The cost effective alternative to heat treatment

Report on Vibratory Stress Relief

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DIAMOND MANUFACTURING undertook an emergency mechanical repair of the USCG Cutter *Escape*, that had only recently been overhauled. The ship had severe drive-train problems, including noise, vibration, and accelerated lubrication use in the bearings holding the propulsion shafts. Once released from the ship's foundations, these shafts were found to be severely warped. Warpage varied from 0.025" – 0.125" over the shafts 20' length, contrary to the USCG specifications which allow a maximum 0.005" over that length.

DIAMOND's heat-straightening of the shafts (which had also been done during the overhaul), proved to only temporarily achieve the required straightness. Merely transporting the shafts from the DIAMOND's machine shop to the ship's dry-dock (a distance less than a 100 yards), caused the shafts to distort 0.025" – 0.035".

Several repeat trips to the heat-straightening press failed to eliminate, or even reduce, the distortion seen at the dry-dock, until the VSR Process was incorporated into the repair. After vibratory treatment, each shaft not only remained dimensionally accurate and stable after the short trip, but also after installation, testing, and operation.

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In November 1985, VSR TECHNOLOGY was contacted by Mr. Ed Harless of DIAMOND MANUFACTURING, Savannah, GA, and Mr. Ulf Uhlig, a Miami, FL marine engineering consultant. They were working on the USCG Cutter *Escape*, which was in DIAMOND's dry-dock. The *Escape* had recently undergone an extensive overhaul and upgrading at Newport News, which included a "re-qualifying" of propulsion shafts. "Re-qualifying" included a metallurgical examination of the shafts, replacement of the bearing journals, and heat-straightening to the required specification of 0.005" straight over a 20' length. The propulsion shafts were 8" Dia x 20' L, made of 4140 steel, and each had two freeze-fit (or in the case of the tail shafts, one) bronze journals.

During the *Escape's* initial post-overhaul voyage, mechanical drive-train noise, vibration, and related problems were detected by the crew, so the ship put in to DIAMOND's Savannah dry-dock for emergency repair. Inspection showed the propulsion shafts were not straight, warpage varied from 0.025" – 0.125" per shaft. The shafts were pulled for heat-straightening, and then returned to the ship's dry-dock to be re-examined and then installed.

The marine engineering consultant, Mr. Uhlig, an expert in the area of laser-alignment examination, had been brought in on the job to more accurately measure the straightness of the shafts. He determined that none of the shafts were straight within tolerance at dockside, even though they had been within tolerance immediately following the straightening operation. The shafts had changed shape during the ≈ 100 yd transport back to the ship, warping between 0.020" and 0.035". The shafts were returned to the machine shop for another round of heat-straightening, where another inspection showed they had warped even more (an additional 0.003" – 0.010") during the return transport.

A repeat heat-straightening was successful in bringing the shafts back within straightness tolerance, but only temporarily. The return transport to the dry-dock again produced the same out-of-straight conditions as had previously occurred: 0.020" – 0.035".

Mr. Uhlig's laser equipment was then used to verify the accuracy of the in-shop measurements. Both inspection methods produced identical dimensional data. Repeated heat-straightening attempts failed to produce acceptable dock-side shaft tolerance. In fact, over time the dimensional data showed clear evidence of increasing amounts of distortion. It was suspected that the heat-straightening operations had been producing powerful residual stresses in the heat-affected-zone (HAZ) on each shaft, and that transport to the dry dock was causing partial stress relief of the shafts which resulted in the dimensional changes. The shafts needed to be stabilized.

It was immediately decided that because the shafts were both finished-machined, and sleeved with new bearing journals, thermal stress was not an option. VSR TECHNOLOGY's Vibratory Stress Relief System was chosen as the only method that could stabilize the shafts. Within 36-hours of receiving the call, the VSR System and a trained operator were on the job.

VSR SETUP

A correct setup for every VSR Treatment requires that the workpiece fully resonate. On a long, relatively uniform cross-section component, such as a shaft or beam, this involves positioning isolation load cushions at two locations along its length, both 30% in from opposite ends. This strategic positioning provides minimal damping of the workpiece, which enables a full resonate response to occur during the Treatment. Four (4) load cushions were used, two at each location, along with wooden wedges to form the two (2) V-blocks that each shaft would safely rest in during stress relieving.

