



## **VSR Report**

**Voith Hydro, Sao Paulo, Brazil**

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Voith Hydro in Brazil tested the VSR Process, both upon a test work-piece of their own design, plus two production work-pieces: A mild steel heavy-plate half-ring weldment and a mild steel fabricated stator half-ring. Results upon the test work-piece showed significantly less distortion (3 times less) than has been achieved using thermal stress relief. The test work-piece results are shown in the table below:

No stress relief	3 mm
Thermal Stress Relief ( T S R )	1 mm
Vibratory Stress Relief ( V S R )	0.5 mm

The heavy-plate half-ring showed insignificant distortion during VSR Processing, but the stator half-ring distorted radially ~ 6 mm. These differing results do NOT mean that stress relief was less effective on one part. Both parts warrant stress relieving (achievable with the VSR Process) to assure good dimensional accuracy.

Voith Hydro in Brazil tested the VSR Process, both upon a test work-piece of their own design, plus two production work-pieces: A steel cast half-ring and a mild steel fabricated stator half-ring. Results upon the test work-piece showed significantly less distortion (3 times less) than has been achieved using thermal stress relief.

The work at Voith was performed over a two day period in late September 2012.

The test work-piece consisted of two mild steel plates, approximately 1 m L, 250 mm wide and 25 mm thick. One of the plates was clamped firmly with welded clamps to a solid block, also 1 m L and 250 mm both wide and thick. The other plate was positioned in the center of the first plate, so the two plates cross-section formed an inverted capital "T". Two passes of fillet welding on each side, ~ 6 mm wide, secured the plates together. Figure 1 shows the test work-piece, but note that the braces, one at each end, were removed prior to VSR Processing.



Figure 1: Test work-piece consisted of two mild steel plates welded securely together, forming an inverted "T", and clamped prior to welding to a solid block. Brackets at each end were removed prior to VSR Processing.

## VSR Setup

To mount the vibrator securely, an adaptor plate was welded to the side of the test work-piece. This plate was slightly larger than the vibrator's "footprint", and had two drilled and tapped holes, which were used to bolt the vibrator to the plate. The plate was oriented so that, using the standard side-mounting flange, the vibrator's Axis of Rotation (AOR) was in line with the length of the work-piece. The work-piece was placed on its side, atop 3 urethane isolation cushions (orange in color, with blue arrow). The vibrator (red arrow) was adjusted to 15% of the max of 4.0 in-lbs unbalance, or 0.6 in-lbs, and the accelerometer (vibration sensor, green arrow) was clamped on the corner of the unclamped plate. See Figure 2.

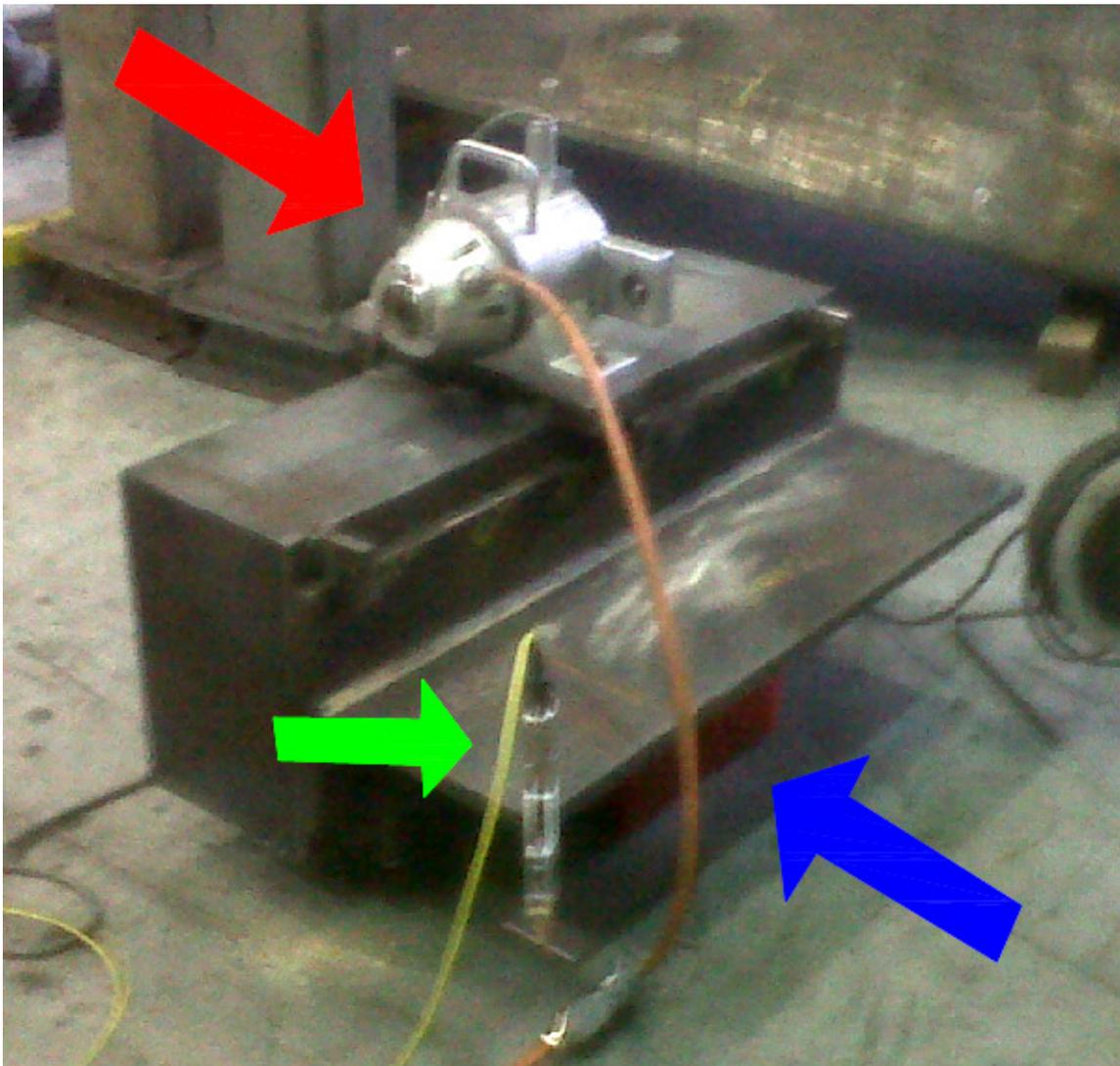


Figure 2: Test work-piece was placed on 3 urethane isolation cushions, two of which are visible (blue =>). The vibrator (red =>) was bolted to an adaptor plate that had been welded to the block. The accelerometer, a vibration sensor (green =>) was mounted on the corner of the unclamped plate, the best locale.

After setting up, the vibrator and sensor were connected to a VSR Model 8 Console and a preliminary Quick Scan was run, to see if there were detectable resonances, and their intensity, within the range of the VSR System.

