the help DAQ, time domain signals from the source are collected; these signals are processed to frequency domain signals to find out the power spectral density (PSD) of the input system. Next phase of the project involves geometrical variation in the weld properties. This exercise yields numbers of combinations; but carrying out analysis and modeling on each of them is time consuming, here modeling exercise is optimized using configuration feature technique and analysis efforts are optimized with the help of design of experimental approach, Taguchi Method.

Further, optimized input results are processed to carry out the random analysis of each of the nine samples selected from the Taguchi optimization method with PSD as an input, with the help of these input Stresses are acquired for the system. Next step is to find out accumulative damage factor of the systems and their by predicting remaining life cycles for the component. With help of results acquired for various geometries efficient component is selected to be in the practical environment. Overall these efforts set a procedure to collect variable input, optimize modeling exercise, choosing best samples amongst the set of all combinations and predicting accumulative damage using probabilistic approach.

**Key Words:** random vibration, weld component, fatigue life, Power Spectral Density, Data Acquisition System, Taguchi Method

## 1. INTRODUCTION

This All components in dynamic conditions always tend to experience variable loading during its life cycle span. To be illustrative for such an environment is, transportation machineries like automobiles travelling on rough road surfaces, arbitrary load impact experienced by the industrial equipment's, bulky static structures having dynamic arrangement in the localized zone facing earthquakes. During static loading conditions input loads are easier to assign i.e. either based on the total weight experienced by the structure under consideration, or impact force; this is static environment scenario. But when it comes to random loading as explained in the examples, extracting the loading pattern is not straight forward and cannot be easily extracted from the source by traditional measuring equipment's. Inputs are therefore collected in terms of spectrum or also known frequency domain loading. When

the input is in terms of static loading, single force is acting at a time; but in the case of random loading multiple forces acts at the same time. This is the situation which causes difficulty in terms of measurement. So now a question comes how to simplify these inputs to have easiness in the signal conversation though not the measurability. These processes can be easily explained by traditional examples from physics. The laser beam which contains single frequency can be compared with the static loading. Similarly when it comes to the random loading, we have an option called as white light, which does have number of frequencies. How do we analyse the white light? Yes it is by the spectrum, which disintegrates entire frequency pattern. In the mechanical terms, random loading is converted to frequency domain, and this is done by the technique known as the Power Spectral Density. These inputs are processed to analyse the component life in terms of cumulative damages, which plays an important role in the prediction of fatigue life of random environment. This complex environment also creates challenges when physical or environmental changes occur onto the component under consideration. For example a structure is excited to random loading which is either welded, bolted or experiencing environmental challenges like thermal fatigue; it very important to understand the life of the component, number of random variations structure has undergone, so that fatigue failure is predicted, monitored, controlled.

Present work contribute towards the measurement of the random inputs from the generation source, changing the geometrical parameters which can be controlled by the process and are important in deciding the structural stability of the component, optimizing them for design improvement. This is done by random analysis to find out the stresses generated in the system. Further this data is calculated for the cumulative damages to find out the fatigue life of the component.

## 2. PROBLEM STATEMENT

In the world of joining process, weld process has its own significance due to its assembling nature or due to the complexity of the working areas. When these types of joints are subjected to random environment, their behavior in the prospective of fatigue behavior is the point of curiosity. But prior to calculating fatigue by traditional method, understanding the random behavior of 'input loading source' in the limited measuring equipment sources, is the key working challenge. Processing random inputs to the desired set of logic is the second stage before predicting fatigue model, thereafter estimating accurate fatigue life for the

safety of the product and thereby avoiding dependent loss of important assets like life, time, money etc.

The danger of a catastrophic fatigue failure in the structure may be eliminated/suppressed after knowing the criticality of the welding zones or can help of monitor the situation instead of sudden failure; by designing the structure to have a safe life or to be fail-safe. A proper methodology has to be set to predict the catastrophic failure of weld joints due to fatigue failure in random environment.