The Vibrator was mounted to the shafts using a “sandwich-clamp” fixture (See page 8). The clamp was fabricated of two mild steel weldments, which were bolted together with a 1/16" shim between them. Then, the ID of the fixture assembly was bored-out to the OD of the shafts, disassembled, and then reassembled on the shaft (minus the shim). This type of fixture assembly provides the strong, firm base needed to mount the Vibrator so that efficient energy transfer into the workpiece can take place during Treatment.

The clamp was placed just inside one of the load cushion locations, approximately 1/3rd the distance from the end of the workpiece. The Vibrator was oriented so that its shaft was parallel with the workpiece, an orientation that can drive the workpiece in the two directions that it can resonate. (Long parts resonate little, if at all, in the direction of their length, but will resonate in the two directions perpendicular to their length.) Initially, the Vibrator's unbalance was set to 1.2 in-lbs (20% of the maximum 6.0 in-lbs) later, based on the shaft's response to vibration, the unbalance was increased to 30% (1.8 in-lbs) of maximum.

An Accelerometer (an electronic device whose output is proportional to acceleration), was placed on the end of the workpiece, and oriented so as to be most sensitive to the vertical and horizontal deflections that were perpendicular to the length of the shaft. Because acceleration is proportional to force (F = ma, Newton's 2nd Law), VSR Technology uses relative force as the engineering unit most indicative of a workpiece's response to vibration treatment.

PRE-TREATMENT SCAN

After calibration of the System’s XYY Plotter, an automatic, slow scan through the Vibrator's speed range is run, so that an accurate depiction of the workpiece’s resonance character can be recorded. This is referred to as the Pre-Treatment Scan. Both workpiece acceleration and Vibrator input power (the vertical plots) are plotted vs. Vibrator RPM (the horizontal axis). A copy of the Pre-Treatment Scan Chart for the starboard, intermediate shaft is shown on page 5. The green ink plots acceleration, and the red ink plots Vibrator power. As you can see on the Chart, two resonance peaks, the larger one 7.5g tall, were recorded.

VSR TREATMENT

Treatment is performed by tuning the Vibrator speed precisely upon the resonance peaks of the workpiece. As stress relieving takes place, two changes, which the VSR System monitors, occur in the resonance pattern:

1. The resonance peaks grow to higher amplitudes;
2. The resonance peaks shift in the direction of lower frequency (to the left on the Chart).

Either, or both, of these changes can take place during a Treatment. These changes are consistent with the lowering of workpiece rigidity, which is inflated by the presence of residual stress.

The changes occur very fast at the beginning of Treatment (when a great deal of stress is in the workpiece), but become slower and smaller as Treatment continues, eventually resulting in a stable resonance pattern. The stability of the resonance pattern is indicative of the dimensional stability of the workpiece.

The resonance peak that was initially 7.5g tall was tuned upon, and within seconds started to grow. To record this pattern of growth, the System operator momentarily dropped the pens of the XYY Plotter, making a series of dots to show the history of peak growth and/or shifting that takes place during Treatment. This series of dots, referred to as "progress dots", plot the progress of the resonance pattern (and therefore the workpiece) towards stability. A clear pattern of progress dots can be seen on the Chart, rising from this peak. Near the top of the progress dot pattern, the distance between the dots becomes increasingly smaller, which indicates that less change was taking place during this portion of the Treatment. Eventually the height of this resonance peak stabilized, but at 13.5g – almost double its initial height.

The second peak, which was slightly shorter and to the left of the first peak, was then treated. Although, it had already grown to over 10g, it continued to grow when treated, eventually to a height of ≈ 15g, before stabilizing – it more than doubled during the course of Treatment.

POST-TREATMENT SCAN

The Plotter's pens were reversed: red for acceleration; green for power, and a Post-Treatment Scan was performed. This scan documents the changes that took place during Treatment. Looking at the completed VSR Treatment Charts (pages 6 & 7) a subtle shift in resonance peak frequency can be seen, the new peaks shifted slightly to the left of the old peaks. This shift represents an ≈ 1.3 % change in resonance frequency, while the growth of the resonance peaks roughly doubled. These treatment responses are typical when relieving shafts or beams, *ie*, workpieces in which length is the dominant dimension.

