



Report on Vibratory Stress Relief

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THREE D METAL

Andrews, SC

GERDAU AMERISTEEL Job

THREE D METAL has employed VSR Technology On-Site Service on two previous projects, involving 250-ton capacity Lifting Yokes and 400-ton capacity Clamshells. In this latest project, performed at GERDAU's Knoxville, TN mill, a Lower Shell for an electric arc furnace, measuring 30' L, 20' W, and 10' H, was stress relieved in less than 3 hours using the VSR Process. In addition to relieving the weld stresses produced in THREE D METAL's shop during fabrication, the Job also required stress relieving a full-length field weld, joining the two Furnace Halves.

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THREE D METAL employed VSR Technology On-Site Service to stress relieve a Lower Shell for an electric arc furnace, measuring 30' L, 20' W, and 10' H. Besides the weld stresses produced in THREE D METAL's shop (Andrews, SC) during fabrication, the Treatment was asked to stress relieve a full-length field weld, joining the two Furnace Halves back together, at THREE D's customer, GERDAU AMERISTEEL's plant.

VSR Setup

The workpiece was placed on four Isolation Load Cushions, located beneath the outer four of the six temporary brace legs welded to the Shell (*see* Figure 1). Workpiece configuration did not allow for ideal location of the Cushions. Locating the Cushions closer to the center of the workpiece is preferred, but this Cushion arrangement still allowed sufficient flexure of the workpiece during resonance to perform the VSR Process effectively.

Resonant frequency vibration is used because it can maximize flexure of the workpiece, which is key to the effectiveness of vibratory stress relief. Several independent research works, including those of Hahn¹, Shankar², and Yang, Jung and Yancey³, have proven that resonance frequency vibration is the most effective form of vibration to relieve stress.



Figure 1: VSR Setup. Four Isolation Load Cushions (circled) supported the workpiece. The Vibrator was mounted on the left (circled), adjacent to one of the support legs. The Accelerometer (vibration sensor) was mounted on the opposite side of the workpiece, mounted to a protruding member, and oriented so as to be most sensitive to vertical deflection.

The Vibrator was mounted to a locally stiff portion of the workpiece, between two vertical plates, and the Vibrator's Axis of Rotation was Horizontal (AOR-H), and aligned with the opposite side of the workpiece (effectively with workpiece length).

A trial run starting at a low (20%) unbalance setting, and then incrementally increased settings, found that a setting of 80% unbalance (of the available 4.0 in-lbs, ie, 3.2 in-lbs) was required to generate distinctive resonance peaks of suitable amplitude to perform the VSR Process.