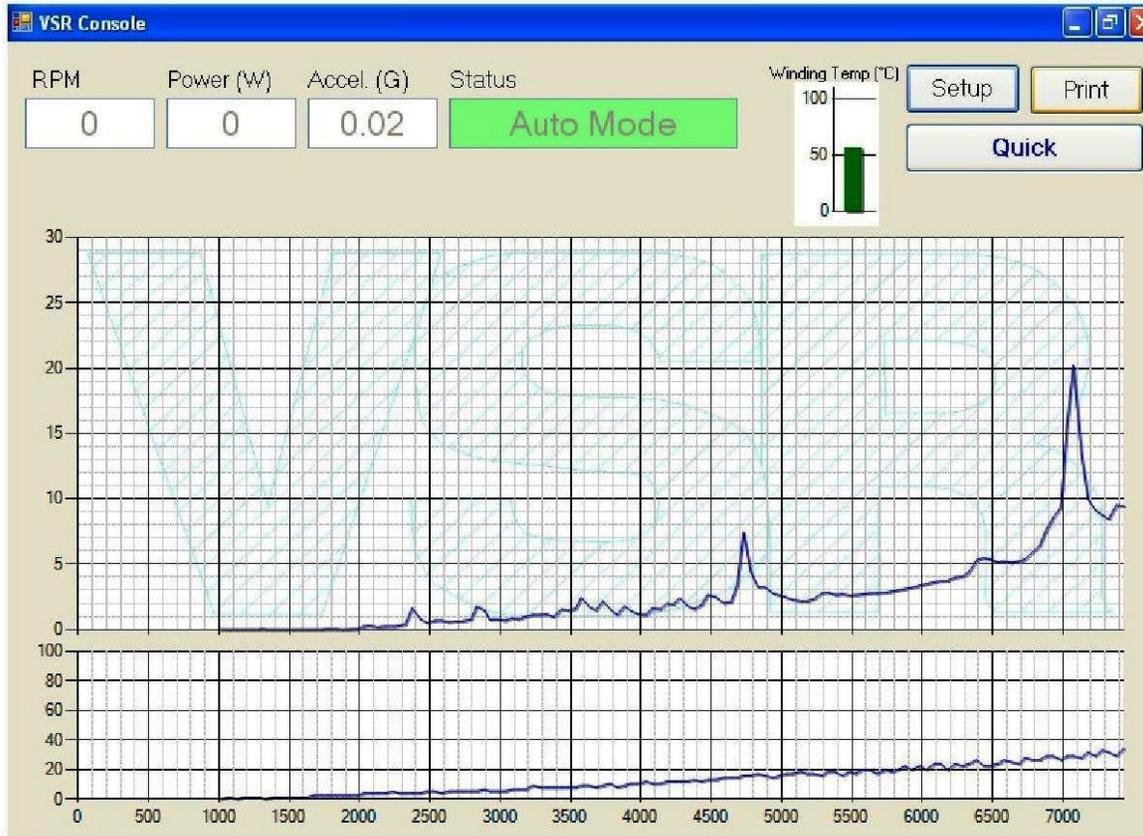


Figure 3: Quick Scan of test work-piece. VSR Charts consist of two curves: An upper ACCELERATION curve and a lower VIBRATOR POWER curve, each of these parameters plotted vertically (Y – direction), vs. a common X – axis of VIBRATOR SPEED (RPM). Both the ACC and the RPM scales are adjustable, and can be adjusted either before or after making a chart, while maintaining chart data integrity. POWER is a fixed scale, with 100 being 2.3 kW, the capacity of the BL8 vibrator.

Quick Scans (QS's) are plotted at a rate of 50 RPM / sec, which is too fast for high-resolution data to be recorded. QS's are plotted in blue.

Both Pre-Treatment (baseline, plotted in green) and Post-Treatment (documentation, plotted in red) Scans were made at the standard rate of 10 RPM. This rate can be adjusted prior to a scan, if needed.

Here the ACC Full – Scale (FS) has been adjusted to 30 g's, and the RPM FS to 7500 RPM. Resonance peaks at ~ 4500 and 7200 RPM can be seen.

After this QS was plotted, a Pre-Scan (baseline) was made which generated the higher resolution data shown in Figure 4.

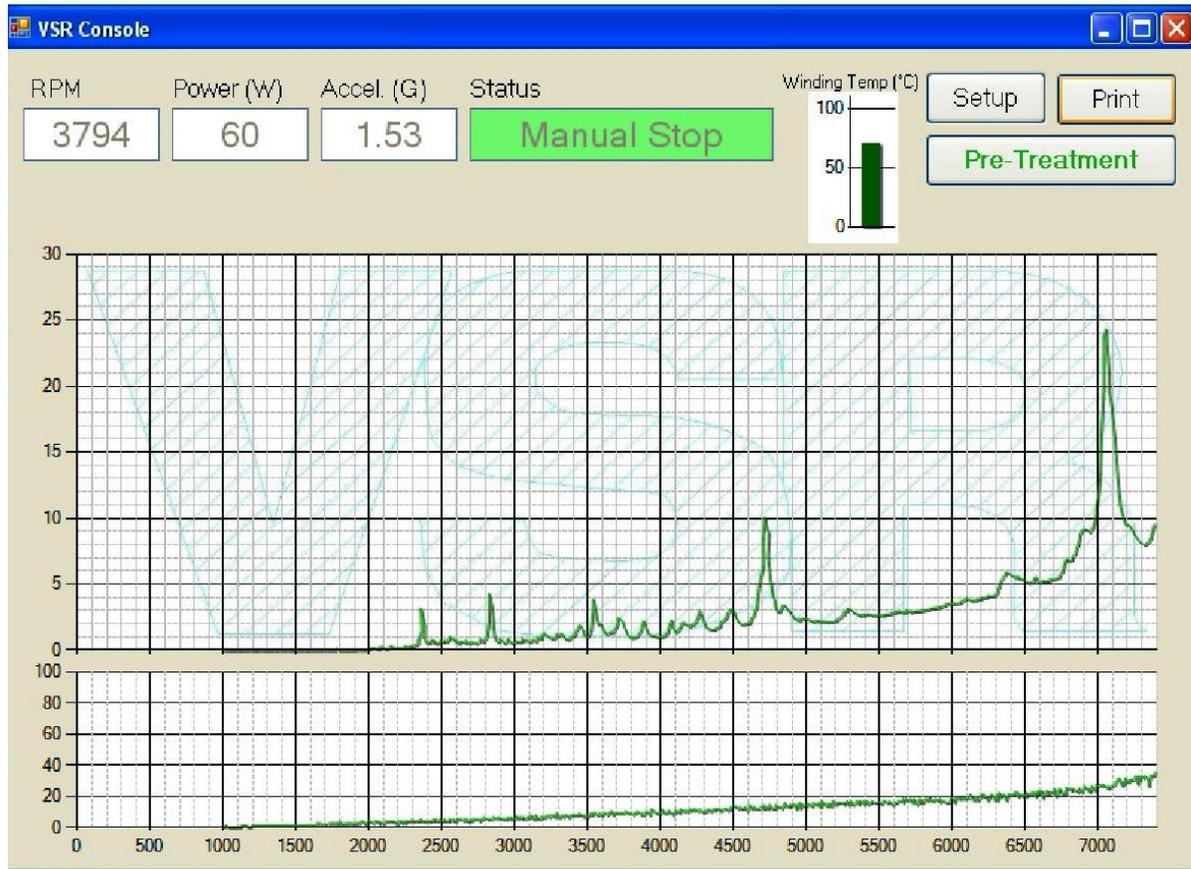


Figure 4: Pre-Scan shows a higher resolution set of data than in the QS, which is used as a baseline to perform VSR Treatment. Peaks in the ACC (upper curve) are tuned upon, and monitored for change. The classic changes during the VSR Process are peak growth or peak shifting, most often, but not always, to the left (lower frequency).

During treatment, the operator tunes the vibrator, using the Pre-Scan as a guide to tune upon peaks. A real time CURSOR, a black dot on the screen, depicts the real-time vibrator speed and work-piece acceleration. If peak growth or shifting take place, either the cursor, or the digital displays (which also display real-time data)

Little change took place during the first VSR Treatment, as shown on the completed VSR Treatment Chart, Figure 5.

