VSR Technology Group
The cost effective alternative to heat treatment

Report on Vibratory Stress Relief

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VOITH-SIEMENS is a manufacturer of power generation systems. One of their more recent designs involved the use of both low-carbon and austenitic stainless steels in the construction of a 4-quadrant hydro-turbine Bottom Ring.

The VSR Process was used to prevent distortion occurring during either final machining, or the transport of the disassembled Bottom Ring to the installation site.

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Austenitic stainless steels respond marginally to PWHT, due to the steels' high-strength at elevated temperatures. For this reason, precision components made out of 300 series stainless steels are often vibratory stress relieved. When these steels are combined with low-carbon steel thermal treatment is precluded altogether. VOITH-SIEMENS has learned through experience that using PWHT on such components is likely to initiate cracking.

When VOITH-SIEMENS incorporated bimetallic construction in the design of a 4 quadrant Bottom Ring, it recognized that the problems of residual stresses, and how to best relieve them, were unresolved issues. Previous designs that included bimetallic construction would distort during transport, causing on-site fit-up and assembly difficulties. In fact, this phenomenon of the precision-machined components changing shapes during transport was the historical path which led to the discovery of Vibratory Stress Relief more than half a century ago.

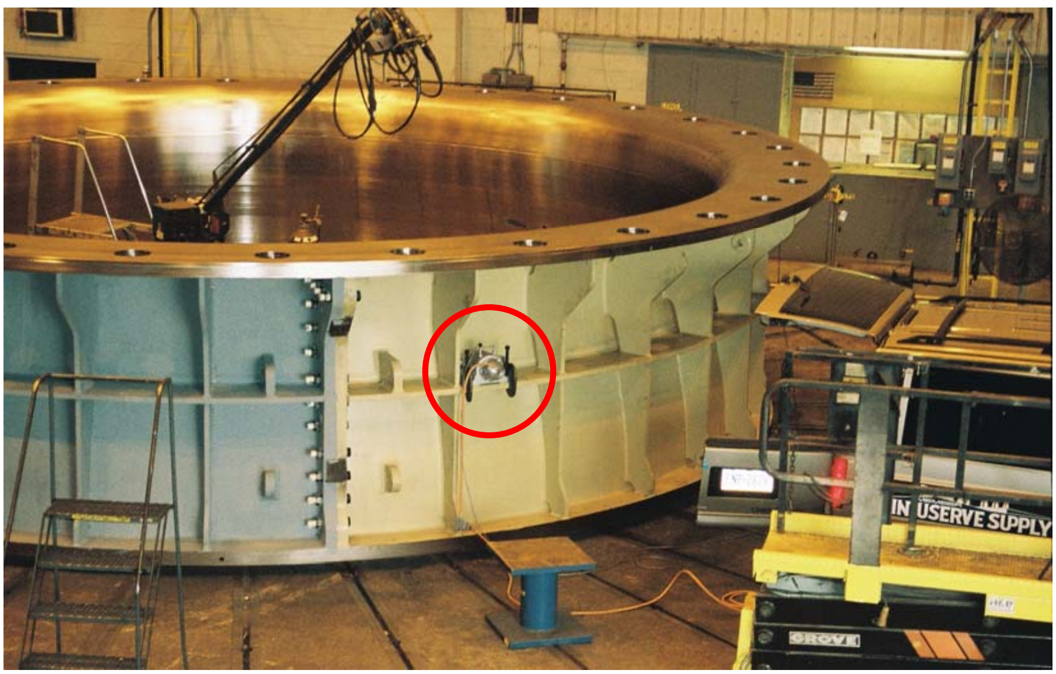


Figure 1: Bottom Ring setup for VSR Treatment. Vibrator can be seen near center of image (circled), oriented so its axis of rotation (AOR) is horizontal, which will drive the Ring into resonance modes having axial amplitude.