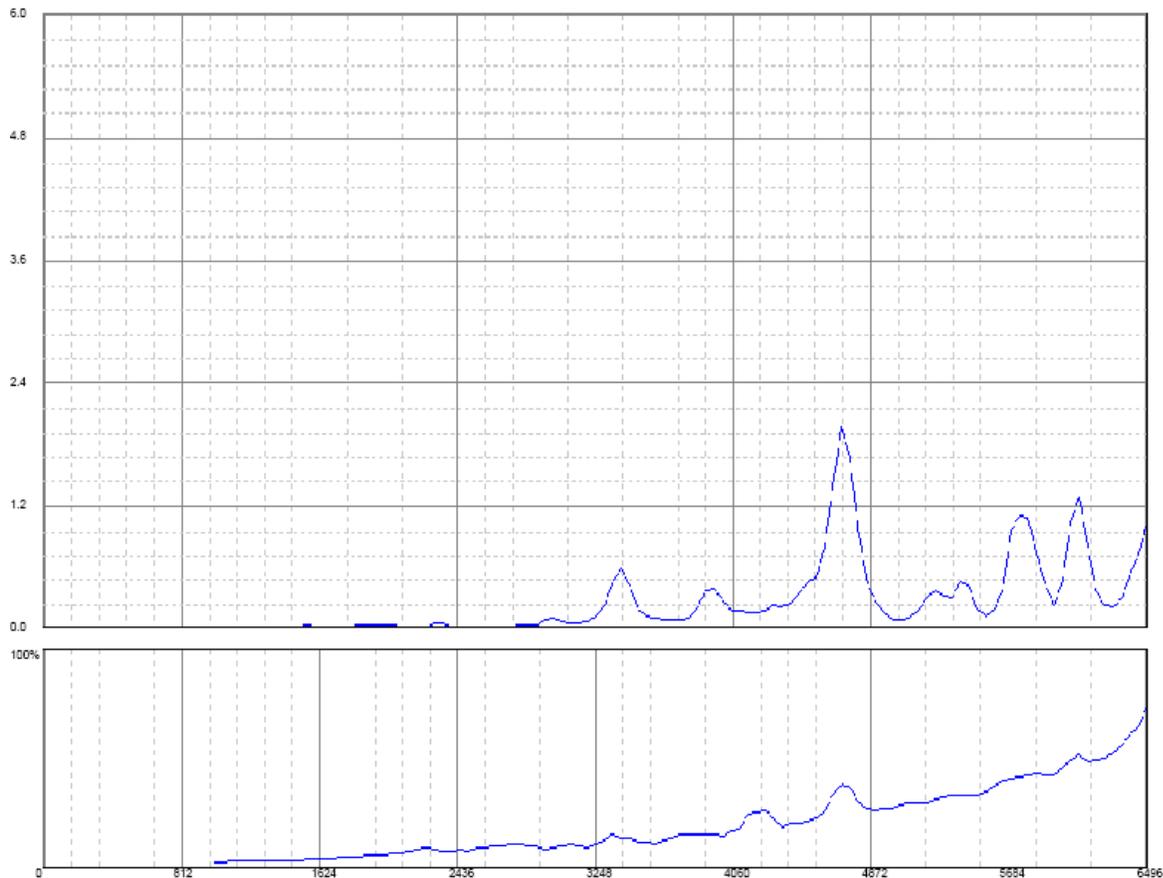


Figure 2: QUICK SCAN. This Scan, run to determine if resonances are within the unbalance setting and speed range preset by the operator, shows the general pattern of resonance peaks that will later be seen during a Pre-Treatment Scan. Upper curve is workpiece acceleration (vertical) vs. vibrator RPM (horizontal). Lower curve is vibrator power (vertical) vs vibrator RPM. (More detail on VSR Chart layout in Figure 3.)

The Accelerometer (a vibration sensor whose output is proportional to acceleration), was mounted on the furthest of two protruding members (the near member being partially visible in Figure 1, on the left), and oriented so as to be most sensitive to vertical vibration amplitude.