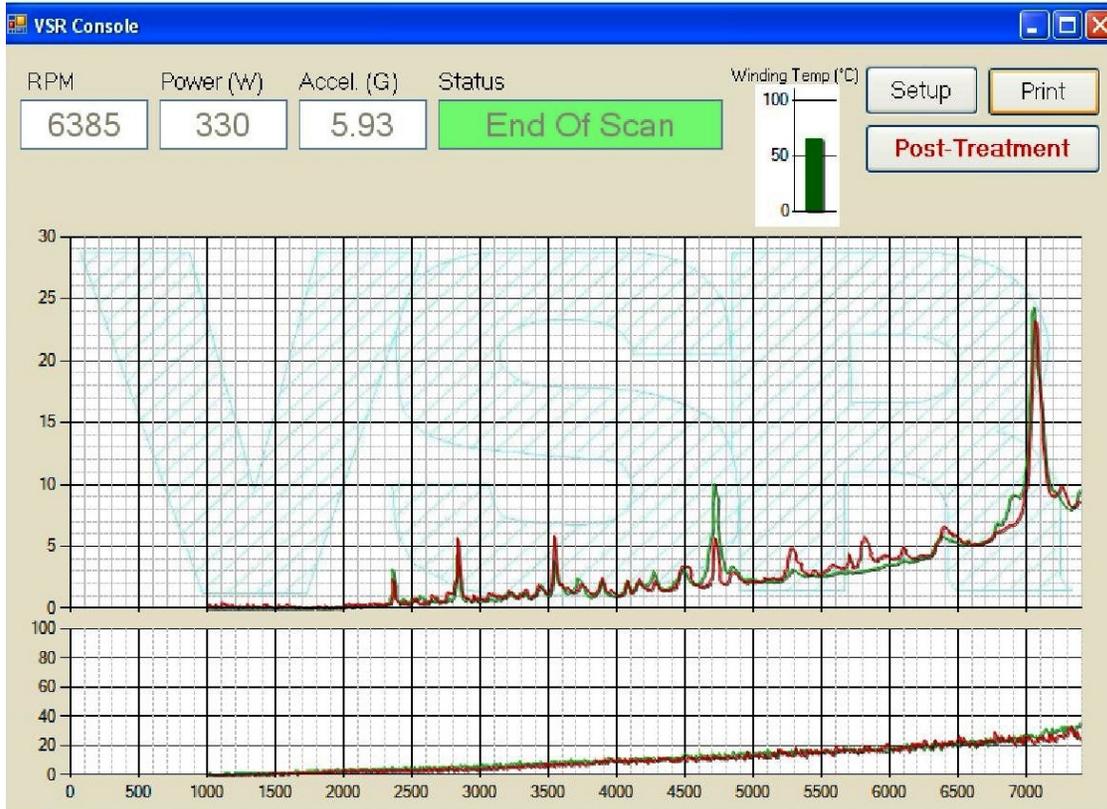


Figure 5: 1<sup>st</sup> VSR Treatment Chart shows little change. Some slight peak growth in short peaks between 5000 and 6700 RPM, together with the peak reduction at 4700 are insufficient evidence of stress relief occurring.

Due to this modest response, a second VSR Treatment was performed at higher unbalance, but with a more limited RPM range.



Figure 6: 2<sup>nd</sup> VSR Treatment used 70 %, or 2.8 in-lbs of vibrator unbalance, and shows significant peak growth at 4700 RPM. After peak growth max'd at almost 14 g's, the data remained stable. Treatment time was approximately 15 minutes. Scan time for each scan (Pre- and Post) was ~ 6 minutes.

## RESULTS

Before VSR Treatments were performed, the shape / configuration of the test work-piece was mapped using a computerized portable Faro Arm dimensional coordinate system. Voith had performed similar tests upon similar work-pieces, some of which had undergone thermal stress relief, and others that received no stress relief at all. Upon release from the welded clamps, thermally stress relieved work-pieces deformed slightly, on the order of 1 mm.

Those work-pieces that had received no stress relief deformed significantly more, typically 3 mm.

After the test work-piece was VSR Processed, during the evening of the 1<sup>st</sup> day, the test work-piece was unclamped and examined by the Faro Arm system. After the release from the welded clamps, the VSR Processed test work-piece distorted 0.3 mm.

These results are summarized in Figure 7.

## Effects of Thermal and Vibratory Stress Relief

Figure 7

No stress relief	3 mm
Thermal Stress Relief ( T S R )	1 mm
Vibratory Stress Relief ( V S R )	0.5 mm

### VSR TREATMENTS OF PRODUCTION PARTS

Two additional work-pieces were VSR Processed. These were setup for VSR Treatment in a manner similar to other work on large half-rings. This work has been done regularly at Voith in York, PA, USA, CIE in Paraguay, Impsa in Argentina, and other companies producing such large components.



Figure 8: Welded half-ring being setup for VSR Treatment. One of three urethane isolation cushions, red in color, can be seen near the center of the half-ring. The other two were placed within 2 m of each end, the left-ward location being also where the vibrator was mounted. A similar adaptor plate was used to mount the vibrator, and vibrator's orientation was aligned approximately to the furthest portion of the half-ring, in the right foreground. The accelerometer (vibration sensor) was attached to the left end, and oriented to be most sensitive to vertical amplitude. The vibrator's unbalance was adjusted to 20% of the max, or 0.8 in-lbs. The Quick Scans and Pre-Scan (baseline) is shown in Figures 9 and 10.

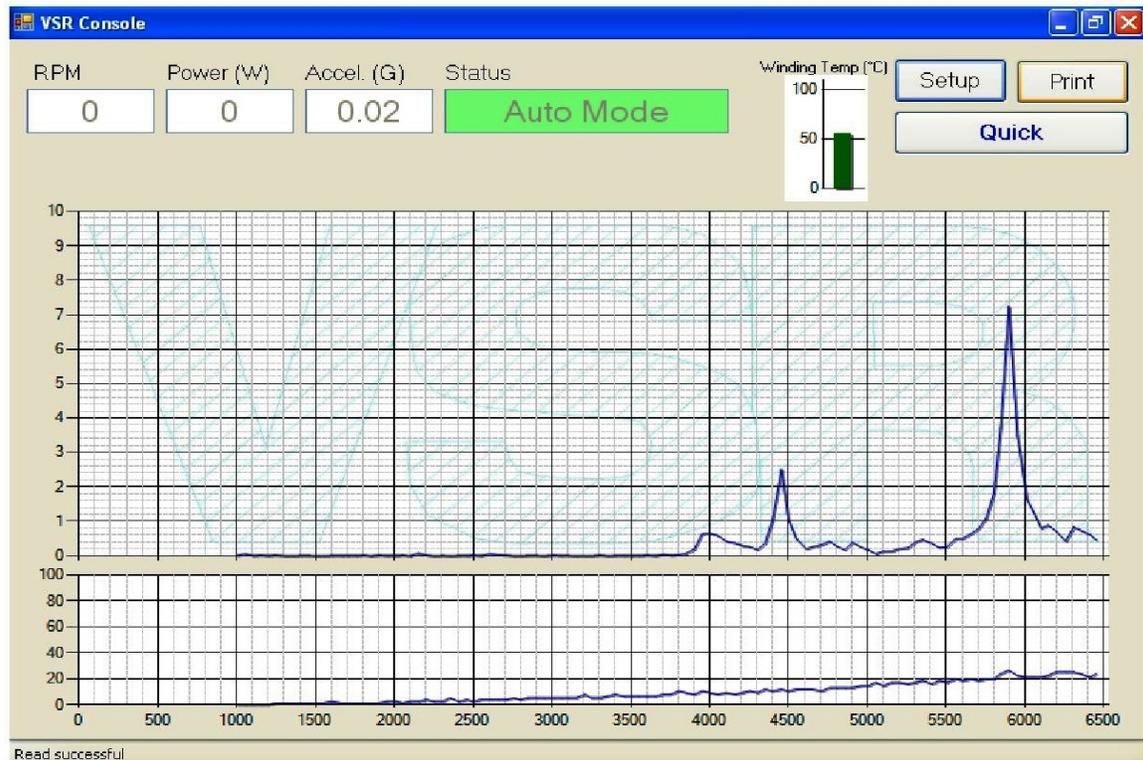


Figure 9 shows two significant peaks, which were then depicted with higher accuracy in Figure 10.

