Vibration stress relief of DH 36 rectangle welded plates

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Abstract. Vibration stress relief (VSR) is widely used in reducing residual stress in welded structures. However, the effectiveness of this method is still instable in some circumstance. In this study, a covert negative treatment phenomenon was investigated, i.e. natural frequency of welded structures decreased after VSR but residual stress in one direction increased. When the alteration of natural frequency after VSR is significant, the residual stresses in both the longitudinal and transversal directions shall decrease. Otherwise, residual stresses may increase on one direction. Thus, sufficient power shall be applied to the welded structures to avoid negative results.

1. Introduction

Significant residual stresses are often caused by the uneven heating in the welded structures, which can cause decrease of strength, deterioration of fatigue resistance [1, 2] and corrosion performance [3]. Thus, residual stresses relieving is an essential issue for welded structures.

Vibration stress relief (VSR) of welded structures has been approved by massive experiments as an efficient stress relief method [4, 5]. Vibration can cause dynamic stress and further promote the propagation, twisting and tipping of dislocations [6], especially in high residual stress areas. This induces local yielding in the materials and relief of residual stresses. Comparing with other stress relief methods, this method is especially favorable for time-saving[7].

Structures with higher residual stress usually have higher natural frequency, which is named as stress stiffening effect [8]. Decreasing of natural frequency after VSR is usually used as a criteria of successful stress relief. This is the most popular empirical effectiveness criteria for VSR effectiveness estimation in practice [9-11]. However, quantitative relationship between decrease amplitude of natural frequency and variation of the residual stresses has rarely been investigated, which makes that empirical criteria can only be used to estimate general variation trend of residual stress. Here we present that quantity of the decrease of natural frequency during VSR shall be taken into account in using this method, and an experimental research was carried out to support this view of point.

2. Materials and methods

Welded rectangle DH36 plates were treated by VSR to authenticate effectiveness of the natural frequency criteria. DH 36 steel is a representative low alloy high strength steel in marine engineering. The chemical composition and mechanics properties of the DH36 steel are shown in Table 1 and 2. 14 mm × 200 mm × 1000 mm DH 36 steel plates were welded by metal inert-gas welding. The filler metal was TWE-711Ni (Tientai (Kunshan) Co. Ltd.). The welding procedure values are shown in the
Table 3. 60° welding groove with a 4mm bottom was used and the gap between the two steel plates was 2mm, as shown in the figure 1.

![Diagram](image.png)

**Figure. 1.** Schematics of experiments. (a) Geometry of the welded planes and VSR assembling; (b) Groove of welding plates.

| Table 1. Chemical composition of DH36 steel (wt. %) |
|-----------------|--------|--------|--------|--------|--------|--------|--------|-------|
| C               | 0.12   | Si     | 0.18   | Mn     | 1.44   | Cr     | 0.08   | Cu    |
|                 |        |        |        |        |        |        |        | 0.06  |
|                 |        |        |        |        |        |        |        | V     |
|                 |        |        |        |        |        |        |        | 0.07  |
|                 |        |        |        |        |        |        |        | Ni    |
|                 |        |        |        |        |        |        |        | 0.08  |
|                 |        |        |        |        |        |        |        | Fe    |
|                 |        |        |        |        |        |        |        | Bal.  |

| Table 2. Composition of TWE-711Ni filler metal (wt. %) |
|-----------------|--------|--------|--------|--------|--------|--------|--------|
| C               | 0.035  | S      | 0.007  | Mn     | 1.42   | Si     | 0.41   |
|                 |        |        |        |        |        |        |        | 0.011 |
|                 |        |        |        |        |        |        |        | Ni    |
|                 |        |        |        |        |        |        |        | 0.39  |
|                 |        |        |        |        |        |        |        | Fe    |
|                 |        |        |        |        |        |        |        | Bal.  |

| Table 3. Welding parameters |
|-----------------|--------|--------|--------|
| Layers          | Current A | Voltage V | Welding speed mm/min |
| Base            | 75~100    | 21~23   | 80     |
| Middle layers   | 170~210   | 22~25   | 200    |
| Top layers      | 160~190   | 21~23   | 200    |

