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Vibratory Stress Relieving — an Effective Alternative to Thermal Treatment for Component Stabilisation?

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Part 2: Industrial Applications*

In this concluding part of a review of the benefits and limitations of vibratory stress relieving, the author describes a variety of industrial applications of the technique and provides some guidelines for its successful implementation.

INTRODUCTION

Previous papers[23,27-32,36*] have contained many industrial applications of the vibratory stress relieving process (**VSRP**). Honestly-related examples are invaluable in giving confidence to the engineer and a signpost to the researcher. Effective AC-VSR equipment is now being used across whole industries[37]. In the UK, over thirty machine-tool companies, all of the paper-machinery companies, and the majority of steel and printing machinery builders use AC-VSRS, instead of thermal stress relieving, to give the ultimate in precision and long-term stability. Names have been given before[27] and, as an up-date with regard to machine tools in the UK, the list now includes Devlieg, Crawford Swift, Butler Newall, Beaver, Inca Geometric, Bridgeport, BSA, Pollard, Wavis, Dean Smith & Grace, Wadkin and Griffin — using AC-VSRP on cast-iron or mild-steel fabricated bedplates, columns, tables and saddles, etc. In the UK paper-machinery industry, the list includes Pamac, Beloit Walmsley, Vickery, Albany and Parson Skillforce where many components are stainless steel fabrications. However, for the most part, the following examples look beyond the commonplace to more challenging areas and areas where thermal stress relieving cannot be used.

INDUSTRIAL APPLICATIONS OF VIBRATORY STRESS RELIEVING

Effectiveness trials: AC-VSRS versus DC-VSRS

In 1975, APV Ltd. developed the world's largest plate heat-exchanger consisting of hundreds of stainless-steel pressed plates, sandwiched between two massive end bolsters drawn together with tie-bars. The end bolsters were 3.4m x 1.3m x 70mm mild-steel plates extensively ribbed on one side and machined very flat on the other. Welding was with flux-cored CO_2 with multi-pass 12-15mm fillet welds. The VSRP was evaluated following instability problems on the first batch of ten pairs of plates and the requirement of no reduction in rigidity. ASME approval was sought and granted.

Two VSRS were evaluated: a borrowed Formula 62 DC-VSRS 0-100Hz machine and an AC-VSRS type VCM80 0-200Hz machine. APV were warned not to rely on the automatic mode of the DC system and so it was manually tuned to the first resonance; first torsional for three minutes. First bending mode was also treated for three minutes but, after eight plates, the DC motor burned out as it repeatedly overloaded in order to obtain resonance. Upon final machining, average TIR for eight plates was 0.25mm (0.009in). The following twenty plates were AC-VSRS treated at the first torsional, first bending and second torsional modes, the last being above 100Hz. The average TIR for the twenty plates was 0.04mm (0.0015in). APV purchased an AC-VSRS and were interested to find that the massive Devlieg-Jameson Boromill, purchased to machine the components, had also been solely treated using the same system. The company remains very pleased with both the AC-VSRS and the Boromill.

Machine tool castings/supreme accuracy

Some eight years ago, Dean Smith & Grace became disillusioned with thermal stress relieving when cast-iron saddles, consistently in tolerance on final inspection in the UK, were 20% out on arrival in the USA, necessitating rework. A VSRS solved the problem and today it is all they use to stabilise saddles, beds, etc. Previously, QA records showed that, using thermal stress relief, 9% of beds were reworked after final machining due to movement during handling. In the first eight years of using the VSRS, only 1 of 533 beds was reworked — a mere 0.2%.

Dean Smith & Grace subcontract machine shop also finishes mild-steel fabricated beds up to 10m long and 1m x 900mm section, basically in 12mm plate, but with slideway sections up to 100 x 300mm and weight up to 12 tonne. A 10m bed involves a welding time of approximately 50 hours. Operation procedure is to fabricate, apply VSRP, inspect, rough machine removing up to 35mm to produce slideway profile, ship to Dean Smith & Grace, apply VSRP and finish machine to 5 microns in 6m by grinding.

No machinability problems are encountered at any stage, despite extensive machining of flame-cut edges up to 100mm thick. For QA, a graphic record is produced by the VSRS which is also used by the end-customer as valuable design feedback data with regard to vibration characteristics of the beds.