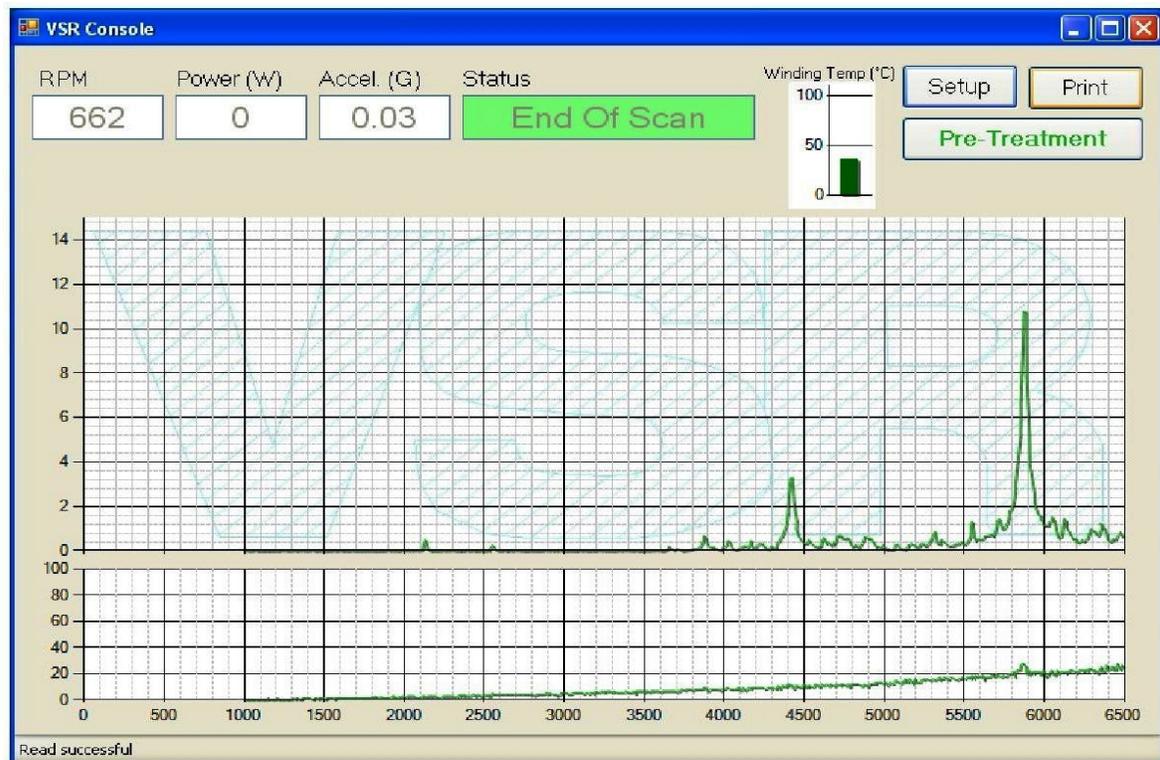


Figure 10: Pre-Scan of cast half-ring shows two significant peaks, with heights of ~ 3 and 11 g's. Although the 3 g peak changed little, the 11 g peak grew, plus a new peak, not seen before, appeared at ~ 3500 RPM. See Figure 11.

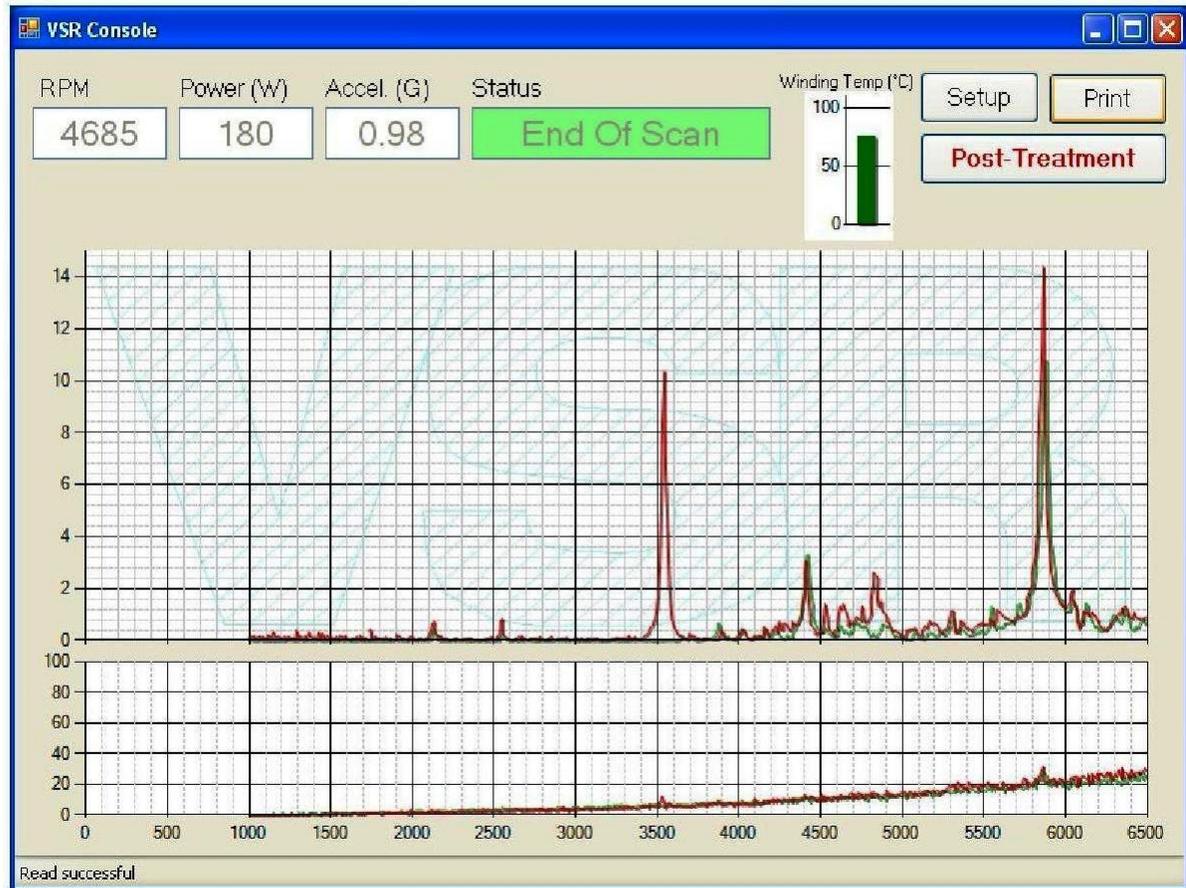


Figure 11: VSR Treatment of welded half-ring shows significant change at the largest peak, at ~ 5800 RPM, plus a new peak, not seen before, at ~ 3500 RPM. Since the 3500 RPM peak had not been seen, Post-Scan was stopped to treat this peak, but little additional change took place, so the Post-Scan was begun again and completed. Total treatment time, with setup, scans, treatment, and knock down, was ~ 2 hours.

To further illustrate the physics of the VSR Process, which employees resonant vibration to amplify the force from the vibrator, which then is sufficient to stress relieve, sawdust was placed on the half-ring. Besides resulting in a peak in amplitude, resonating of a large solid body also generates a clear, stationary pattern on the body of high and low amplitude.

Powder, such as sand, Oil Dry ®, or sawdust, spread on horizontal surfaces of such a resonating body, will be driven off the high amplitude locations, and come to rest on low amplitude locations, which are called **nodes**. Different nodal patterns occur with different resonant peaks, so the way the vibrator's effect is distributed is not by moving the vibrator, but by tuning it to different peaks.



Figure 12: A portion of the nodal pattern on the half-ring. Five such nodes occurred over the full length of the structure, on the largest peak, but fewer on other, lower frequency peaks. A node is a good location to place the vibrator, and also cushions, but not the accelerometer. Using nodal patterns to improve VSR setups is a standard portion of the VSR Operator Training.