### 3. GEOMETRY OF THE WELD

Geometric modeling is carried out by using Solid-Works 15 software .Geometric dimensions and CAD model of weld under consideration are shown below. All dimensions are in mm and angle is in degree. Weld geometry is defined by the various characteristics; below image demonstrate the few of them, these can be controlled by the operator or by specially designed machine. Here the sketch at T section is controlled by the weld reinforcement angle.

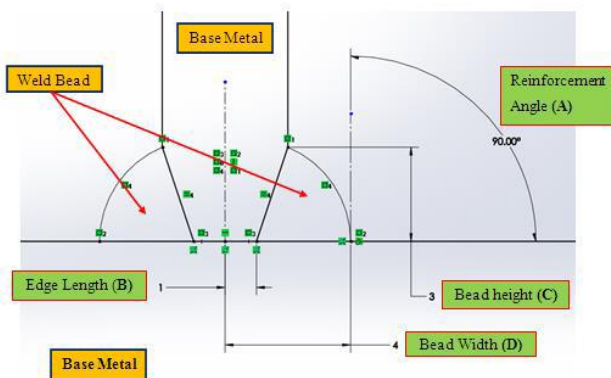


Fig - 1: View defining Geometrical variable

#### 3.1 Selection of Sample Using Taguchi Method

These parameters are formulated in terms of Orthogonal Array to determine samples. Here reinforcement angle is assigned with A, weld preparation edge from the center is defined as B, weld bead height indicated as C and its width as D. All these factors have three levels and tabulated in the Table-1.

Table -1: Parameters and variables for experiment

| Level/<br>Factor | A<br>(Reinforcement<br>angle) | B<br>(Base) | C<br>(Height) | D<br>(Width) |
|------------------|-------------------------------|-------------|---------------|--------------|
| 1                | 90                            | 1           | 3             | 3.5          |
| 2                | 100                           | 1.25        | 3.5           | 4            |
| 3                | 105                           | 1.5         | 4             | 5.5          |

Table -2: Orthogonal array for 3-level, 4Factor

| Experiment | Reinforcement<br>angle<br>(A) | Base<br>(B) | Height<br>(C) | Width<br>(D) |
|------------|-------------------------------|-------------|---------------|--------------|
| 1          | A1                            | B1          | C1            | D1           |
| 2          | A1                            | B2          | C2            | D2           |
| 3          | A1                            | B3          | C3            | D3           |
| 4          | A2                            | B1          | C2            | D3           |
| 5          | A2                            | B2          | C3            | D1           |
| 6          | A2                            | B3          | C1            | D2           |
| 7          | A3                            | B1          | C3            | D2           |
| 8          | A3                            | B2          | C1            | D3           |
| 9          | A3                            | B3          | C2            | D1           |

Table -3: Orthogonal array for Parameters and variables under consideration

| Experiment | Reinforcement<br>angle (A) | Base<br>(B) | Height<br>(C) | Width<br>(D) |
|------------|----------------------------|-------------|---------------|--------------|
| 1          | 90                         | 1           | 3             | 3.5          |
| 2          | 90                         | 1.25        | 3.5           | 4            |
| 3          | 90                         | 1.5         | 4             | 5            |
| 4          | 100                        | 1           | 3.5           | 5            |
| 5          | 100                        | 1.25        | 4             | 3.5          |
| 6          | 100                        | 1.5         | 3             | 4            |
| 7          | 105                        | 1           | 4             | 4            |
| 8          | 105                        | 1.25        | 3             | 5            |
| 9          | 105                        | 1.5         | 3.5           | 3.5          |

#### 3.2 Material properties for base metal and filler metal

Table -4: Material properties for Base metal & Filler metal

| Material             | E<br>GPa | Poisons<br>ratio | $\sigma_t$<br>MPa | $\sigma_y$<br>MPa | $\rho$<br>g/cm <sup>3</sup> |
|----------------------|----------|------------------|-------------------|-------------------|-----------------------------|
| Base-Steel<br>AS36   | 70       | 0.29             | 449               | 324               | 2.78                        |
| Filler-Steel<br>A514 | 71       | 0.33             | 538               | 490               | 2.78                        |