VSR SETUP

The assembled Bottom Ring was placed on 3 Isolation Load Cushions to isolate the workpiece. Two of the Load Cushions were placed 6' apart on one side, beneath the workpiece's bottom flange. The third Load Cushion was placed on the opposite side, directly across from the midpoint of the other 2 Load Cushions.

This 3-point, unequally-spaced arrangement minimizes dampening of the workpiece, enabling maximum flexure during resonating to take place, a fundamental requirement of the VSR Process. See **Figure 2**.

A VSR-8000 System with a BL8 Vibrator was used to stress relieve the Bottom Ring. This vibrator offers a RPM range of 10 RPM to 8000 RPM, and an unbalance range of 0.2 to 4.0 in-lbs. Combined with the tight vibrator speed regulation, rated at 0.02%, this system is capable of driving the relatively sharp resonances that this large, highly rigid, ring configuration would exhibit.

Rings have two general families of resonance: Bend and Torsional Axial Modes, and Elliptical (egg shaped) Radial Mode. These two families are highly independent: A rotary eccentric vibrator, whose force-field output is a plane perpendicular to the vibrator's AOR, cannot be positioned and oriented at one locale, and successfully excite both resonance families.

Therefore, based on the configuration of the workpiece, the VSR Technician knew that two VSR Treatments were required:

- The first Treatment would have the vibrator oriented such that its AOR would be horizontal. This would require 2 steps (Treatments 1A and 1B) as to excite both the Ring's Bend and Torsional Resonance Modes.

- The second Treatment (Treatment 2) would have the vibrator oriented so the AOR was vertical. This would excite the Ring's Elliptical Mode.

The combination Treatments would cumulatively result in a comprehensive and highly effective stress relief. The BL8 Vibrator, with two sets of perpendicular mounting feet, easily allows two treatments with distinctively different vibrator orientations to be performed.

The first VSR Treatment used an orientation with the vibrator's axis of rotation (AOR) horizontal, as shown in **Figure 1** and **3**. Resonance data gathered during this Treatment also revealed two groupings of resonances at divergent frequencies. These two groups of resonances could not be effectively treated using only one vibrator unbalance setting, and so two Treatments (1A and 1B) were performed using the vibrator's initial horizontal AOR orientation: One at a relatively high-unbalance (3 in-lbs) for the lower-RPM resonances, and one at 0.8 in-lbs, for the higher-RPM resonance.

FIGURE 2. One of three orange Isolation Load Cushions can be seen in the left foreground (circled). The second Load Cushion (not visible) was placed under that area of the workpiece in the right foreground, 6' to the right of the visible cushion. The third Load Cushion was opposite the midpoint between these two, under the far side of the workpiece. The Accelerometer is clamped on the upper right of this image (circled). One of the Vibrator's clamps is visible to the right (circled) of the VOITH-SIEMENS employee.