### **HALF-RING RESULTS**

Little distortion took place of the welded half ring, but that does NOT necessarily mean that stress relieving did not take place. Rather, it is highly likely that tensile stresses from welding were very symmetrical, top to bottom, inside to outside, prior to stress relief. Likewise, plastic-flow / stress relief of these highly stressed areas was also symmetrical in nature, resulting in little net distortion due to stress relief.

This result is fairly typical of effective vibratory stress relief. However, in situations where the welding is done asymmetrically, such as chiefly on the inside or the outside of a half-ring, distortion can result during VSR Processing. Such distortion can be controlled / reduced by bracing across the half-ring, doing all the welding, and then performing a VSR Treatment prior to brace removal. Such was the experience with a bottom ring repair done at Voith Hydro, York, PA in 1997.

One way of describing the distortion that can take place during a VSR Treatment is to liken it to a “tug-of-war” between the thousands of locations that have undergone shrinkage due to welding. In situations where little change in net shape occurs, the “war” can be considered a “tie”, a “draw”. Such is likely the case with the heavy-plate work-piece. This does NOT mean such a VSR treatment is ineffective or unnecessary: Such parts are still at risk of distortion during subsequent operations (machining, assembly, transport) any of which can be quite asymmetrical in nature. In situations where the welding is highly asymmetrical, bracing re-establishes / gives a short-term boost to the symmetry, and thus controls the resulting distortion.

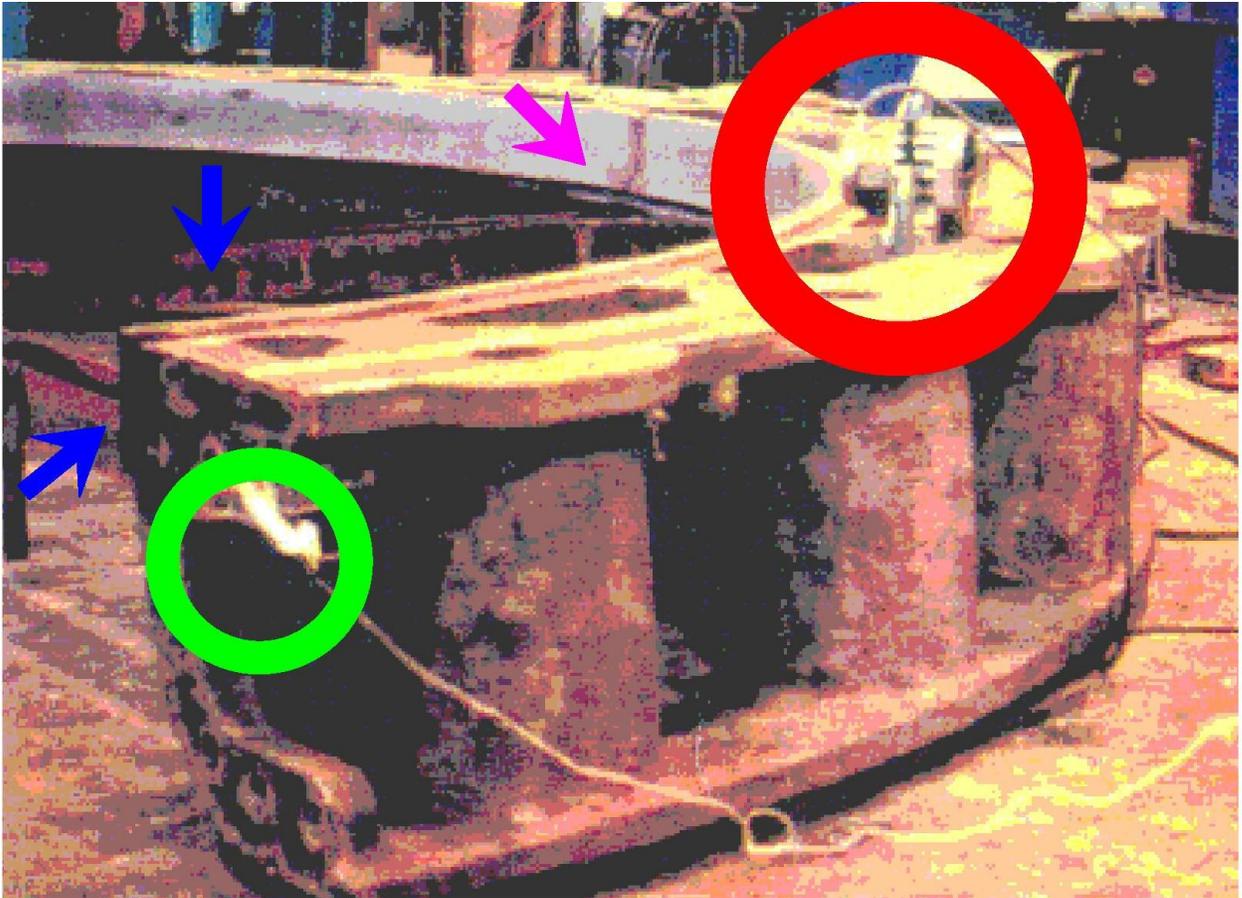


Figure 13: Voith Hydro York, PA VSR 1997 Setup: Bottom ring underwent extensive weld repair, including a stainless steel liner insert, 250 mm wide and 30 mm thick, in two sections per half.

The Vibrator is marked with a red circle.

The Accelerometer is marked with a green circle

The braces are marked by blue arrows.

The butt-weld seam is marked with a magenta arrow.

The results of this work convinced Voith Hydro York to use the VSR Process later on assembled bimetallic (stainless and mild steel) discharge rings. A few dozen discharge rings have been VSR Processed since 1997, resulting in rings that are more accurate circles when assembled on-site.