#### 4. ACQUIRE PSD (POWER SIGNAL DENSITY) SIGNALS FROM DAQ (DATA ACQUISITION SYSTEM) AND FINITE ELEMENT ANALYSIS:



Fig - 1: View defining Geometrical variable

Above shown physical setup requires to be replicated into a Labview circuit, which should be able to measure the force and accelerations inputs exist at the source or the area of evaluation. Hammer is the instrument can be seen in the above figure. does have Piezoelectric Transducer at the tip of impact area; other end of the Hammer is connected to the cDAQ via. Cable. Similarly accelerometer is placed at the area-of-consideration, to acquire the acceleration signal. Both these signal are collected by DAQ, but to understand in the system we need to connect them at particular ports, in this case they are named as a0, a1, a2,a3 (present DAQ is 4 port system). All acquired signals. Once the circuit is built to extract the input signals now next step is to convert this time domain signals into the desired format. Working environment of the project is random in nature, as discussed in the chapter 3, processed signals has to be in frequency domain and known as power spectral density. Below circuit is the basic inclusion of the VI's into the circuit, and consequent graphs indicate the acceleration and PSD format

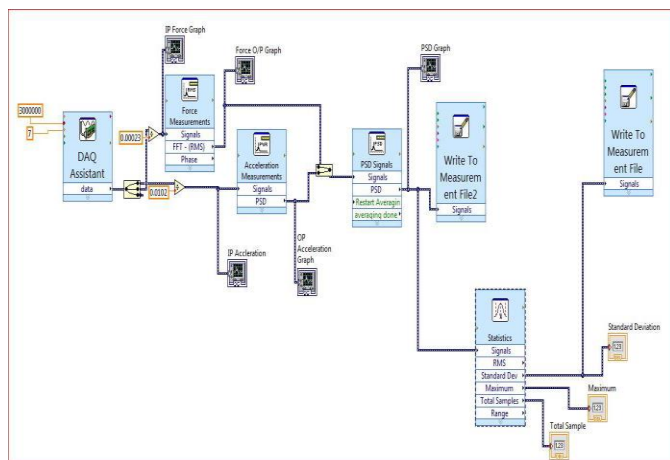


Fig - 2: View of corrected PSD circuit

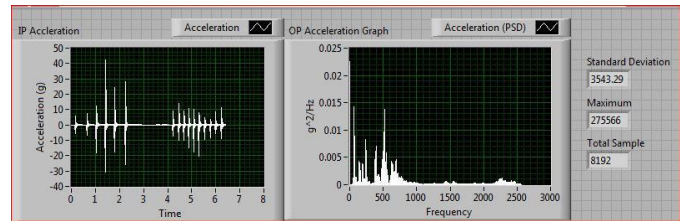


Fig - 3: Output graph of time domain acceleration & frequency domain PSD

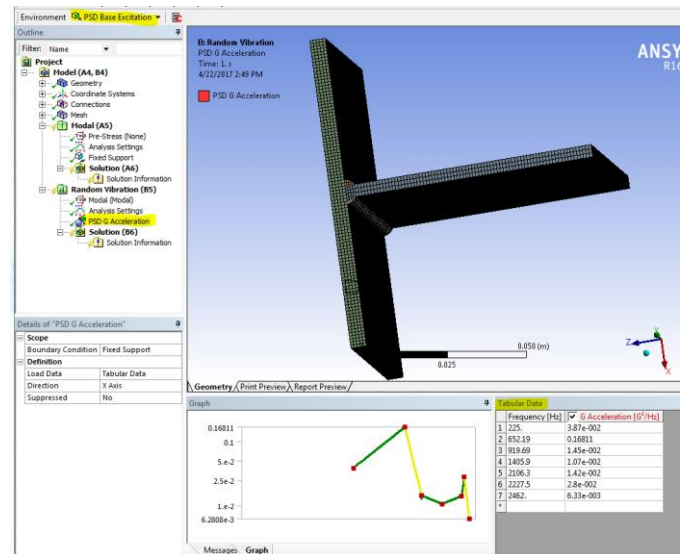


Fig - 4: View of PSD input to find out Stresses.

