VSR REPORT

Report on VSR Treatments Performed at

Superior Machine, Florence, SC

September 9, 2020

Superior Machine has used Advanced VSR's On-Site Stress Relieving Service several times before. In this project, a 36 ton weldment, made chiefly of ASTM 516 Grade 70 steel, measuring approximately 217" L X 170" W X 112" H was stress relieved in preparation of machining. Two treatments were done, so as assure stability of the structure for subsequent operations and usage.

Report prepared by:

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Figure 1: Workpiece was placed on four urethane isolation cushions, positioned to minimize the damping of the structure, and thus promote resonance, a key requirement of the VSR Process. Vibrator is seen in the lower left corner, where it was during the first VSR Treatment. The accelerometer (vibration sensor) was placed on the far corner from this view, and oriented to be most sensitive to vertical amplitude.

Figure 2 : Closeup of vibrator taken during 1st treatment. Two sets of mounting feet make easy orienting the vibrator properly for greatest vibrational response. Here the vibrator was oriented with the shaft midway between horizontal and vertical, i.e., roughly 45 degrees.

Hardened steel inserts in the feet allow firm clamping while minimizing wear & tear on the housing.

Figure 3: View from other side of shows accelerometer mounted on lower tube, oriented to be most sensitve to vertical amplitudes.

The VSR Process uses resonant vibration to cause sufficient flexure of the work-piece, so to combine the dynamic load from resonant vibration with residual stresses trapped in the material, resulting in plastic flow. Several independent research works, including those of Hahn[1], Shankar[2], and Yang, Jung and Yancey[3], have proven that resonance frequency vibration is the most effective form of vibration to relieve stress.

Normally the vibrator should be located in the central 1/3rd of a workpiece, but with very stiff structures with fairly thick walls, locating it on the end will boost the force injected into the structure, sometimes called a “crack-the-whip” approach. Using only 50% of the available 4.0 in-lbs of unbalance, resonance peaks reaching 6 g's were achieved. Later these would grow ~ 9 g's achieved during scanning, and above 10 g's when dwelling on the largest peak.

The initial vibration gathered was a Quick Scan (see Fig 4.), a plot made at 50 RPM / sec scan rate, used to provide a preliminary view of subsequent Pre- & Post-Treatment Scans.

[1] Dr. William Hahn, Vibratory Residual Stress Relief and Modifications in Materials to Conserve Resources and Prevent Pollution
[2] Dr. S. Shankar, Vibratory Stress Relief of Mild Steel Weldments
[3] Drs. Y. P. Yang, G. Jung, and R. Yancey, Finite Element Modeling Of Vibration Stress Relief After Welding