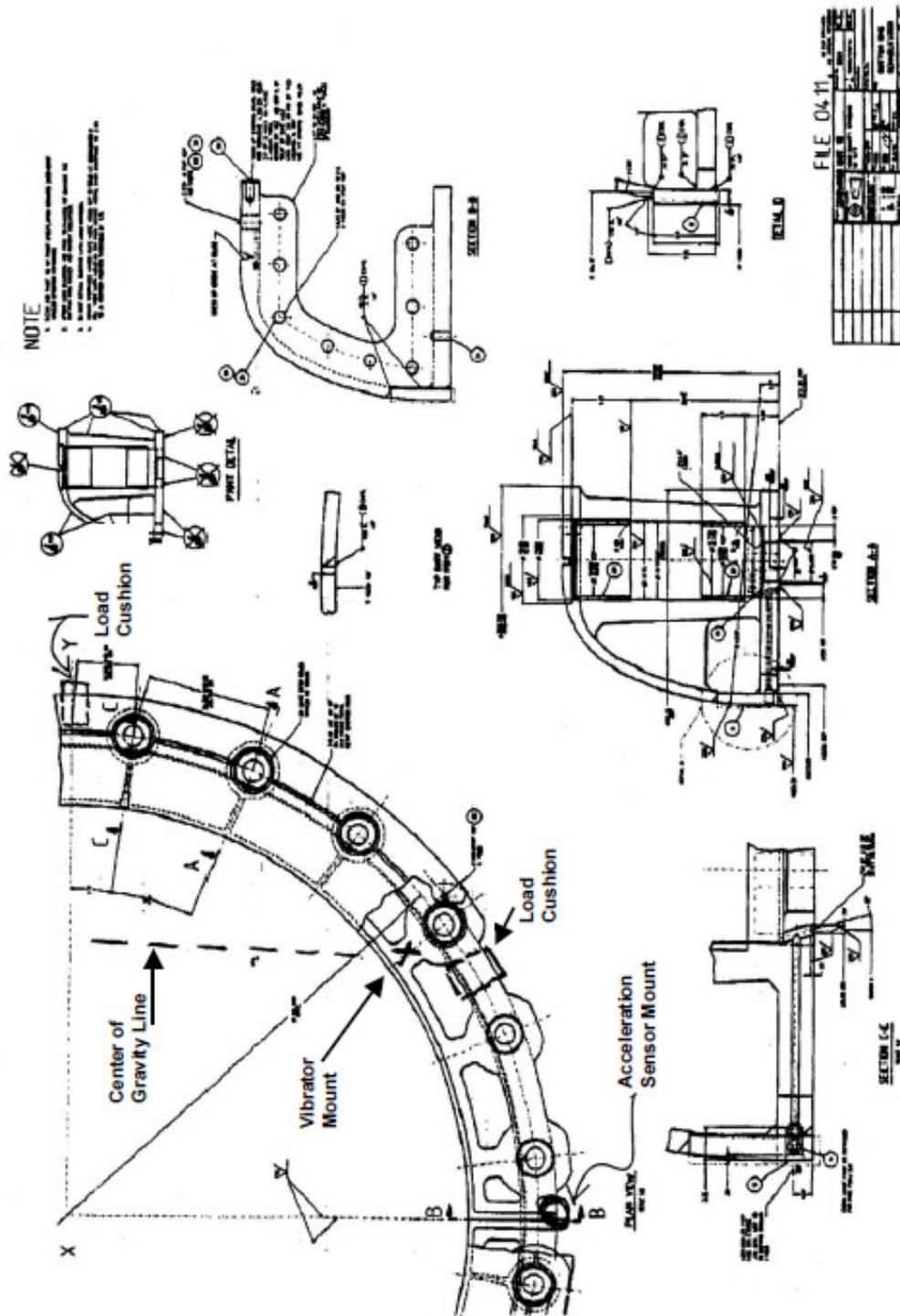


Figure 14: Drawing of bottom ring that underwent weld repair in 1997, which included astainless steel plates welded to its inside diameter.

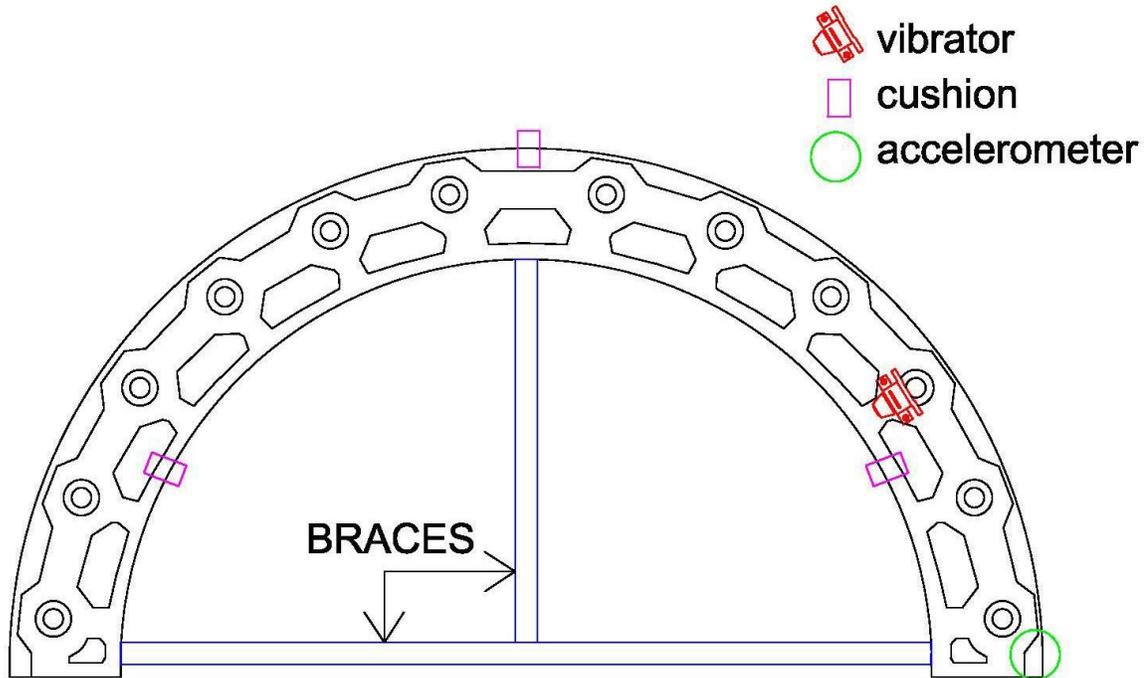


Figure 15: VSR Setup / Plan View used to stress relieve bottom ring halves shown in Fig 14. Without use of the VSR Process, brace removal would result in tightening of the span across the long brace. Once the end of the long brace was cut, the half-ring would grab it, due to distortion. Removing the braces required either using a sledge hammer and / or jack, or cutting out the brace in sections. Once the braces were fully removed, the typical distortion across the span was – 6 to – 12 mm.

For this work, prior to brace removal, punch-marks were made at six points near the ID of each ring-half. A precision tape was then used to measure the distances across the large and small spans between the punch marks. The dimensional map, showing the distances of both ring halves, is shown in Figure 16.

After the punch marks were made, and the first data set was gathered (green in both Figures 16 and 18, the braces were torch-cut.

Something then occurred that had not been witnessed during brace removal on similar projects performed at the York plant before:

**The braces fell out.** They were not grabbed by the distorting half-ring.

**DIMENSIONAL MAP OF RING HALVES BEFORE BRACE REMOVAL  
DISTANCE BETWEEN PUNCH MARKS SHOWN IN MILLIMETERS**

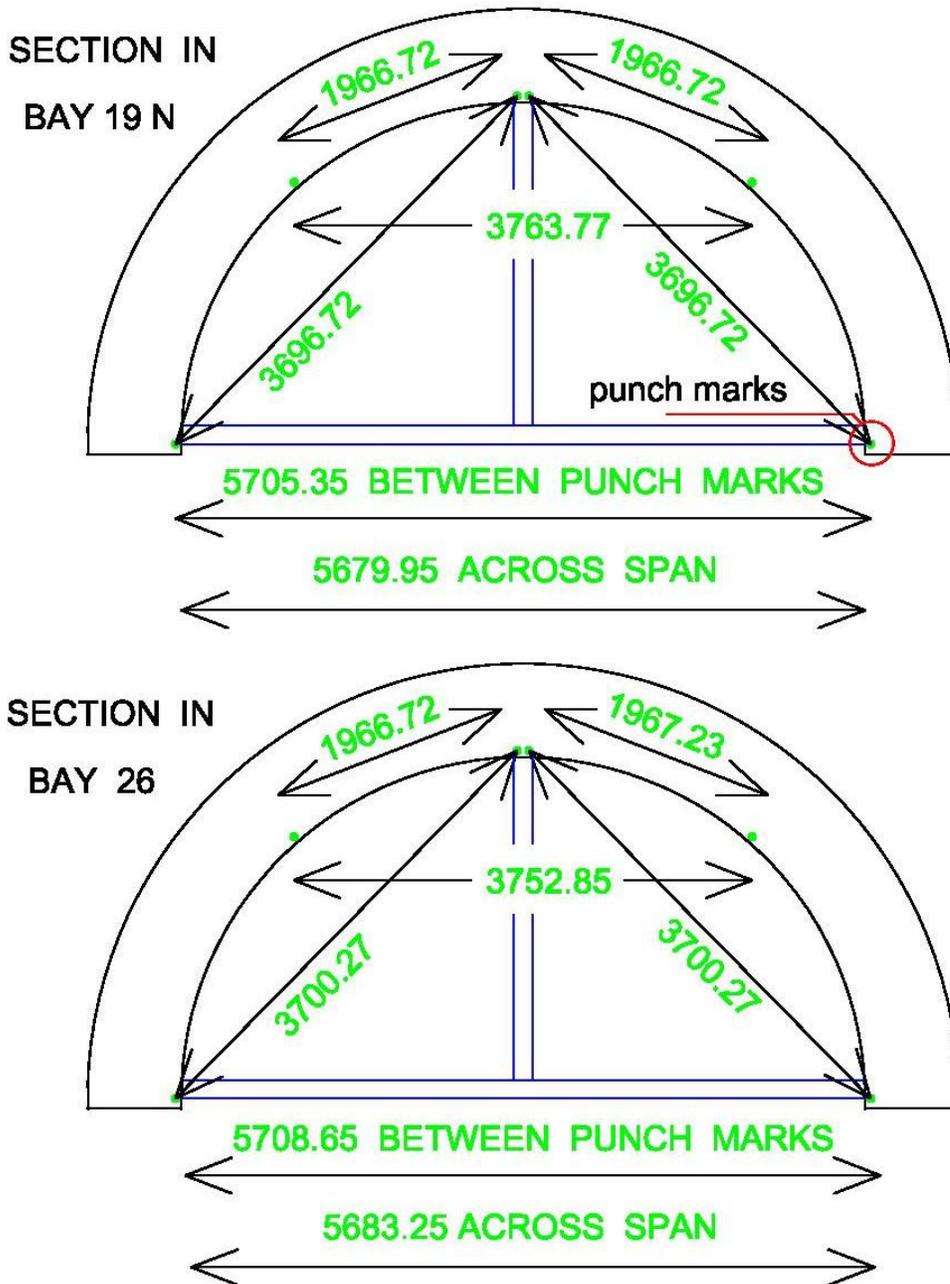


Figure 16: Before brace removal, six punch marks were made on each ring half, to track the change in shape that would take place, comparing before and after brace removal. Numbers in green are before brace removal. Note: Originally these distances were measured in inches, but have been converted to millimeters.

**DIMENSIONAL MAP OF RING HALVES AFTER BRACE REMOVAL  
DISTANCE BETWEEN PUNCH MARKS SHOWN IN MILLIMETERS**

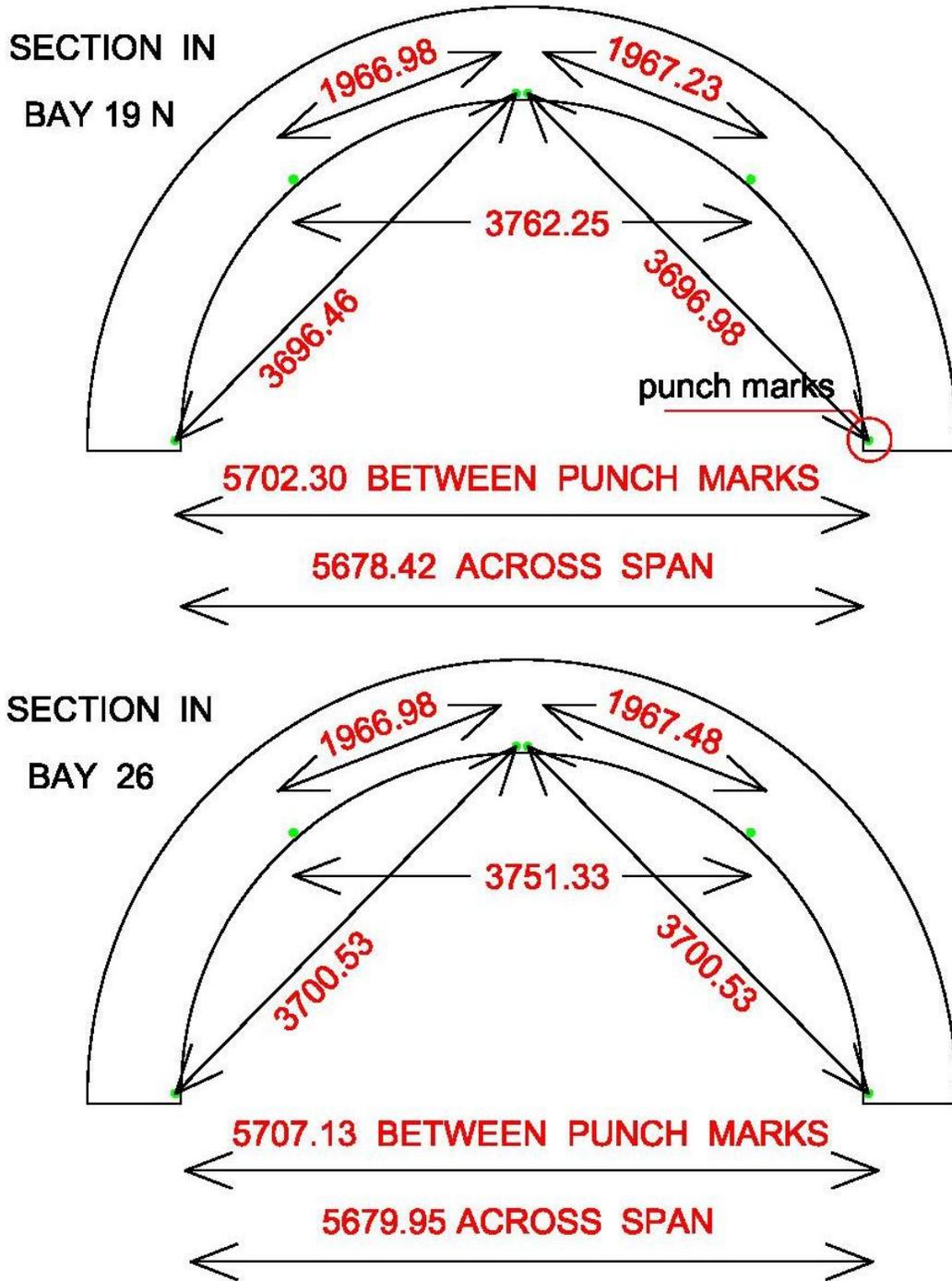


Figure 17: Dimensional map of ring halve after brace removal. Changes in distances, together with distances between punch marks and arc spans are shown in Figure 18.

## BAY 19 N

BEFORE BRACE REMOVAL	AFTER BRACE REMOVAL	DIFFERENCE
5679.95	5678.42	- 1.53
5705.35	5702.30	- 3.05
3696.72	3696.46	- 0.26
3763.77	3762.25	- 1.52
3696.72	3696.98	+ 0.26
1966.72	1966.98	+ 0.26
1966.72	1967.23	- 0.51

## BAY 26

5683.25	5679.95	- 3.30
5708.65	5707.13	- 1.52
3700.27	3700.53	+ 0.26
3752.85	3751.33	- 1.52
3700.27	3700.53	+ 0.26
1966.72	1966.98	+ 0.26
1967.23	1967.48	+ 0.25

Figure 18 Dimensional data from Voith Hydro York 1997 bottom ring weld repair project shows a small change in dimensions after brace removal, compared with the historical change of 6 – 12 mm. This small change kept the work-piece “within its drawing”, i.e., eliminated the need for corrective straightening, besides allowing the braces to fall out after being cut.

The two ring halves mating faces were then machined to mate, assembled, and the complete ring was machined to final target dimensions. No significant distortion took place during subsequent disassembly, transport or installation-site reassembly.

Such a technique might well reduce the distortion seen during fabrication of stator half rings. Numerous hydroturbine builders employ such a method, not only on stators, but upon discharge ring fabrication, an example of which is shown in Figure 19.



Figure 19: Discharge ring for IMPSA project, fabricated by CIE in Paraguay. Again, after fabrication, the half rings were VSR Processed, and then the braces were removed. Distortion was nominal, so that machining was able to commence, without additional / corrective manufacturing steps.



Figure 20: Stator half-ring being setup for VSR Treatment. Setup was very similar to the cast half-ring, using three cushions (although they were gathered in pairs, totaling 6, due to the work-piece weight) Two treatments were performed, using first a low unbalance, high speed range, then a higher unbalance, limited speed range. Both treatments showed change, but less during the 2<sup>nd</sup> treatment. See Figure 21.