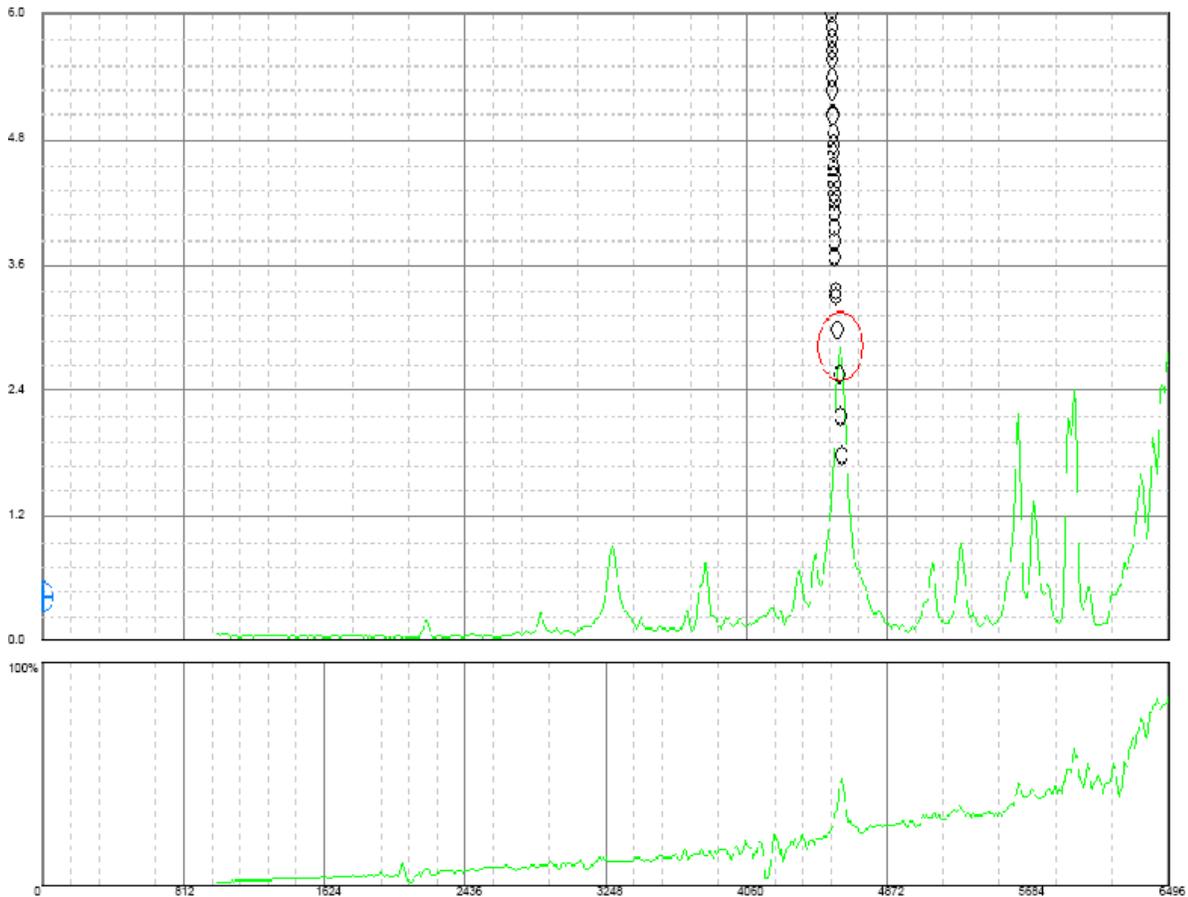


Figure 3: Pre-Treatment Scan. VSR Treatment Charts consist of two plots: An upper plot of workpiece acceleration and a lower plot of Vibrator input power, both of these plotted on a vertical axis vs a common horizontal axis of vibrator RPM. Peaks in the upper plot are resonances of the workpiece. Peaks in the lower plot are resonances that cause increased, perhaps excessive, vibrator input power, requiring minor adjustment to the VSR setup (lowering of unbalance and/or repositioning of vibrator).

Full-scale for acceleration is adjustable from 1 – 50g, and can be adjusted after a scan is made, in the event the plot is too "short" or "tall". Max g setting for this Chart is 6g.

Full-scale for vibrator power is factory set, with 100% = 3 HP (≈ 2.2 kW), the power capacity of the brushless DC motor that powers the BL8 Vibrator.

Full scale for vibrator RPM is adjustable up to 8000-RPM, the max speed of the BL8 Vibrator. In this case, max RPM was adjusted to 6500-RPM (defaulting to 6496 by the touchscreen PC used to display the data.)

By having the data from both plots, a VSR operator can gauge the correct Vibrator RPM range, acceleration range, Vibrator unbalance setting, and Vibrator location.

Pre-Treatment Scan data is plotted in green, since the workpiece is “green” (not stress-relieved, like a green casting.)

An Accelerometer was placed on the corner of the workpiece, and oriented so to be most sensitive to vertical deflection. Both science and experience have shown that Acceleration (not velocity or deflection) is 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.

VSR Treatment

Treatment is performed by tuning on and then dwelling upon the workpiece 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 in the direction of lower frequency (to the left on VSR Treatment charts)

The first of these changes (increase in height) is consistent with a reduction in the stiffness of a workpiece, which is a consequence of effective stress relief. The second change (shifting) has been shown to often be a consequence of the first change, ie, peak growth.⁴

VSR Treatment was done by tuning to all the major peaks, and monitoring them for the classic changes in resonance that accompany stress relief: Peak growth and shifting. These include the peaks at 3250, 4600, 5322, 5597 and 5958-RPM. The following table details the peak growth (the stronger response), seen for these five peaks.