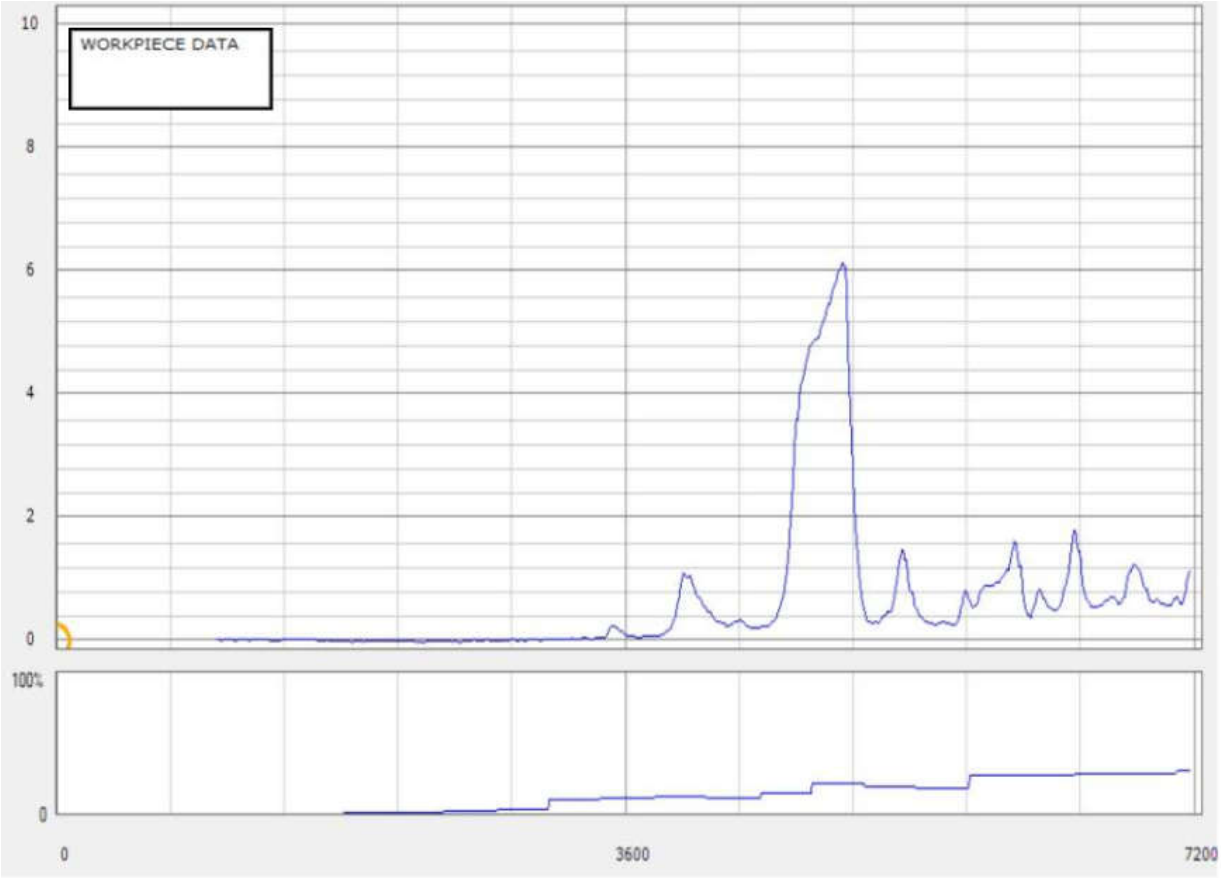

Figure 4: A Quick Scan (scan rate of 50 RPM / sec) was used to provide a preliminary view of the workpiece resonance pattern. Not only were a number of peaks generated, but the structure produced both audible and visible amplitudes when the various peaks were being plotted. Pre- & Post-Scans used a scan rate of 20 RPM / sec, which produces a more detailed view of the resonances. See Figure 5.

Full scales for this chart:

Acc = 10 g's	**(adjustable from 1 – 50 g's)**
Vibrator speed = 7200 RPM	**(adjustable up to 8 KRPM)**
Power = 2000 watts	**(fixed)**
Unbalance = 50% of 4.0 in-lbs.	