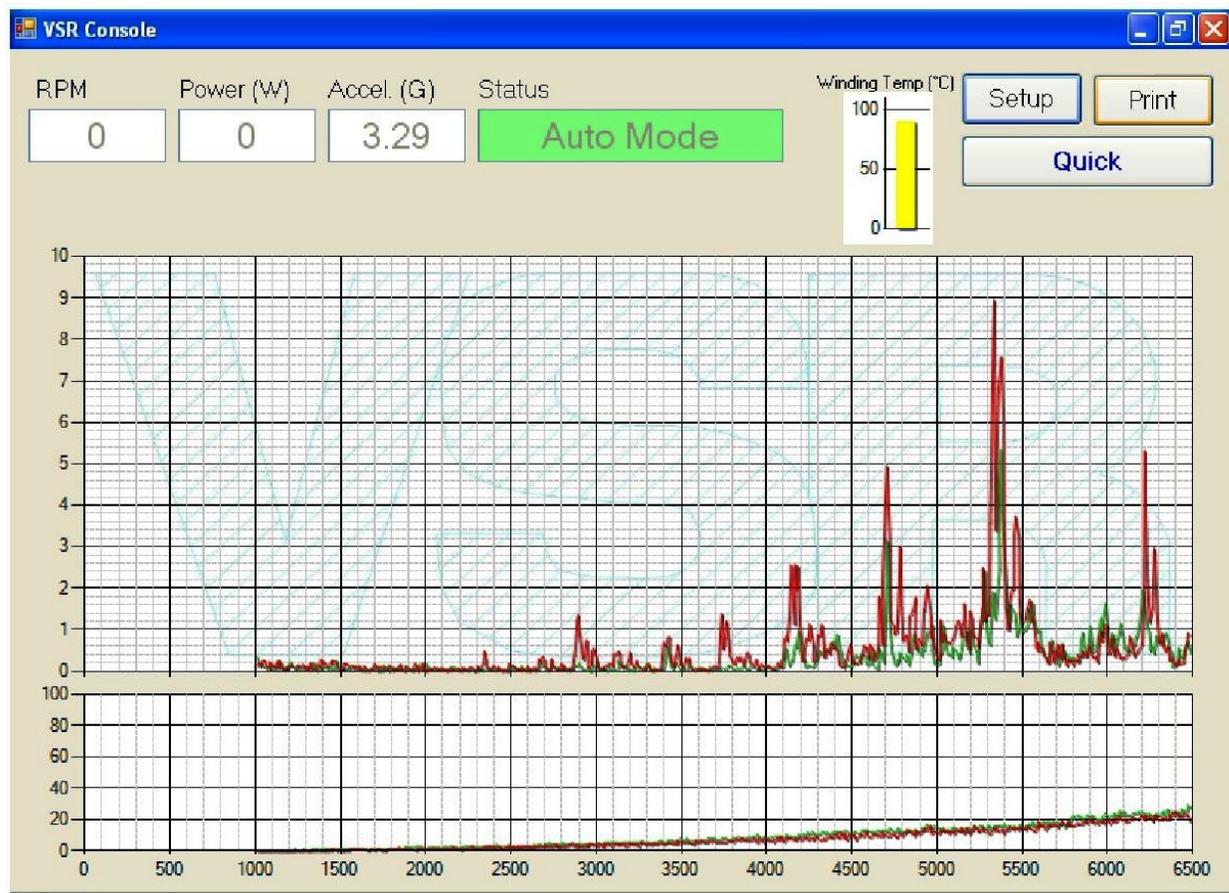


Figure 21: Treatment of stator frame using 20 % unbalance, and 6500 RPM max speed.

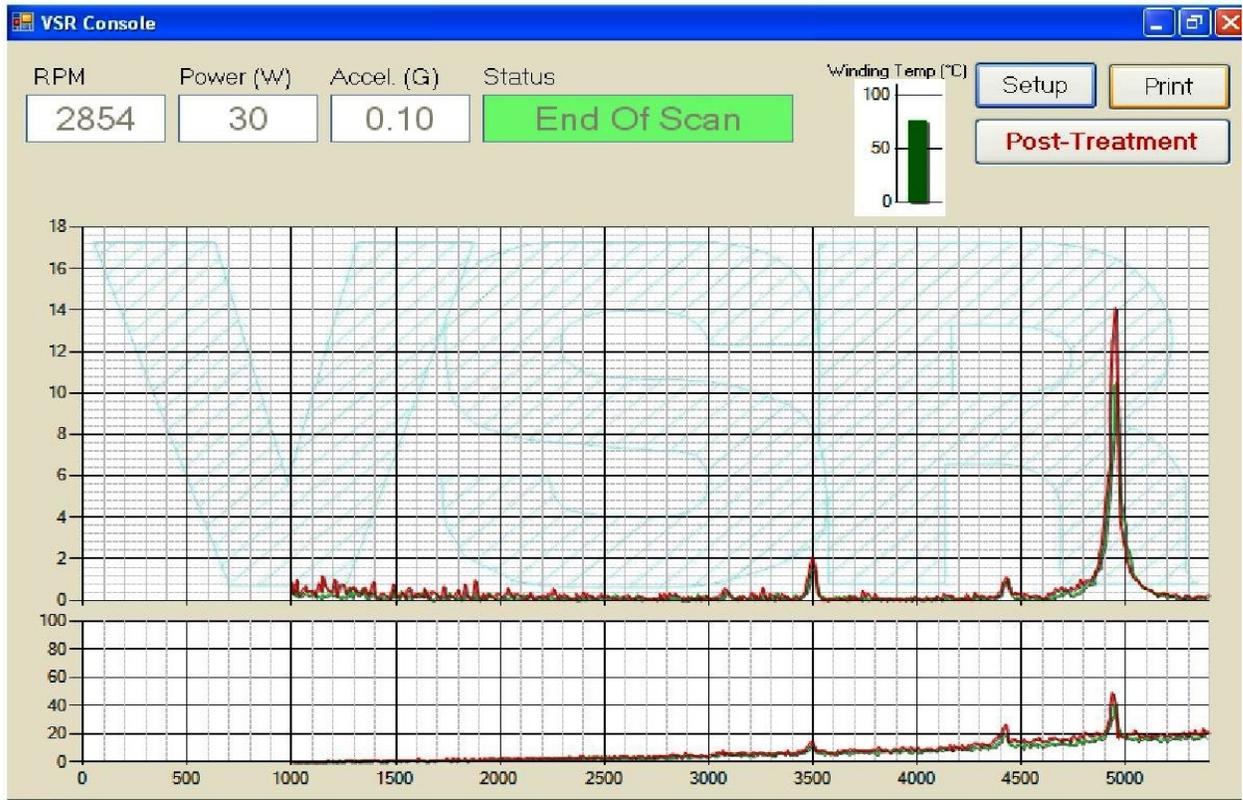


Figure 22: 2<sup>nd</sup> VSR Treatment used 40% unbalance, but a max RPM of 5500. Although less change took place, a significant growth of the peak near 5000 RPM justified the 2<sup>nd</sup> treatment.

## CONCLUSIONS

The VSR Test designed by Voith indicates that the VSR Process can significantly reduce the deformation associated with welding stresses. Results indicate a reduction in deformation energy similar, at times exceeding, that of thermal stress relief.

Additional work-pieces, which include the half-rings of mild, should display good dimensional behavior during subsequent machining and assembly procedures, similar, perhaps surpassing, the performance that had been achieved in the past using thermal stress relief. If not braced across the arc-span during VSR Processing, certain types of parts, esp. those with asymmetrical welding patterns (more welding on the inside / ID or outside / OD of the work-piece) can distort radially.

Both thermal and vibratory methods have their application areas, best outlined by noting their limitations, the most obvious being that the VSR Process has no metallurgical effects. If metallurgical changes are needed, the VSR Process is likely not the best choice, but many times such changes are unwanted, in which case the VSR Process could well be considered the best practice.