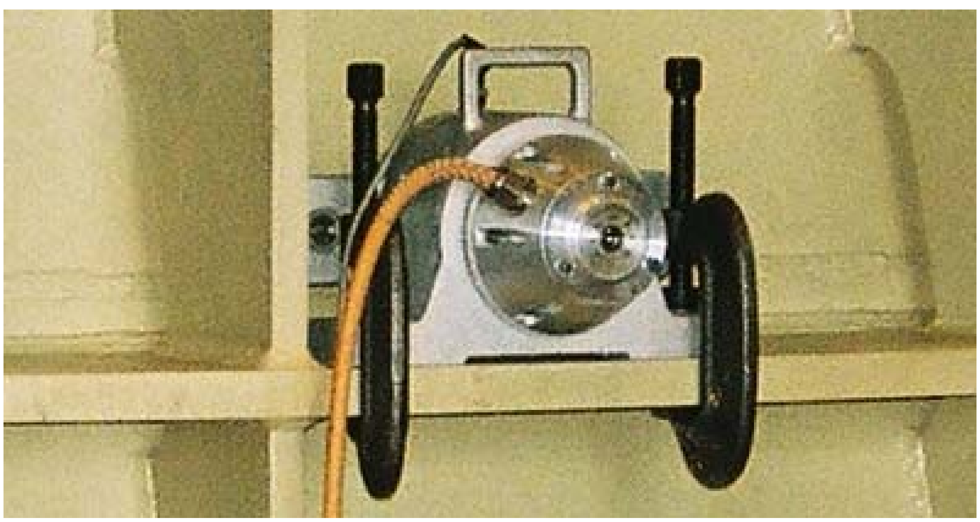


FIGURE 3. Close-up of BL8 Vibrator mounted for Treatments 1A and 1B, with the AOR oriented horizontally. The scale on the face of Vibrator motor is used to adjust the unbalance from 5% to 100% of its 4.0 in-lbs available unbalance. This Vibrator is powered by a 3 HP (≈ 2.2 kW), brushless DC motor.

VSR Treatment Charts

VSR Treatment Charts are a collection of data displaying the response of a workpiece to vibration both before and after Treatment, and can include data gathered during the actual Treatment. Treatment Charts include plots of both the workpiece acceleration and vibrator input power, each represented along its own vertical Y-axis, with the common X-axis of vibrator frequency.

The units of measure for each of these sets of data are:

- Acceleration: one "g" is equal to the gravitational acceleration of the earth (32 feet or 10 meters / second / second.) This acceleration parameter is used (rather than deflection or velocity), since the force to which the workpiece is subjected is proportional to the acceleration (Newton's 2nd Law: **F= ma**, where "**F**" is force, "**m**" is mass, and "**a**" acceleration). The VSR Technology Group has standardized on relative force measurement, since it is the most scientifically indicative parameter to monitor the progress of Vibratory Stress Relief Treatment.

- Vibrator input power: Watts and percentage of motor power rating.

- Vibrator frequency: RPM or rotations-per-minute. Using RPM as the measurement allows 4 significant digits to be expressed without having to use a decimal point. (Divide by 60 for conversion to Hz).

There are three steps in generating a VSR Treatment Chart:

1. The Pre-Treatment Scan (Pre-Scan). This shows the initial response of the workpiece to vibration, prior to VSR Treatment. This data is gathered using the AutoScan feature to sweep through a selected vibrator speed range that includes workpiece resonances. The Pre-Scan is recorded in green (since the workpiece at this point is "green", like a fresh casting or weldment, ie, full of stress). An example of a Pre-Scan is shown in **Figure 4,** Pg 5.

2. The VSR Treatment. This step requires the System to be tuned upon each of the workpiece resonances identified during the Pre-Scan, while changes in the resonances are being monitored. These changes occur in two forms:

   - Peak Growth: Peak(s) grow to a higher amplitude – the stronger of the two responses.

   - Peak Shift: Peak(s)shift in the direction of lower vibrator frequency (to left on Chart), this is the weaker of the two responses.

If the Treatment is being performed using the System's AutoTreat software, the path of growth and/or shifting of the resonance is recorded as a series of circles called Progress Dots. Progress Dots are placed at the vibrator speed and corresponding workpiece acceleration at that moment. These were recorded automatically every 15 seconds. The display of Progress Dots can be selected, both during Treatment, and in the automatically saved archive of the Treatment, from rates of once every 15, 30, 60 or 180 seconds (or none). Examples of Progress Dot patterns are shown in **Figures 8** and **9.**

3. Post-Treatment Scan (Post-Scan). This scan, recorded in red, records the stable resonance pattern as changed due to Treatment. When the resonance peak(s) are extremely narrow, Progress Dots more clearly depict the workpiece's response to Treatment than the Post-Scan recording. This was the case during the workpiece's second Treatment (Treatment 2), as shown in **FIGURE 9.**