Following comparison trials in 1990, between thermal stress relieving and an AC-VSRS, Bradford University recommended the resonant AC-VSRP for stabilising the famous Butler Elgamill machine beds. These are of similar size and are required to similar accuracy as in the previous example, but are cast iron and have slideways on two adjacent sides.

*Including a full list of references, part 1 of this article, covering research, equipment and processing aspects, appears in the 1991.2 issue of HEAT TREATMENT OF METALS (pages 53-59).

Fig. 1. Very stiff British Rail components being treated using the VCM80 VSRS.

Rolls and shafts/straightening

Shaft and roll straightening is a notoriously stress-inductive process, resulting in immediate instability during subsequent machining and long-term instability. A case in point: nine En16 pump shafts, 75mm diameter x 5m, straightened to within 0.13mm (0.005in) TIR using a Galdabini 160-tonne straightening press, moved to 2.3mm (0.090in) TIR on arrival in Egypt.

A replacement batch was finish machined, straightened to within 0.13mm (TIR) and then subjected to VSRP. First and second bending modes were obtained. Treatment consisted of 1000 cycles north-south in both modes, rotate 90°, 1000 cycles east-west in both modes. Peak to peak amplitude at the ends was 12mm and, at the mid-span point (antinode), 4mm. All of the shafts moved out to a general bow in one plane. Measured between centres, this bow ranged from 1.1mm (0.043in) to 2.3mm (0.090in) for the eight shafts. The ninth inexplicably moved to a massive bow of 6.2mm (0.24in). The shafts were then restraightened to slight overbend and then retreated as previously. The bow stayed within the required 0.13mm tolerance. Plastic moulding machine screws are a similar case.

QA records exist for these and subsequent shafts. Complete stability and reliability resulted. The work was pioneered by W H Allen Division of NEI-APE and has now been refined to a procedure that involves only one straightening and one VSRP application, as the percentage recovery after straightening is very predictable.

Regularly-treated solid components range from splined, hardened and ground shafts, 25mm diameter x 400mm long for machine tools, to fan shafts, 500mm mid-diameter tapering to 170mm end-diameter x 6m long (these, for example have bending modes at 80Hz and 166Hz). Hundreds of hollow rolls for the plastics, paper and printing industries are treated each year and range from 50mm diameter x 2m long to 2m diameter x 2m face. Hunt Moscrop, manufacturers of the latter item, state that, prior to their purchase of a VSRS some eight years ago, complaints were received regularly from customers trying to obtain greater accuracy and stability. Since applying their AC-VSRS in the frequency range 25-190Hz, complete stability and 2-3 micron TIR are held, even under extremes of temperature and pressure. There are now no customer complaints.

Fig. 2. Vibratory stress relieving being applied to an 18-tonne bedplate. The vibrator is mounted at the top right-hand corner. (Courtesy: Ingersoll Rand).

Rigid fabrications/instability

The mild-steel fabricated press bolsters for British Rail, shown in *Fig. 1*, have no requirement for thermal stress relief but, without treatment, bores went oval and faces crowned during machining. Over forty were finished trying various machining sequences, but all were between 100% and 300% out of tolerance. Applying the VSRP reclaimed the majority. Prior to machining, the remaining 500 were stabilised using a VSRS — first torsional resonance at 123Hz for 1 minute with approximately 0.13mm (0.005in) peak-to-peak amplitude at the corners. All are 100% non-destructively tested after VSR and one in ten are magnetic-particle tested. None have been rejected — all have been in tolerance.

Bedplates/frequency response

John Brown and Ingersoll Rand, world leaders in gas compression equipment, chose the same VSRS to stabilise their bedplates. *Fig. 2* shows a mild-steel fabricated 18-tonne Ingersoll bed, CAD-designed to sit on three points and carry 45 tonnes of equipment, including two horizontal opposed compressors. VSRP was used to stabilise the bed and check computer predictions of resonant frequencies. The QA department received a print-out of frequency response, treatment cycle and dwell time, as for the thermal stress relieving process. Bed dimensions: 10m x 3.5m x 1m. VSRP: first three modes of vibration between 40Hz and 150Hz.