In the VSR, the exciter was placed on the edge of the plate and the vibration sensor in the middle. The exciter vibrated at 70 Hz for 20 min. 12 welded plates were divided into three groups. One of them was not treated and the other two were treated by VSR at two power levels, i.e. 1 kW and 2 kW. The variation of power was not intended to optimize the treatment parameter. The lower power was used to realize a situation that residual stress in one direction would increase, simulating an possible improper VSR treatment. The plates were supported by four rubber cylinders, therefore, the vibration of the plates was considered as un-constrained. Natural frequency of the plates was measured by frequency scanning. According to our previous research, maximum residual stress locates in the areas near the middle of the weld line. Residual stresses in the middle of the welded plate was valued by the blind-hole method. Each group contained 6 points. Distances between the points and the welding line were 0 mm, 3 mm, 16 mm, 33 mm and 48 mm, respectively. To guarantee the accuracy of measuring, 3 groups of points were measured on each plate. Location of the groups were set 20mm far from each other to avoid interference.

3. Results and discussion

3.1 Decrease of natural frequency

Figure 1 shows the relation between the VSR power and the plates’ natural frequency. Natural frequency of the untreated plates averaged 71.8 Hz. When the vibration power was 1 kW, average 1st natural frequency of the plates after the VSR was 69.8 Hz. When the vibration power was 2 kW, the average 1st natural frequency decreased to 66.5 Hz after VSR.
Natural frequency criteria are usually used qualitatively. Decreasing of natural frequency is considered as a sign of residual stress decrease. Decrease amplitude is not taking account. Therefore, both the two VSR treatment shall be considered as successful According to traditional natural frequency criteria.

3.2 Decrease of residual stress

When the vibration power was 1 kW, the average 1st order natural frequency decreased by 2.2 Hz. The maximum longitudinal residual stress, $\sigma_{x_{\text{max}}}$, decreased by ~20%, while the maximum transversal residual stress, $\sigma_{y_{\text{max}}}$, increased ~13%. When the vibration power was 2 kW, the average 1st order natural frequency decreased by ~5.3 Hz, and both the longitudinal and transversal residual stress decreased. In the areas of weld line central, the longitudinal and transversal stress decreased by 46.9% and 72.1%, respectively. The maximum longitudinal and transversal stress in the plate decreased by 11.9% and 58.7%. In both situations, the average 1st order natural frequency decreased and the two VSR treatment procedures shall be judged as effective according to conventional criteria. However, variation of residual stress indicated that the low power treatment procedure is less effective and cause increase of residual stress in one direction.

In the practice, residual stress increasing can be occasionally encountered. Sun treated D6AC steel welded bars with VSR and reported residual stress perpendicular to the weld line increasing [5]. Similar results were reported by Munsi [12]. The experimental results in this study indicated that stress increasing after VSR is not a mistaken phenomenon. It would occur when improper treatment was applied. The experiment results in this study indicated that a clearer cognizance of the quantitative relationship of residual stress and natural frequency shall be made to indicate such effects.

Natural frequency criteria is often used in practice to substitute actual measuring of stress variation because of its significant convenience. However, the research in this study clearly showed an contradictory result. Though both the two VSR treatments shall be judged as successful according to
traditional natural frequency criterial, stress measurement indicated that low power VSR treatment obtained decrease of stress in one direction. This indicates that tradition natural frequency criterial is not absolutely accurate in even quantitative judgement. Further study on the qualitative relationship between natural frequency and residual stress shall be carried out in the future.

4. Conclusions
VSR treatment with 1kW power caused decrease of residual stress in one direction and increase in the other. That with 2kW caused decrease of stress in both two directions. Decrease of natural frequency of the plates can partially indicate decrease of residual stress. Traditional natural frequency criteria shall be used cautiously when the VSR treatment power is low because it may lead to improper judgement. Qualitative study between natural frequency and residual stress in welded plates shall be carried out further.

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