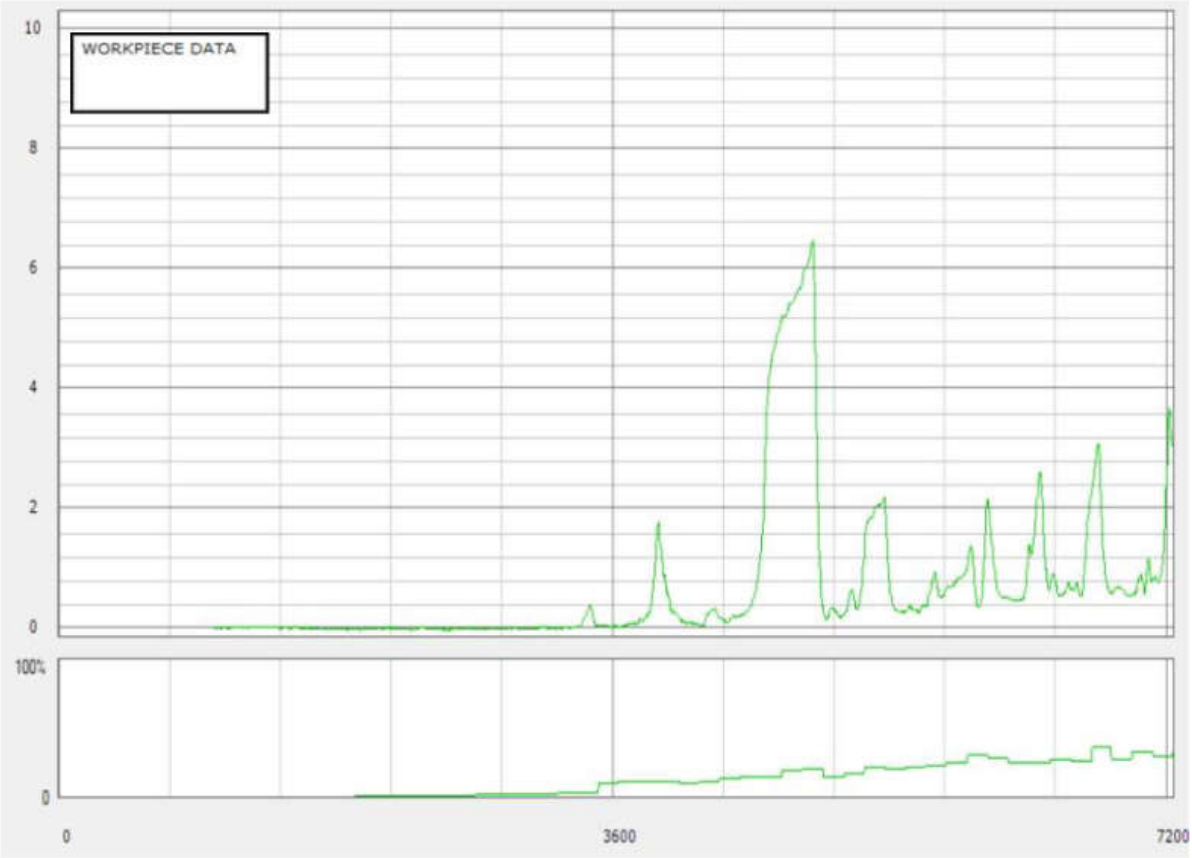

Figure 5: 2nd Pre-Scan was done using an unbalance of 50%, and showed a number of peaks, most of which grew during the 1st treatment. This Pre-Scan functions as a baseline from which the progress of treatment is gauged.

Full scales for this chart:

Acc = 10 g's	**(adjustable from 1 – 50 g's)**
Vibrator speed = 7200 RPM	**(adjustable up to 8 KRPM)**
Power = 2000 watts	**(fixed)**
Unbalance = 70% of 4.0 in-lbs.	

Acceleration has been found to be the best parameter to gauge vibration intensity, due to its proportionality to force, based upon Newton's Second Law:

F = ma where **F** is force, **m** is mass, and **a** is acceleration.