Repaired pumps and fans/dynamic balancing

Hewson & Turrel have found the VSRP indispensable for two vastly-different product groups: fans/impellers and pump housing repairs. Aluminium, stainless steel, cast steel and Cr/Mo steel pump housings, passing corrosive or abrasive media, wear badly in service and are built up, by MMA and MIG welding, then machined back to correct dimensions *(Fig. 3)*. Prior to the introduction of VSRP, service leaks occurred. Housings treated by the VSRP after rough machining, at frequencies between 80 and 170Hz, were found to change shape up to 0.8mm (0.030in) TIR and then, on finish machining and in service, components have been stable with no leaks.

Similar advantages are reported from Turkey's leading metallurgy laboratory, Zumre Metallurgi, but here marine-valve stems and bodies, 350mm diameter with 4140 steel base metal, are first preheated to 250-350°C then deposited with stellite GR6, whilst the part is vibrating at an undisclosed high frequency. This technique has resulted in an approximate 20% reduction in pin-holes and flaws generally, improved dilution and provided an easier surface to machine as the bead profile is reduced by approximately 50%. (If the damage is more than 6mm deep, the crater is first built up with stainless-steel GR316L by TIG and then stellite-deposit overlaid). New and reconditioned plastic-moulding machine screws and hard-faced barrels are treated similarly at many companies worldwide.

The other main use of the VSRP at Hewson & Turrel is to stabilise fans and impellers ranging in size from 800mm diameter x 100mm to 2m diameter x 900mm in fabricated mild steel and stainless steel — sometimes repaired components and sometimes replacements. After fabricating, but prior to dynamic balancing *(Fig. 4)*, the components are subjected to the VSRP. Since introducing

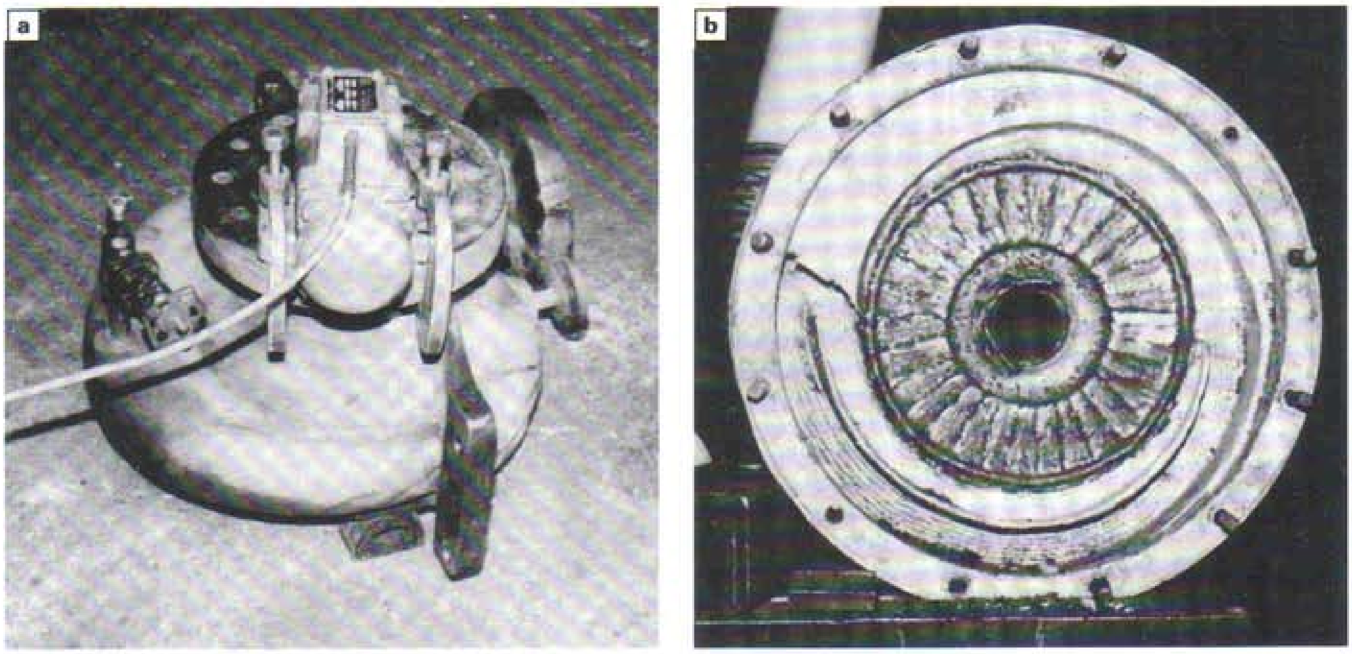

Fig. 3. Weld-repaired pump body being stabilised by VSRP (a). A view of the inside of the pump body, showing the extent of the repair, is seen in (b).

this treatment, no fans or impellers have gone out of balance in service, even under hot conditions — hitherto a troublesome area. Installations are now much quieter and last longer between overhauls.