FIGURE 4. Pre-Treatment Scan: Treatment 1A. Upper plot is workpiece acceleration vs. vibrator RPM; lower plot is vibrator input power vs. vibrator RPM. Upper plot (which is full scale adjustable from 1g to 50g) shows resonance peaks that are tuned upon to perform Treatment. Lower plot (whose full scale equals 3 HP or 2.2 kW) data allows operator to choose vibrator location and unbalance. For Treatments 1A and 1B, vibrator AOR was horizontal see **Figure 3**. For Treatment 1A, vibrator unbalance was set at 70% (2.8 in-lbs). Accelerometer was oriented to be sensitive to vertical amplitudes for both treatments 1A and 1B. The blue cursor above the peak at 3920 RPM shows that, at the moment this image was saved, the vibrator was tuned upon this peak. Both this peak and the larger, 3800 RPM, peak (to the left) grew ≈ 25% before stabilizing during the 47 minute treatment.

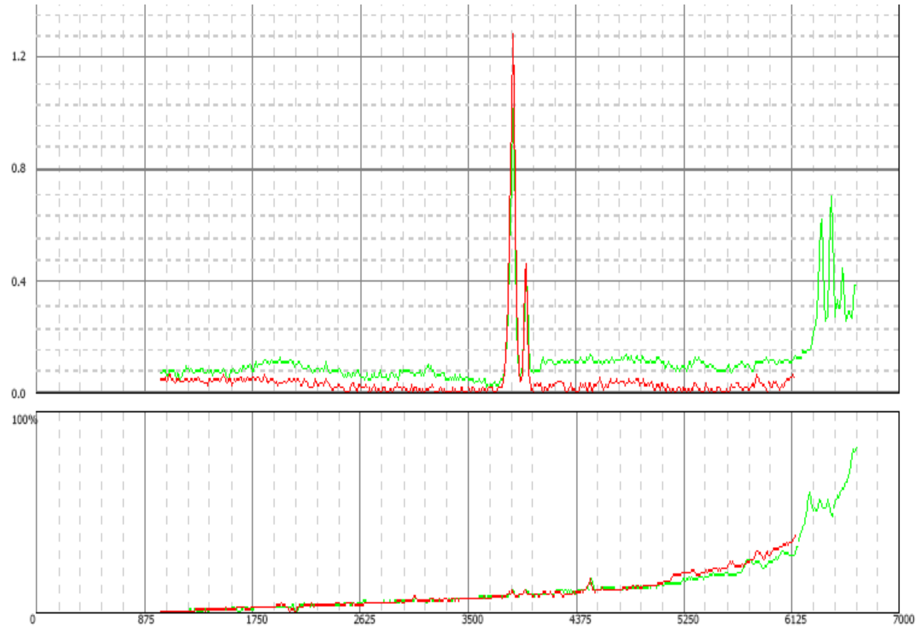


FIGURE 5. Treatment Chart: Treatment 1A. Green Pre-Scan remains intact while red Post-Scan is made. This documents changes that occurred during Treatment. This VSR Treatment Chart shows growth of ≈ 25 % for both peaks near center of Chart. Resonance peaks on right were not tuned upon during the Treatment 1A, since they were precursor peaks to a larger resonance further to the right, which is indicated by sharp increase in vibrator power. To address resonance peaks in the range above 6000 RPM, vibrator unbalance was lowered, which reduced vibrator input power, and allowed scanning up to 7000 RPM during Treatment 1B. (See **FIGURE 6**.)