RPM	PRE-SCAN HEIGHT	POST-SCAN HEIGHT
3250	0.93g	1.44g
4600	2.70g	4.45g
5322	0.93g	1.24g
5597	1.97g	2.48g
5958	2.38g	3.21g

These changes are represented graphically in Figure 4, the completed VSR Treatment Chart.

The most dramatic increase was the 40% growth of the peak at 4600-RPM, which also shifted 30-RPM in the direction of lower vibrator speed, a change of $\approx 0.65\%$. This peak was treated using the MX-8000 Console's AutoTreat software. This program produces a series of small black circles

called "progress dots", which show the history of peak growth. AutoTreat tunes the vibrator to a speed 50-RPM higher than the selected resonance peak, and then proceeds to lower speed, seeking the peak's maximum height.

Tuning and dwelling upon a peak, especially when the peak is relatively narrow (as is the case here), will often generate "g" figures above that seen during Pre- or Post-Treatment Scans, due to the delay of the workpiece reaching full resonant response during scanning. (The exact resonant frequency is only tuned upon momentarily, even when scanning at the modest rate of 10-RPM / sec, the recommended scan rate. Slower scan rates can be calibrated by the VSR Operator as needed.)

This series of progress dots continues up the page, and off-scale (full-scale was 6.0g for this Treatment) but was verified with the Console's digital display, maxed out at 6.8g.