Novenco Aerex, the UK's largest fan and impeller manufacturers, have had their own AC-VSRS for many years and endorse the benefits stated above. Their components range up to 8m diameter. Their Canadian plant also uses the VSRP. In both cases, the VSRS paid for itself in 4-5 months.

Moulds and dies/the biggest flamecut?

Moulds and dies treated by the VSRP have received much publicity recently, especially in the USA. This application is neither new nor demanding, particularly for the very 'chunky' steel dies concerned. Many require no stress relief at all. For over twenty years, typically 1m x 1m x 200-300mm components have been rough-machined and vibratory treated by leading companies such as BMF in the UK, using AC-VSRP, and Karmann in Germany using DC-VSRP. Sub-resonant vibrations are traditionally used for solid compact components. More flexible components are treated by the normal resonant method. The VSRP automatically selects the appropriate treatment.

British Moulded Fibre Ltd. replaced thermal stress relieving with in-house VSRP when they purchased their AC-VCM80. Components are either cast iron or steel and only the large ones, typically 2m x 3m x 200mm, are treated in resonance. If movement occurs during rough machining, it is immediately stopped using VSRP.

Coopers Payen Ltd. found sub-resonance VSRP ineffective on small flexible die and mould components in P20 material. The resonant method, mounting the components on a vibrating table, has proved very successful in stabilising typically 300 x 100 x 5mm to 500 x 250 x 8mm components required flat and parallel even under adverse temperatures (see *Fig. 5*).

Ford overcame instability problems on twenty steel press components (10m x 2.5m x 300m) for its *Transit* van manufacturing facility in the UK by using an AC-VSRS. During machining, gross distortion occurred, despite a thorough thermal stress-relieving treatment. Following one application of VSRP with a VCM80 machine at the rough-machined stage, no further movement took place. Resonances were at Hz 19(B_1), 30(T_1), 71(B_2), 100(B_3 transverse), 108(T_2), etc. The highest mode was at 213Hz. Sub-resonance VSRP would not have been so successful and quick. Each component was treated in less than one hour. These large 20-tonne profiled plates *(Fig. 6)* are at the upper end of another wide area of application; Rolls Royce (Bristol) are amongst an increasing number of users finding that profiled and precision-ground plates are more accurate and stable

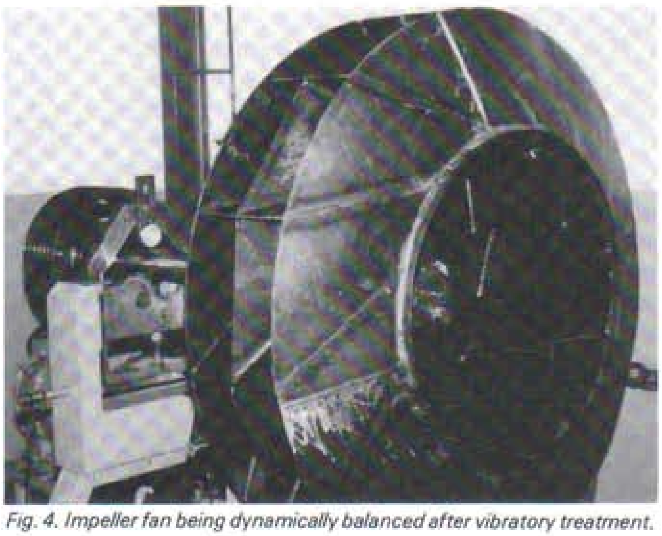

Fig. 4. Impeller fan being dynamically balanced after vibratory treatment.

Fig. 5. P20 dies, 500 x 250 x 8mm, being treated via a vibratory table.