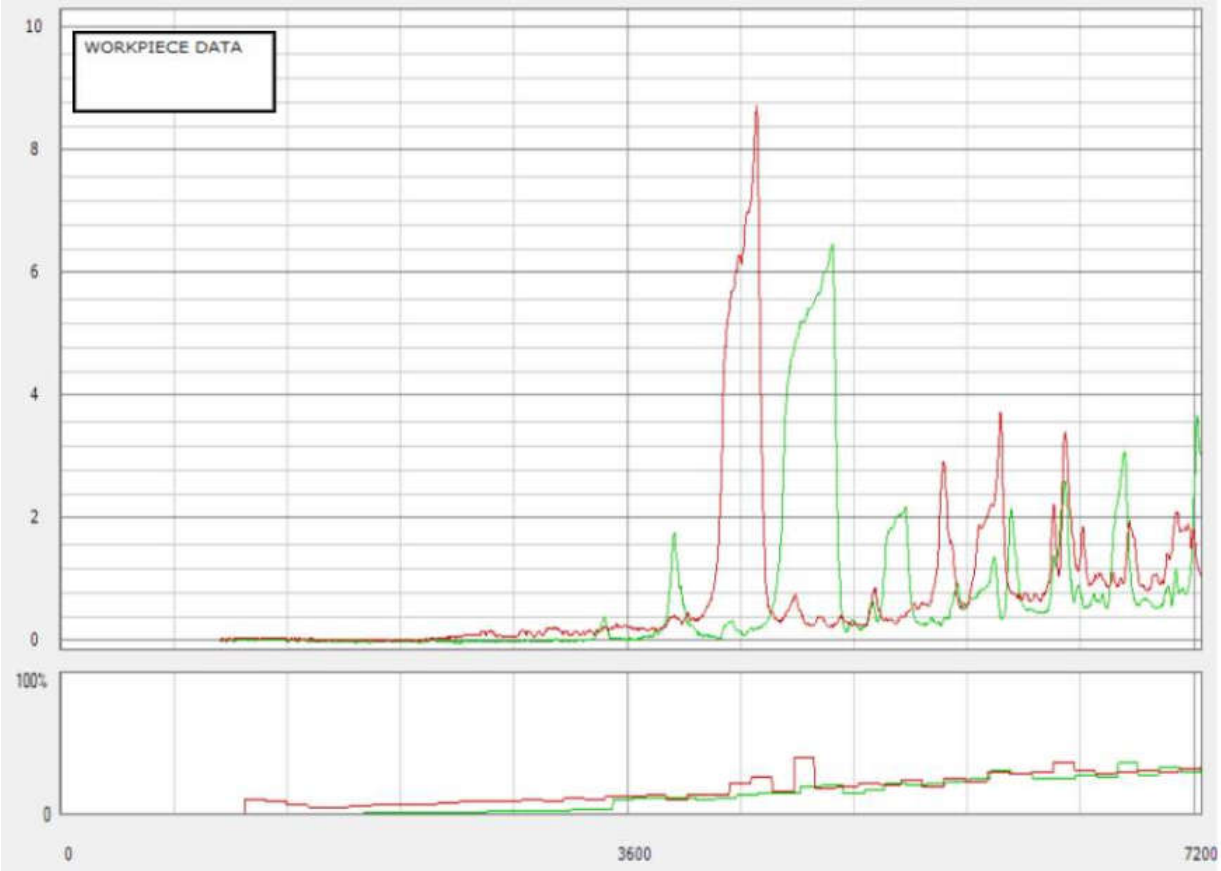

Figure 6: 1st VSR Treatment showed showed both shift and growth of most peaks, although a few disappeared or shorted. During the treatment an audible "pop" was noticed, and the short peak that was being treated reduced greatly, likely due to one of the braces, which were only tack-welded on, coming lose. However, it did not interfere with continuance of the treatment. The large peak, growing from roughly 6 g's to 9 g's, and reducing in frequency by more than 10 %, took roughly 30 minutes to stabilize. Overall, the treatment took a little more than 1 hour.

Full scales for this chart:

Acc = 10 g's	**(adjustable from 1 – 50 g's)**
Vibrator speed = 7200 RPM	**(adjustable up to 8 KRPM)**
Power = 2000 watts	**(fixed)**
Unbalance = 50% of 4.0 in-lbs.	

Full-scale for acceleration is adjustable from 1 – 50 g's, and can be adjusted after a scan is made, in the event the plot is too "short" or too "tall". Full-scale for vibrator power is preset / fixed, with 100% = 3 HP (~ 2.0 kW), the power capacity of the sync

motor that powers the VS9 vibrator. Full scale for vibrator RPM is adjustable up to 8,000 RPM.