RESULTS

Two of the six shafts treated had small dimensional changes during stress relieving, to a distortion of 0.008" over the shaft's 20' Length. It was decided that the variance was acceptable and that no further heat-straightening was necessary. The decision was confirmed when, as a test, the shafts were "transported with vigor" back to the ship, and laser alignment inspection proved the shafts had finally been stabilized.

CONCLUSION

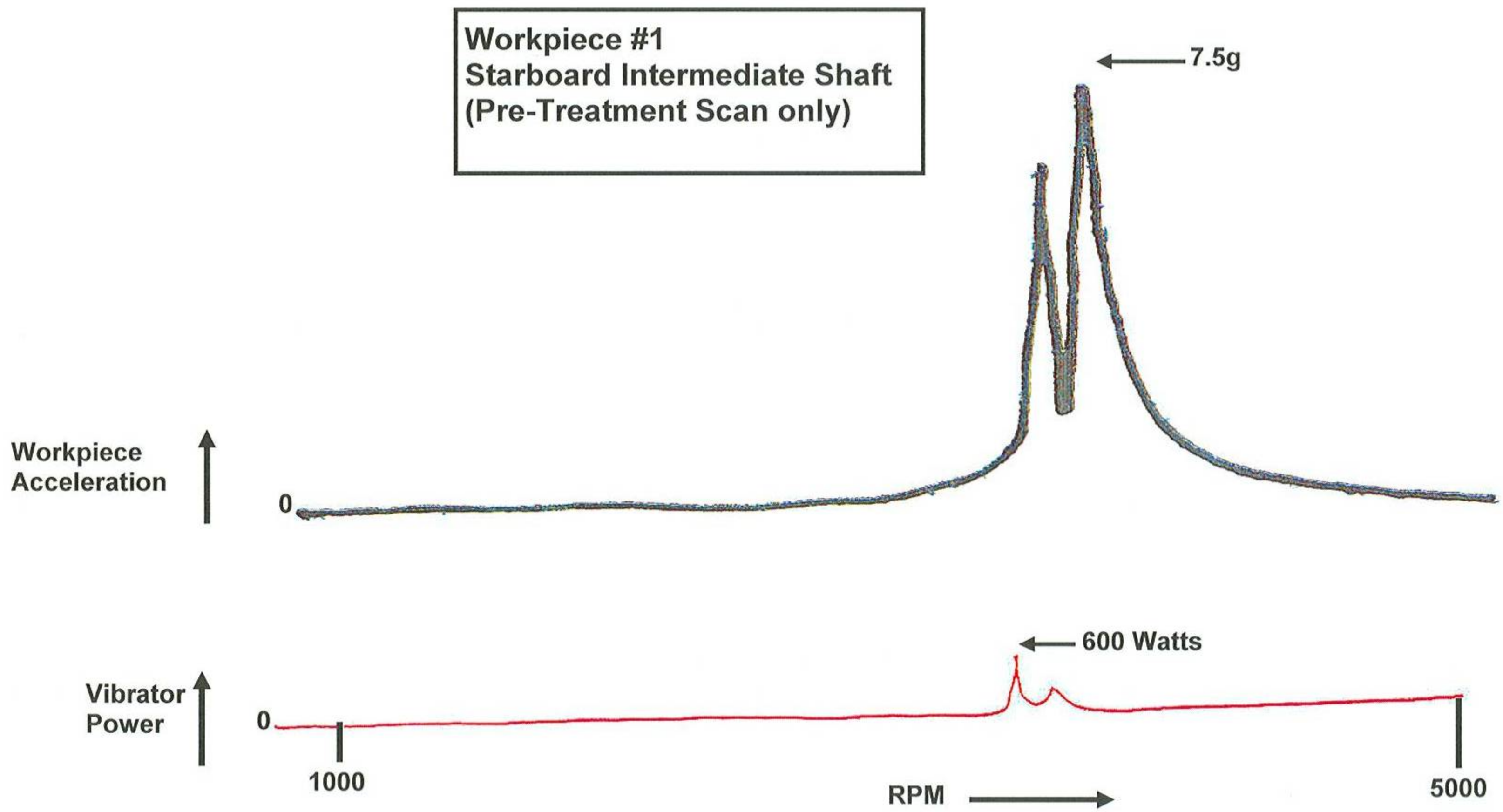
The VSR Process was successful in stabilizing the dimensions generated by the heat-straightening operation on this collection of propulsion shafts; it is logical to surmise it will be a highly effective method of assuring the dimensional stability of other heat-straightened components.