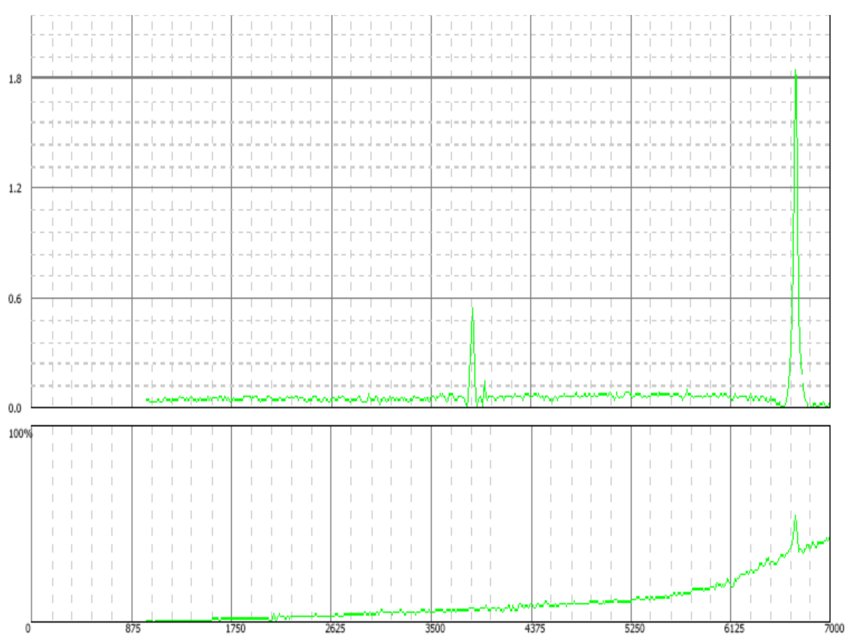


FIGURE 6. Pre-Treatment Scan: Treatment 1B: Vibrator AOR horizontal; vibrator unbalance reduced to 20% (0.8 in-lbs.). Accelerometer oriented to be sensitive to vertical amplitudes (same as Treatment 1A). Treatment was performed on the large peak (6685 RPM), which grew 16% during Treatment.

FIGURE 7. Treatment Chart: Treatment 1B. The red Post-Treatment Scan documents growth of 16% of the 6685 RPM peak. The previously treated, smaller peaks also grew, a common occurrence during the VSR Process. Treatment time was 26 minutes.

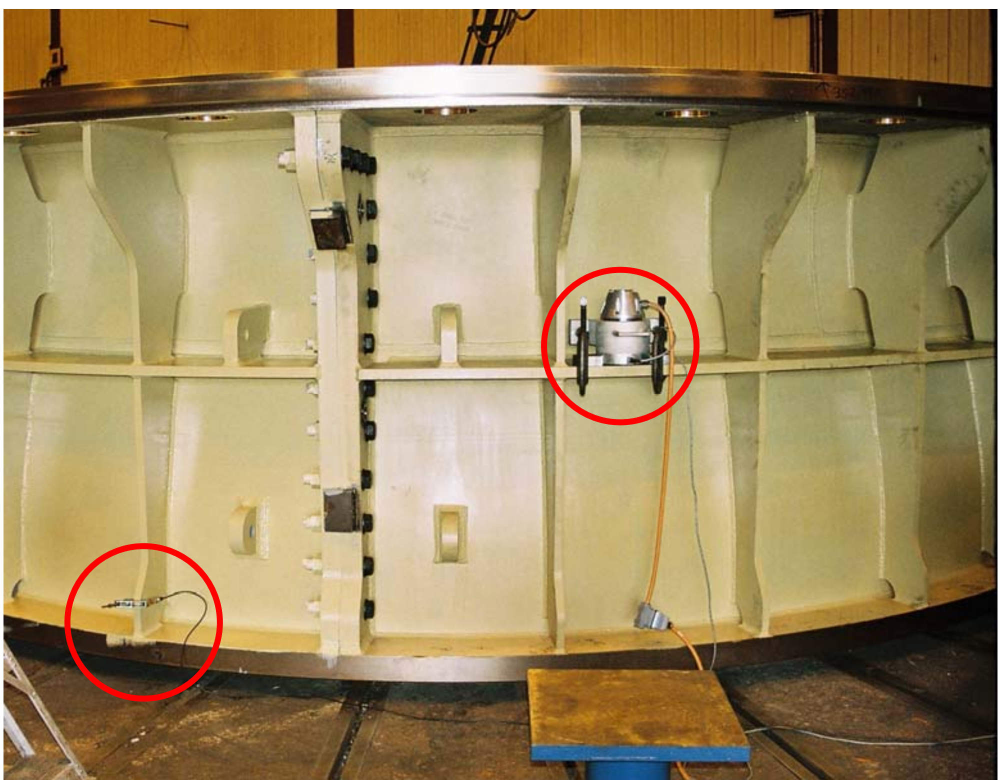
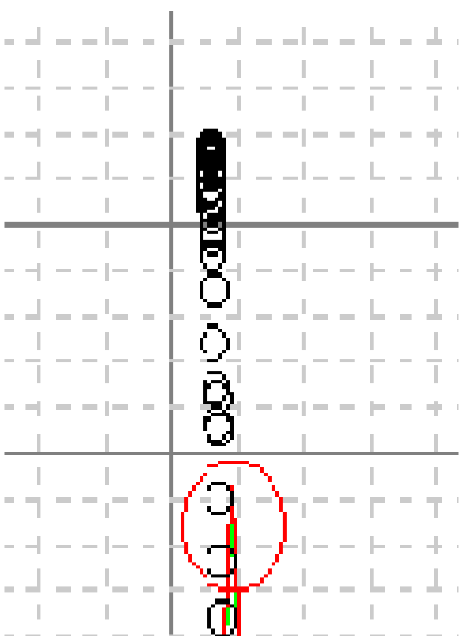