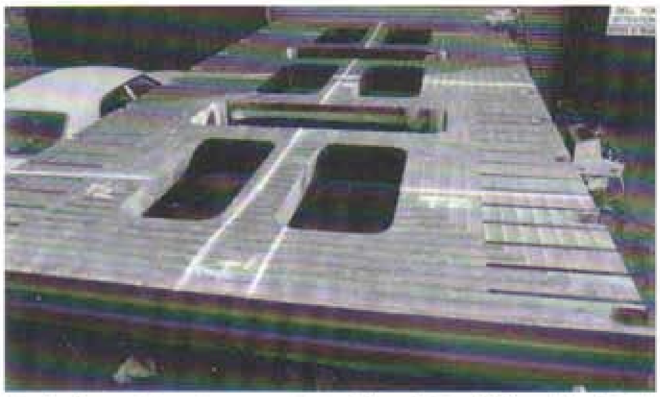

Fig. 6. One of twenty press plates (10m x 2.5m x 300mm) for Ford's Transit van press shop.

when the VSRP is applied than if thermally treated. Several leading profilers have purchased VCM80 machines.

A novel idea has emerged in the US though; applying the VSRP to moulds and dies known to develop surface micro-cracks in service. By monitoring service life, taking the components out of production prior to cracking and applying VSRP, costly down-time is claimed to be eliminated. Hot dies such as diecasting dies are said to be particularly suitable. Again AC systems have an advantage here as the treatment time is even shorter — usually less than thirty minutes. Applying VSRP after repair of dies and moulds greatly extends service life, as it does with many other weld-repaired/deposited components.

Treating the parts that thermal stress relieving cannot treat

There are thousands of components in need of stabilising that cannot be thermally stress relieved but can be treated using a VSRS. There follow some typical examples:

(a) Precision conveyor rolls for nuclear waste disposal, having an outer 304L stainless-steel shell, of 819mm diameter x 884mm face, welded to 789mm-diameter mild-steel end-plates and bosses with integral En8 120mm-diameter shaft. AC-VSRS was specified by Sandvik, approved by British Nuclear Fuels and NIS based on Sandvik's twelve years of complete satisfaction with the AC-VSRS.

(b) Mild-steel rolled hollow-section (RHS) fabricated 'A' frames with reinforcements for a vehicle front chassis, with integrally-welded cast steel 'Rose' universal joints, are manufactured in a jig to tight tolerance. Prior to VSRP being applied, 106 sets were produced and all distorted in service, causing wear. For over 1000 sets, VSRS treating at three resonances between 35 and 180Hz has rendered all completely stable.

(c) Three designs of steel armour-grade investment casting, one with a welded-on tie-bar in the fully heat-treated and final metallurgical condition, were found to be grossly unstable during machining. The largest had a 300 x 400mm picture-frame face, associated bore and pad faces 400mm apart. In the first batch of four, movement continued for two months after machining. TIR allowable in all planes is better than 3 microns. A special VSRP was applied, prior to machining, by mounting the component at its centre of gravity on a small pad on a 400 x 400mm jig table with a vibrator mounted on the underside. Treatment: 11 modes of vibration between 5 and 220Hz which has rendered all subsequent batches completely stable.

A VCM80 AC-VSRS was specified by Short Bros. for this work at their subcontractors and they have used their own VCM80 for stabilising mild-steel and aluminium composite fabrications for many years. A VCM90 system was ordered in January 1991.

(d) A failure rate of approximately 40% has been reduced to zero on parts of mining and quarrying equipment since Trellex (Trelleborg Group) and Skega introduced the VSRP to complex mild-steel fabricated components, often only 14mm x 2mm in section x 4m long.

In the same industry, some vibrating screens now carry a three-year guarantee, thanks to the AC-VSRP. Typically, screens are mild-steel fabrications from 1m x 3m to 3m x 10m and 100 to 200mm deep — usually a complex lattice of RHS, angle and tubular members. If thermally stress relieved, they usually distort badly and need mechanical or thermal straightening, often defeating the object of the original thermal treatment. When no stress relief or thermal treatment was used, butt welds that lacked preparation and had their bead ground off, leaving a weak joint, failed in service. Now, with the introduction of VSRP, welders know that poor joints will break in the weld shop, so they ensure good joints. This 'fitness for purpose' testing is regarded by Goodwin Barsby, Parker, Kue Ken, Pegsons, Babcock Power, etc. as a good reason to use the VSRP, as in-service life has, on average, tripled.