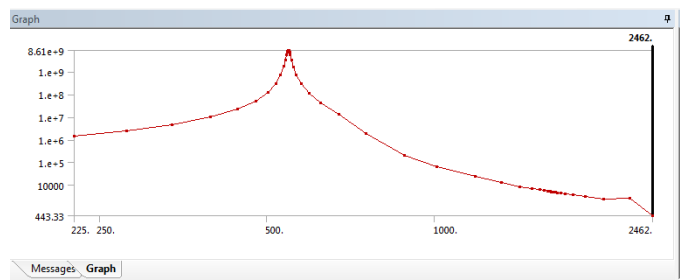


Fig - 5: View of Response PSD at critical zone

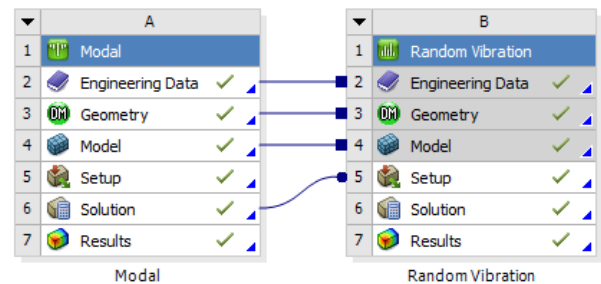


Fig - 6: View of circuit connections developed between Modal and Random modules.



Here in Fig.-7, contour of stress is plotted at left side of the model and is indicated by the different colors according to the stresses generated in the component which has undergone the random loading. From the figure it is evident that a  $1\sigma$  stress of 26.007MPa is generated at the weld bead location indicated by the red zone, blue color indicates the minimum load experienced by the component and is obviously at the fixed support due to constraints and source of frequency generation.

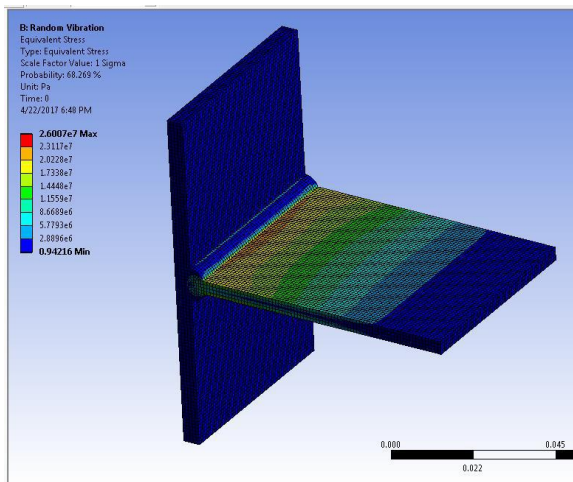


Fig - 7: View of  $1\sigma$  stresses at the weld location

5. FATIGUE LIFE CALCULATIONS:

“Miner Rule”

The approximate number of stress cycles N1 required to produce a fatigue failure in the

beam for the  $1\sigma$ ,  $2\sigma$  and  $3\sigma$  stresses can be obtained from the following equation:

$$N1=N2 [S1 / S2]^{b'}$$

N2 = 1000 (S1000 reference point)

S2 = Stress to fail at S1000 reference point) =279.32 MPa

S1 = =  $1\sigma$  stress from random vibration analysis

For load case 1: 26.007 Mpa

b' = slope of fatigue line =  $1/-b$

Sf = Endurance strength at  $10^3$  cycles

Se = Endurance strength at  $10^6$  cycles and is given by for material endurance of  $Se^*$ :