FIGURE 8. For VSR Treatment 2, the vibrator orientation (but not location) was changed so that vibrator AOR was vertical. This drove the workpiece with a force-field in the radial plane. The Accelerometer (circled) was moved, and reoriented to best detect radial flexure. Vibrator unbalance was set at 40% (1.6 in-lbs.).

FIGURE 9. Pre-Treatment Scan: Treatment 2. The vibrator's AOR was vertical, the vibrator unbalance set at 40% (1.6 in-lbs), and Accelerometer oriented to be sensitive to radial amplitudes. The short peak at 3060 RPM did not grow. The extremely narrow peak at 4485 RPM grew 37% during Treatment, but this growth was difficult to distinguish when comparing Pre-Scan and Post-Scan, due to the peak's very narrow shape, and the large inertia of the workpiece. Peak growth can be clearly seen, however, when using the system's AutoTreat software, by observing the Progress Dot patterns. The interval between Progress Dots is selectable, at intervals of 15, 30, 60 and 180 second spacing. On the Pre-Treatment Scan, shown above, a 60 second Progress Dot spacing was used. The blue, real-time cursor at the top of the peak indicates that this image was saved at the end of this VSR Treatment.



In these images of Treatment 2, a Progress Dot spacing of 15 seconds shows the peak being tuned upon by the system's AutoTreat software, followed by a period of peak growth that lasted several minutes. The growth rate starts to decrease near the end of the Treatment, resulting in a series of Progress Dots overlapping, or "clustering" as the peak stabilizes at its maximum. At the top, several Progress Dots overlap, indicating resonance peak stability. An enlarged view of the Progress Dot pattern is shown to the left.

Worth noting are the distinct groups of frequencies driven by the two different vibrator orientations:

VIBRATOR AOR	PEAK FREQUENCIES, RPM
a. Horizontal (Treatment 1a;1b)	3800,3920,6685
b. Vertical (Treatment 2)	3060,4485

Note that peaks seen during one vibrator AOR do not appear, or are extremely short during the other AOR. (The peaks at 3800 and 3920 are slightly visible on the vertical AOR data.) This is further proof of the independence of the two families of resonance modes found in ring-shaped workpieces, and demonstrates the need for multiple VSR Treatments to achieve an effective stress relief.

The unique combination of the VSR-8000 System's flexible vibrator design, using both sets of its mounting flanges, the highly precise vibrator speed regulation, and the Control Console's process / display instrumentation, enables workpieces such as this 40-ton weldment to receive the full benefits of the VSR Process.

Conclusion

The Treatment results on this Bottom Ring assembly, indicate this assembly will display excellent dimensional stability during subsequent machining, disassembly, transport and reassembly.

Bruce Klauba has a degree in Physics and a Level II Vibration Analysis Certification from the American Society of Non-Destructive Testing (ASNDT). 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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