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:

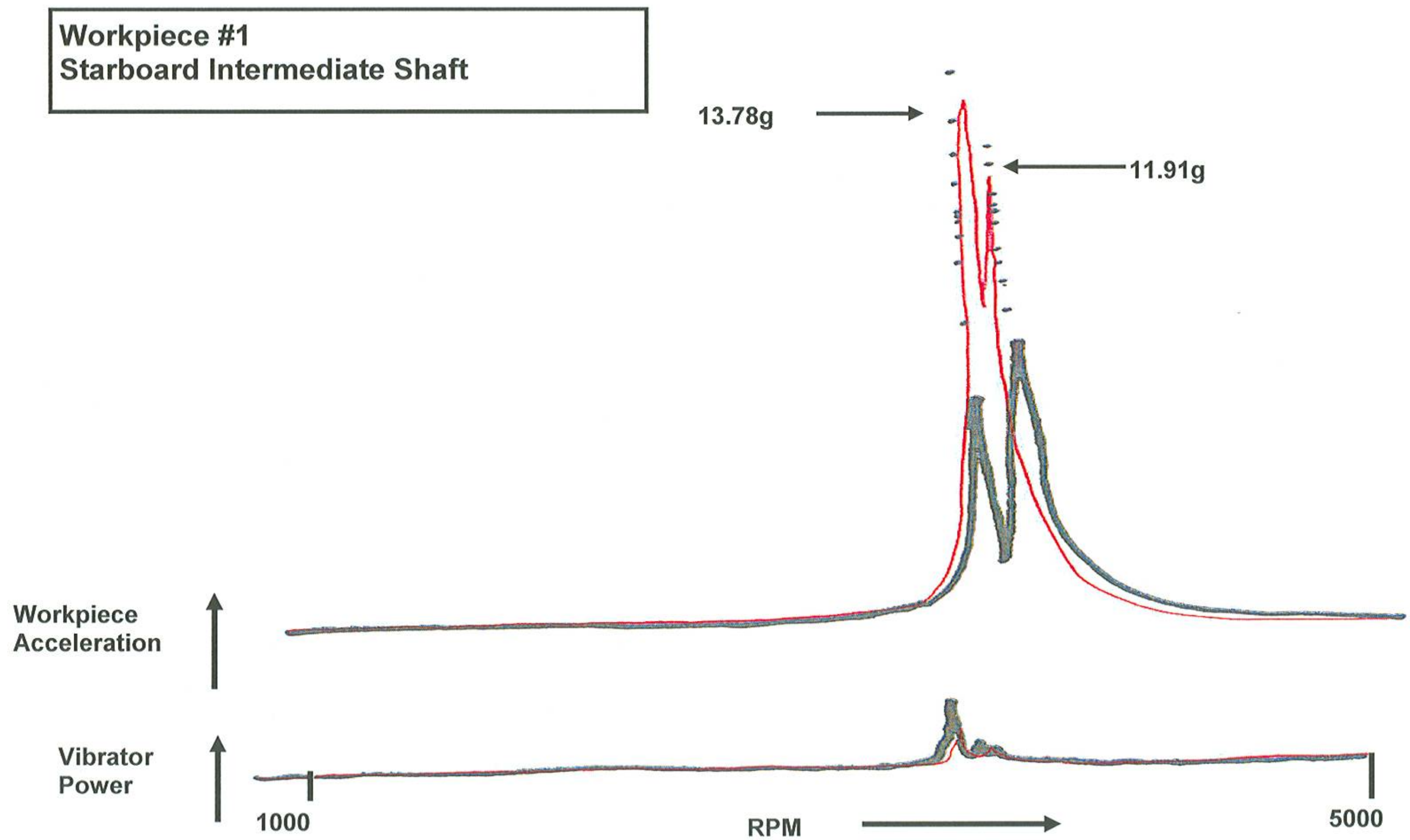
1. "Use and Understanding of Vibratory Stress Relief", *Productive Applications of Mechanical Vibration*, 1983, American Society of Mechanical Engineers.
2. "Vibratory Stress Relief: Methods used to Monitor and Document Effective Treatment, A Survey of Users, and Directions for Further Research", 2005,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