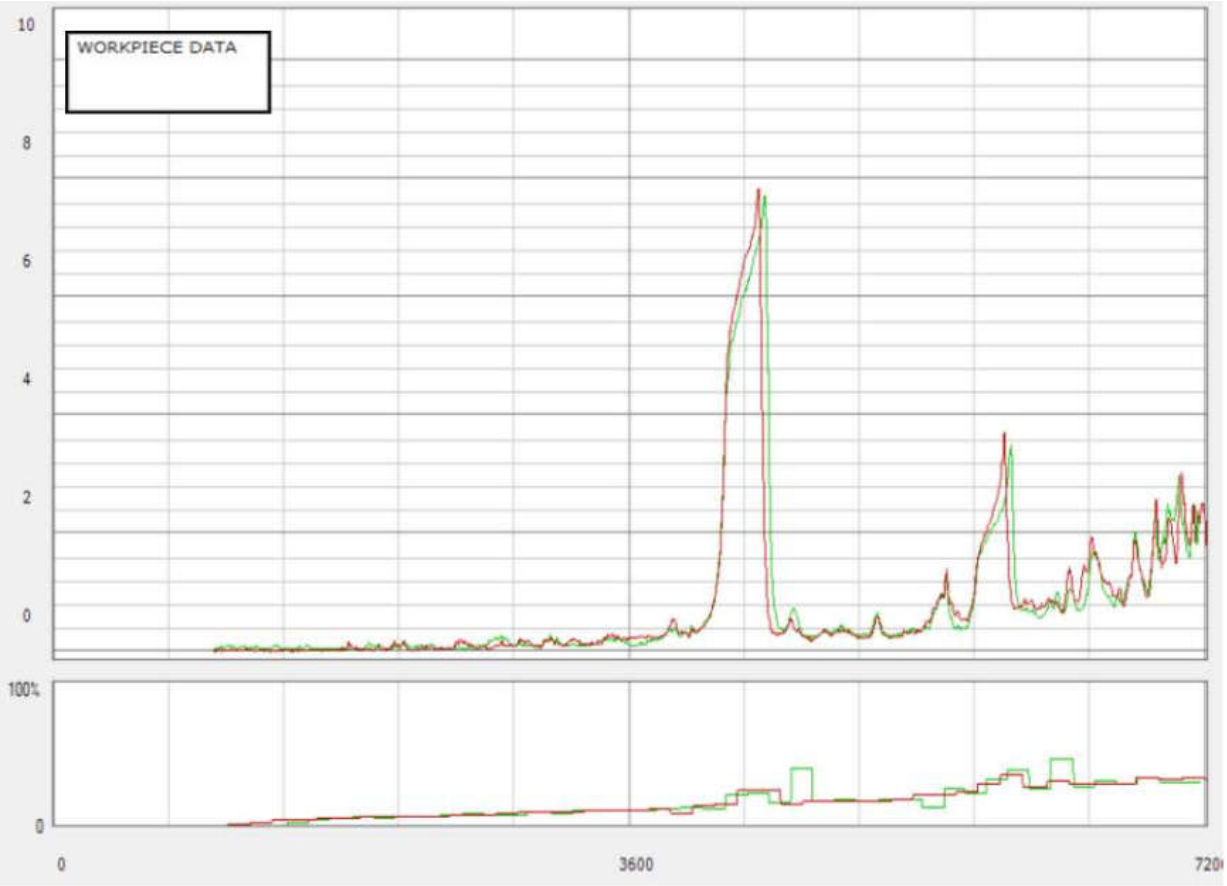

Figure 7: 2nd VSR Treatment showed very little change, even thou treated at the major peaks for a total of 25 minutes. Changes in resonance pattern occur quickly, so this was more than sufficient treatment time to indicate that it had stabilized.

Acc = 10 g's	**(adjustable from 1 – 50 g's)**
Vibrator speed = 7200 RPM	**(adjustable up to 8 KRPM)**
Power = 2000 watts	**(fixed)**
Unbalance = 50% of 4.0 in-lbs.	

The Pre-Scan is all that is visible during the beginning of a Treatment, and functions as a base-line / reference. During effective stress relief treatment, resonance peakswill grow and / or shift (normally to lower frequencies), either change indicating

that the dynamic rigidity of the structure is reduced, a natural consequence of stress relief that is used to monitor and document VSR Treatment progress. Significant peak shifting to the right or peak height reduction, which can occur, are indications of work-piece shape change, or when braces come partially or fully lose.