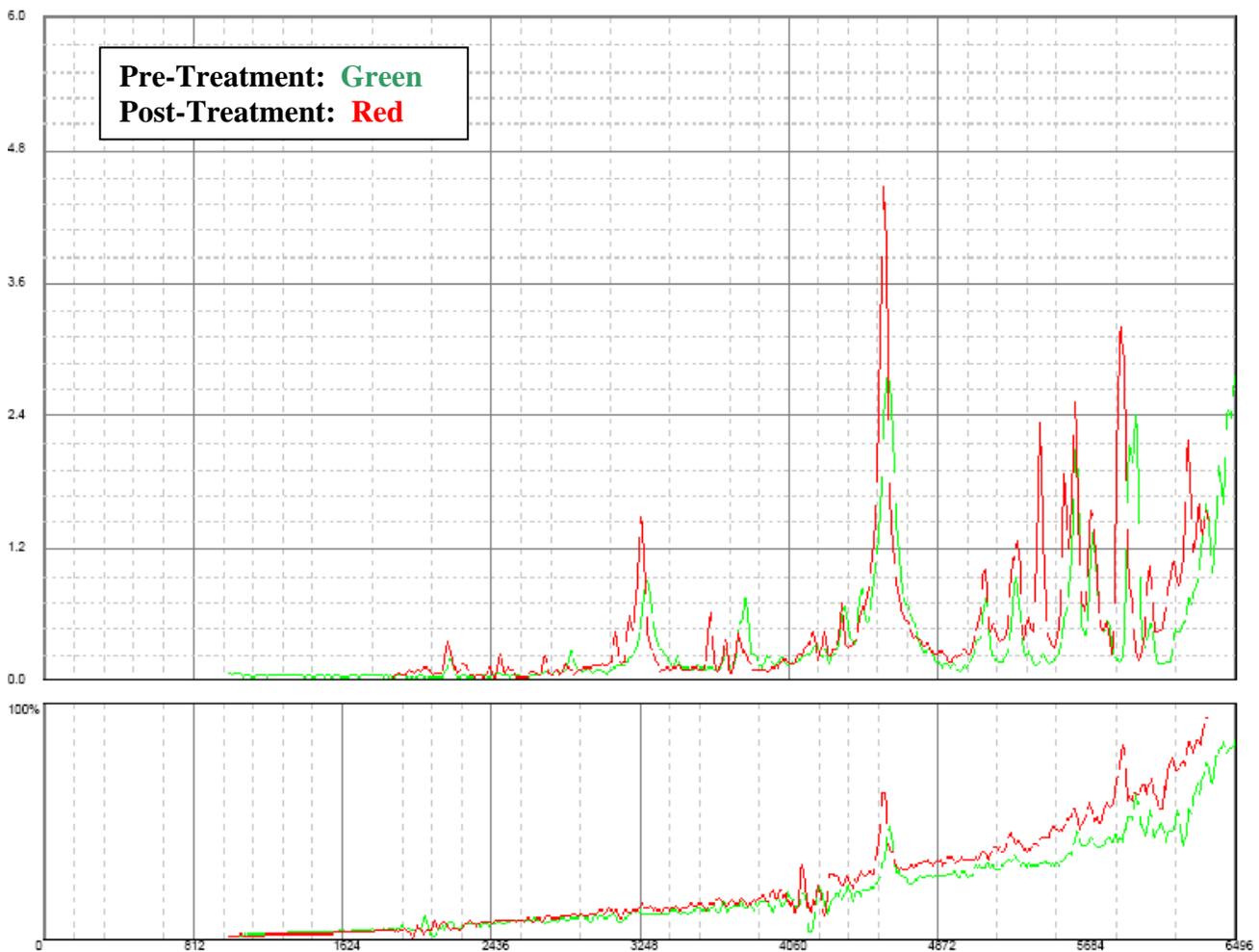


Figure 4: Completed VSR Treatment Chart. The original Pre-Treatment Scan (green) is left intact, and, after all peaks were tuned upon and treated until stable, followed up with a Post-Treatment Scan (red). Changes in the resonance pattern, primarily peak growth and shifting, are due to a lowering of workpiece rigidity, which accompanies stress relief.

To determine if a second VSR Treatment was required, a different VSR Setup was used:

- The Vibrator was reoriented to AOR-V.
- A Trial run at the previously used 80% or 3.2 in-lb unbalance showed this setting to be too high, due to a high power peak tripping the motor protection. Incremental decreases in the unbalance were performed, eventually determining that a setting of 0.6 in-lb (15%) was needed to drive a single large resonance.
- Despite the strong resonance peak, no additional change in resonance pattern, ie, no additional stress receiving, took place.

Thus, the first VSR Treatment was sufficient to render the part dimensionally stable.

Conclusion

As a result of the clear change in resonance pattern during the first Treatment, and the stable resonance pattern seen during the second Treatment, this workpiece should exhibit good dimensional stability and mechanical integrity during subsequent installation and usage.

Footnotes:

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](#)

⁴ Adams, Klauba and Berry, Vibratory Stress Relief: Methods Used to Monitor and Document Effective Treatment, A Survey of Users and Directions for Further Research

NB: Source Research Works available in the VSR On-Line Technical Library @ <http://www.vsrtechnology.net/>

Bruce Klauba has a degree in Physics and a Level II Vibration Analysis Certification from the American Society of Non-Destructive Testing (ASNT). As a pioneer in the cause and effect of Vibratory Stress Relief, Mr. Klauba was named chief inventor (*Klauba et al.*) in U.S. Patent 4,381,673, which is both an equipment and process patent describing advances in the technology. He has authored numerous articles and original research papers on the subject, which have been published in leading magazines and periodicals.

Published papers include:

1. "Use and Understanding of Vibratory Stress Relief", *Productive Applications of Mechanical Vibration*, 1983, American Society of Mechanical Engineers.
2. "Vibratory Stress Relief: Methods used to Monitor and Document Effective Treatment, A Survey of Users, and Directions for Further Research", 2005, *Trends in Welding Research*, ASM International.

A co-author in both papers, Dr. C. Mel Adams, is a leading authority in metallurgy and co-founder of MIT's Welding Research Department. In addition, Mr. Klauba has extensive experience in designing, building, and troubleshooting Industrial and Commercial Electrical Controls with a focus on extending the performance and reliability of Electric Motors and the systems they power.



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