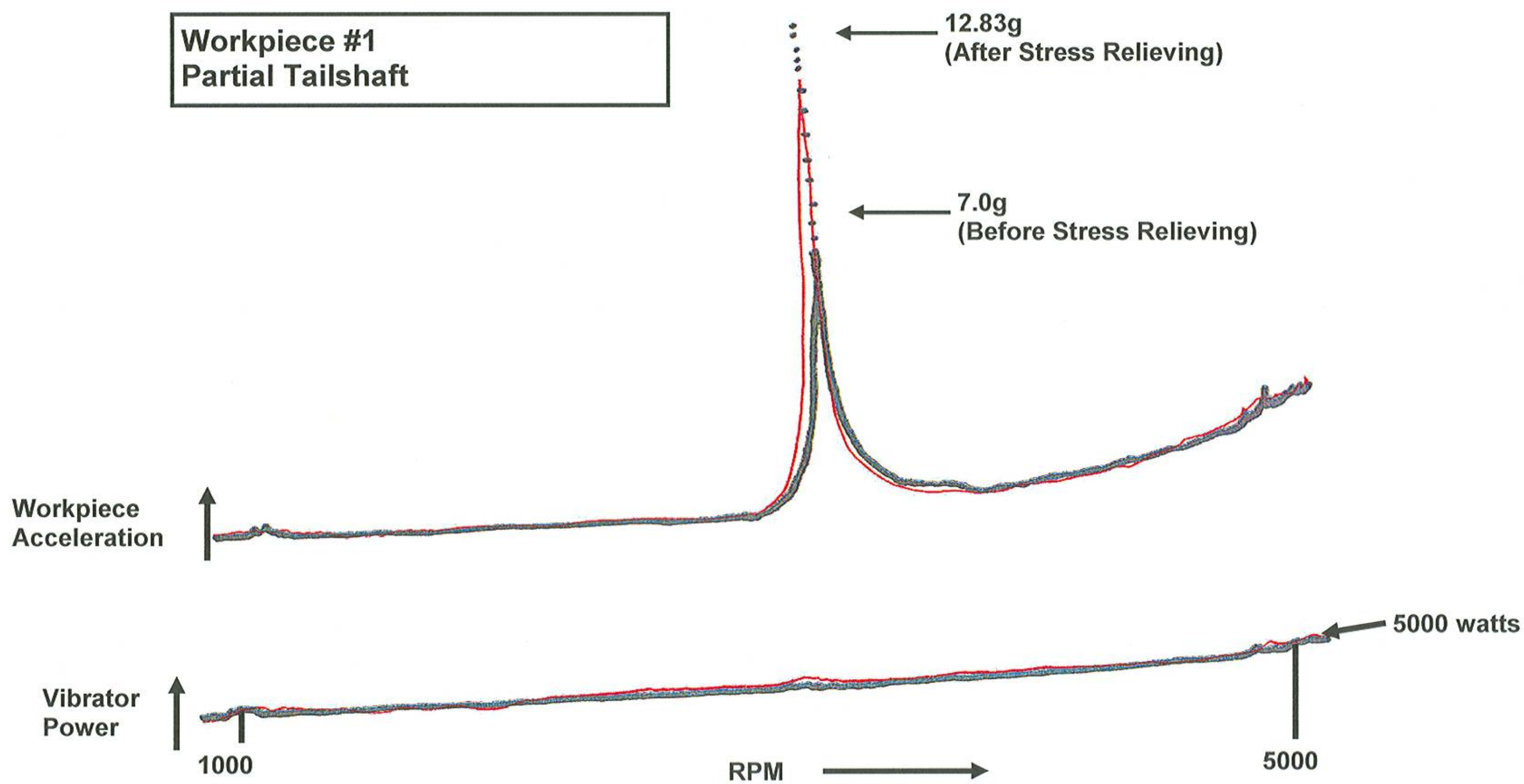
VSR TREATMENT
Diamond Manufacturing
Chart #1