VSR Treatment

VSR Treatment is done by tuning upon the work-piece resonant peaks, and monitoring any changes in resonant response. Generally speaking, stress relieving causes two distinct changes in resonance pattern to take place:

1. An increase in the height of the resonance peak (typically the strongest response)
2. A shift of the resonance frequency, normally in the direction of lower frequency (to the left on VSR Treatment charts)

The result of these changes is a stable resonance pattern, which goes hand-in-hand with both dimensional and mechanical stability.

Conclusion

As a result of the clear changes in resonance patterns, followed by stability, seen during both VSR Treatments, this workpiece should display good dimensional stability and mechanical integrity during subsequent machining, transport, assembly and usage.

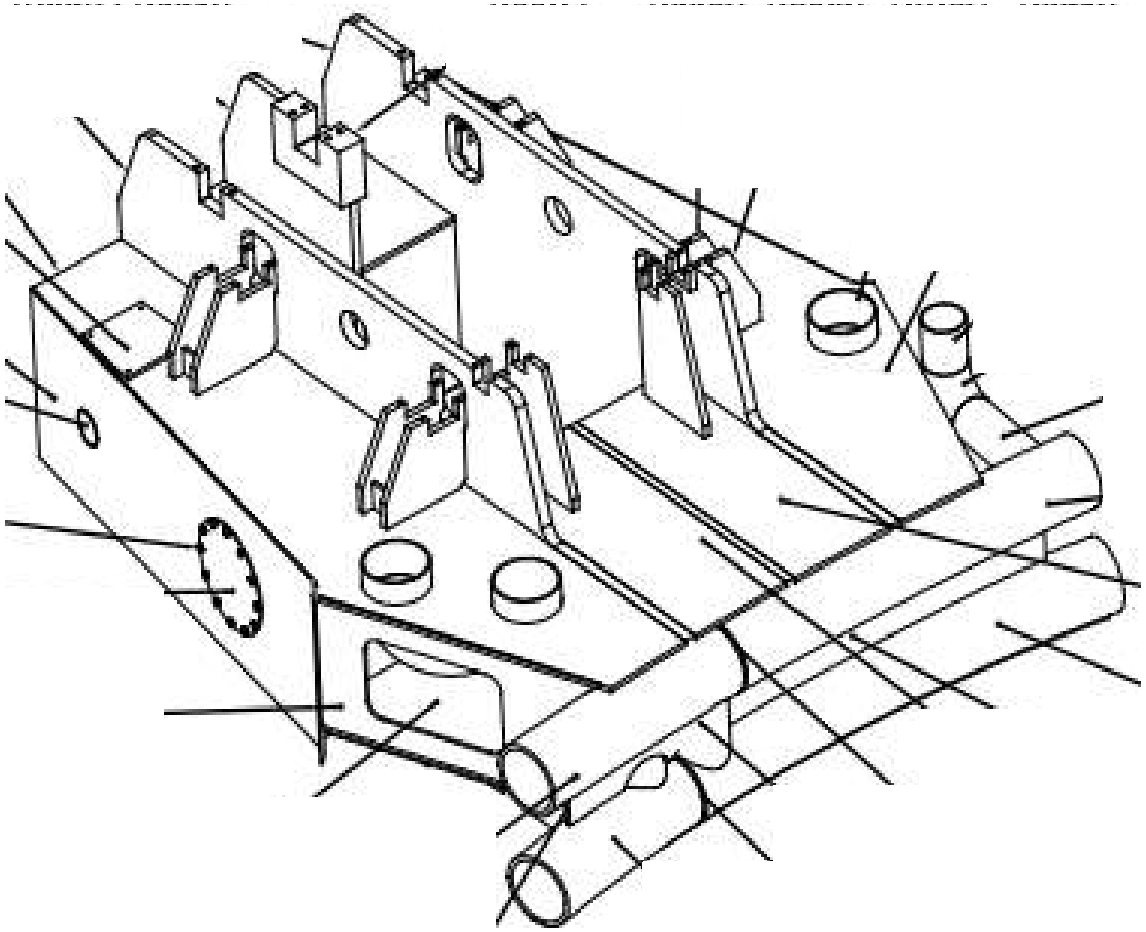

Figure 8 : 3D view of workpiece