$$Se = Ka * Kb * Kc * Ke * Se^*$$

Ka = Surface finish factor =  $271 * \sigma u^{(-0.995)}$

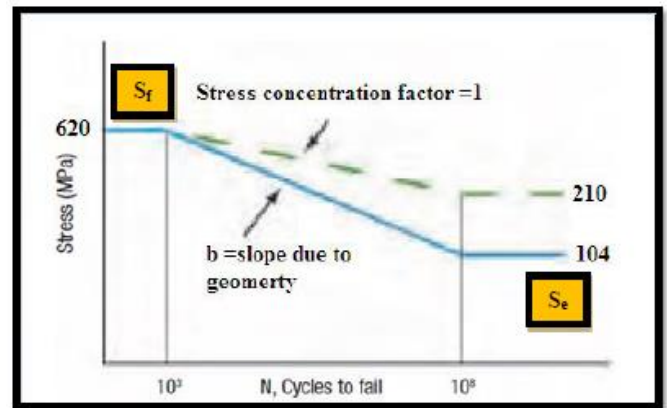
Kb =Size factor

Kc =Load factor=  $1.4335 * \sigma u^{(-0.0783)}$ .

Ke =Stress concentration factor

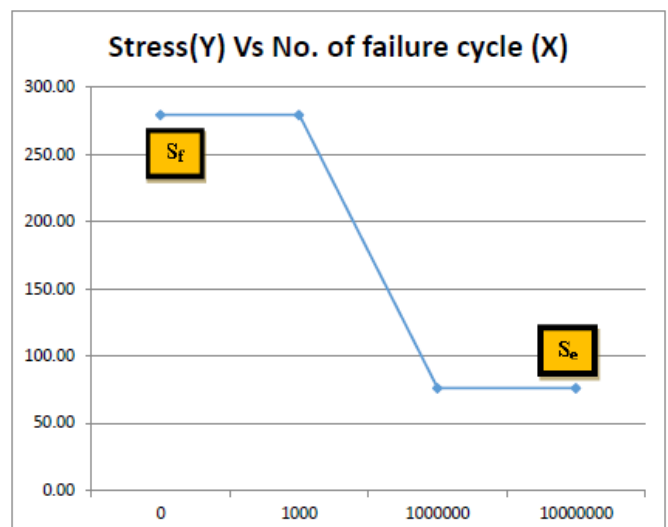
Slope (b) of the SN curve I given by:

$$b = - \frac{\log(\sigma f / Se)}{\log(2 \times 10^6)}$$



Tabulation of SN curve Calculation

|            |  |        |
|------------|--|--------|
| $\sigma u$ |  | 827    |
| $\sigma f$ | $\sigma u + 345$   | 1172   |
| Se         | $Ka * Kb * Kc * Ke * Se^*$                                 | 75.97  |
| Se         | $\sigma f * (2 * 10^6)^{-b}$                               | 75.97  |
| Ka         | $271 * (\sigma U)^{-0.995}$                                | 0.34   |
| Kb         | Kb   | 0.80   |
| Kc         | $1.4335 * (\sigma U)^{-0.0783}$                            | 0.85   |
| Ke         | Ke   | 0.80   |
| Se*        | $Se^* = 0.5 * \sigma u$                                    | 413.50 |
| b          | $((\text{LOG}((\sigma f) / Se)) / (\text{LOG}(2 * 10^6)))$ | -0.189 |
| Sf         | $\sigma f * (2 * 10^3)^{-b}$                               | 279.52 |



**S-N curve graphical indication**

Damage accumulated for the load case 1

$$n1 = 1\sigma \quad n1 = (180\text{cyc/sec}) \times (4 \text{ hr}) \times (60 \times 60 \text{ sec/hr}) \times (0.683)$$

$$= 1.77 \times 10^6 \text{ cycles}$$

$$n2 = 2\sigma \quad n1 = (180\text{cyc/sec}) \times (4 \text{ hr}) \times (60 \times 60 \text{ sec/hr}) \times (0.271)$$

$$= 7.02 \times 10^5 \text{ cycles}$$

$$n3 = 3\sigma \quad n1 = (180\text{cyc/sec}) \times (4 \text{ hr}) \times (60 \times 60 \text{ sec/hr}) \times (0.0433)$$