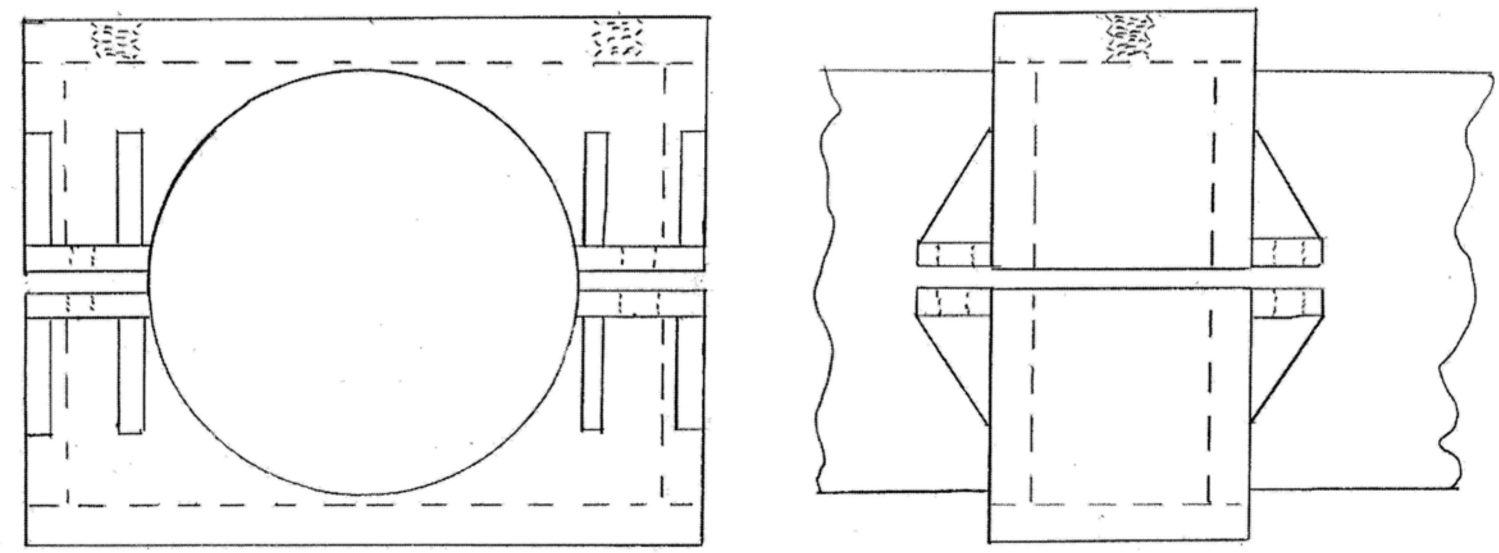
VSR TREATMENT
Diamond Manufacturing
Chart #2



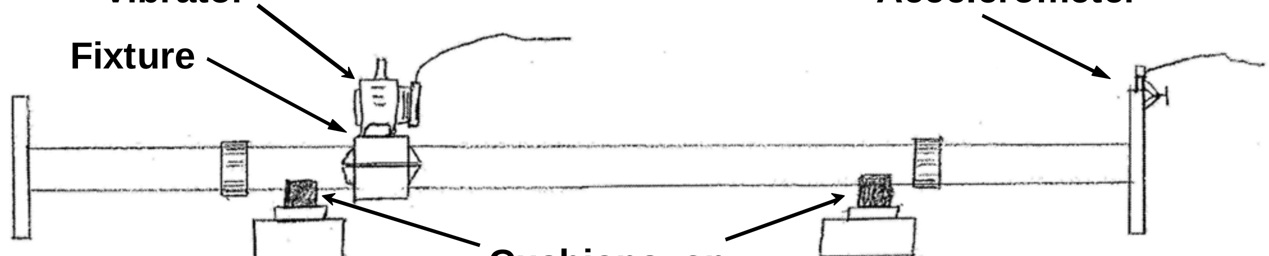
VSR TREATMENT
Diamond Manufacturing
Chart #3



VSR TREATMENT
Diamond Manufacturing
Clamp Fixture



VSR Set-Up



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