$$= 1.12 \times 10^5 \text{ cycles}$$

$$1\sigma N1 = 1000 [279.32 / 26.007]^{5.30}$$

$$= 2.94 \times 10^8 \text{ cycles}$$

$$2\sigma N1 = 1000 [279.32 / 52.014]^{5.30}$$

$$= 7.46 \times 10^6 \text{ cycles}$$

$$3\sigma N1 = 1000 [279.32 / 78.021]^{5.30}$$

$$= 8.68 \times 10^5 \text{ cycles}$$

Damage accumulation for 1σ loading

$$Di = ni / Ni$$

$$D1 = 1.77E^6 / 2.94E^8$$

$$D1 = 0.006$$

Damage accumulation for 2σ loading

$$D2 = 7.02E^5 / 7.46E^6$$

$$D2 = 0.0942$$

Damage accumulation for 3σ loading

$$D3 = 1.12E^5 / 8.68E^5$$

$$D3 = 0.1292$$

Total damage accumulation for all load case is given by

$$D = D1 + D2 + D3$$

$$= 0.006 + 0.0942 + 0.1292$$

$$= 0.2294$$

$$D = 0.2294 < 1$$

Total damage accumulated is 0.2294, which is less than 1. Therefore a crack will not get initiated in the weld component for the given loading condition. Therefore the service life of structure is found out by taking the damage accumulation of 0.2294.

**6. RESULT & DISCUSSION**

In this section discussion should be held in three main stages:

First one is to select the right combination of the geometrical variables, this is done with the help of Taguchi method; below are 9 combinations selected and are processed further to carry out the analysis in the random environment. Here Experiment naming is done to include the variable value selected in the respective experiment.

| Load case | Geometry feature           | σ1 MPa | σ2 Mpa | σ3 Mpa |
|-----------|----------------------------|--------|--------|--------|
| 1         | T Joint_90_B1.5_H4_W5      | 26.007 | 52.014 | 78.021 |
| 2         | T Joint_90_B1.25_H3.5_W4   | 25.528 | 51.056 | 76.584 |
| 3         | T Joint_90_B1_H3_W3.5      | 27.724 | 55.448 | 83.172 |
| 4         | T Joint_100_B1.5_H3_W4     | 28.422 | 56.844 | 85.266 |
| 5         | T Joint_100_B1.25_H4_W3.5  | 28.084 | 56.168 | 84.252 |
| 6         | T Joint_100_B1_H3.5_W5     | 24.804 | 49.608 | 74.412 |
| 7         | T Joint_105_B1.5_H3.5_W3.5 | 26.868 | 53.736 | 80.604 |
| 8         | T Joint_105_B1.25_H3_W5    | 26.399 | 52.798 | 79.197 |
| 9         | T Joint_105_B1_H4_W4       | 27.834 | 55.668 | 83.502 |

For the selected geometry, all results are evaluated in the random environment, here the base of the T-joint is excited at the fixed end with PSD values as an input; all stress results are taken for the common input excitation. Equivalent stresses are plotted against the entire geometry, below table indicates the maximum stresses each geometry experiences. From the available results maximum stresses are observed at the weld bead location. Further 4th load case with reinforcement angle 100°, edge preparation of 1.5mm, weld bead height as 3mm and width from the centre as 4mm experiences maximum stresses amongst the selected samples. At the same time, 6th load case experiences least stress amongst all samples. All results are available in the appendix section. As we are predicting the results based on the probabilistic approach 1, 2, 3 values are calculated in the below table. Below image demonstrate the max and min stress condition stresses.

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| 9         | T Joint_105_B1_H4_W4       | 27.834 | 55.668 | 83.502 |

Once the stress data is available for all the selected samples, we have to evaluate the fatigue life of the component. To calculate the fatigue in the random loading environment Miner Rule is applied. Here ni represent the applied number of cycles for a given input; here for all samples are excited for the same input. Here n1 represents 1σ RMS stress applied for the duration of 4Hrs, similarly n2 and n3 are 2σ and 3σ stress applied for the 4Hrs respectively; totally this counts for 12Hrs. N1, N2 and N3 are total cycles before failure occurs; thus both these results contribute towards calculation of damage factor (D). 6th sample after excitation