(e) Beams, 5m long x 140 x 300mm section, fabricated from RTQ60 material, bowed 2mm during rough machining. Thermal stress relieving was not permissible on metallurgical grounds. The VSRP has completely solved the problem for British Steel.

(f) Deloro Stellite use an AC-VSRS at both their UK and Canadian plants to stabilise carpet knife blades. These are typically mild-steel bar, 5m x 150 x 10mm, grooved out and deposited with stellite along one long edge. This edge is ground to expose the stellite and form a cutting edge. The mild-steel section behind is slotted to give adjustments for the holding screws. Up to ten years ago, it was common for 50% of the wear tolerance to be lost due to movement taking place during transport (typically UK to Italy). Since introducing the VSRP, no movement has occurred and tighter tolerances are maintained.

Hundreds of examples are on file: large copper plates fully machined, screwed and dowelled; flow-brazed aluminium instrument frames; powder-coated enamelled 25mm x 25mm mild-steel angle instrument frames for Marconi; mixed-metal fabrications for Helio tank turrets and a wide variety of materials such as *Inconel*, *Zeron*, duplex stainless steel, *Ferralium*, titanium, P20 (1.7% Cr steel), aluminium in TF condition, composite metal/plastic, metal/rubber fabrications, etc. For these and many other applications, the VSRP is invaluable.

However, it must be remembered that the VSRP cannot be used on pressure vessels, pipework or any parts where metallurgical change is necessary.

GETTING THE MOST FROM A VIBRATORY STRESS RELIEVING SYSTEM (VSRS)

Many engineering concerns have tried a VSRS for stabilising workpieces. Depending on the equipment used, the component chosen, the stage of manufacture, the material and knowledge of how to apply the process, the results have ranged from complete success to complete failure. The situation is completely analogous to the thermal process; various materials are treated for different times and at different temperatures; some materials cannot be treated at all. Those that can, such as mild-steel fabrications, may distort so badly that they are scrapped.

Commercial thermal stress relief companies are pressed to load the furnace with what customers require on a day-to-day basis; thick, thin and mixed-metal often receive one standard treatment cycle. Thermal stress relief has survived decades of misuse and abuse — despite all the textbooks, standards, courses and handed-down wisdom, problems still occur every day, but it has not been rejected.

Admittedly, beyond the accepted areas of vibratory treatment, we are still learning and we must keep striving to understand the problems. As with thermal treatment, we must document the problems, discuss and learn, not reject or neglect. A few simple rules will help:

(1) Choose equipment with a proven track record, both with regard to research and industrial application. Do not rely on manufacturers' brochures; for example one brochure shows a pressure vessel being VSRP treated, a procedure not accepted by any regulatory body. A manufacturer with a genuinely good product can name satisfied customers and hand out testimonial letters.

(2) Select equipment already used successfully on your type of engineering product. A 0-80Hz DC-VSRS may be fine on a rubber-machinery base but not on a precision machine-tool body. For example, in the USA, Devlieg evaluated DC-VSRS and rejected them; Devlieg of UK evaluated an AC-VSRS on the same components and found it gave better accuracy and stability than the triple thermal stress relief traditionally used. They now solely use an AC-VSRS.

(3) Existing vibratory stress relief users should be sure that the operator and management fully understand the limitations of both the process and the equipment. A good system has an extensive handbook with information on all aspects of application, including where and where not to use it.

(4) Ask if in doubt and, if not satisfied, ask again. Agents may change and have little experience — ask the principals of the manufacturers and inform your national institutes if you do not get good technical back-up.

(5) Effectiveness of the process can deteriorate with time or by changing operators. Keep records of previous jobs, either graphically, photographically or simply tabulate the information — component name/number, material, overall size, modes and frequencies. Write the information on the component, mark on the node positions and vibrator position and keep a photographic record. It saves time in the future and gives confidence in the event of a change of operator.

(6) Isolate the component at the node lines for the treatment cycle and do not think that achieving just any form of vibration will result in success. (This is a failing of automatic systems — they take away the need for the operator to think and the instruments, not often genuine indicators of success anyway, can easily be fooled). Correct isolation for the weight of the component is essential — progressive rubber cones are ideal, typically with a range up to 3.5 tonnes each (see *Fig. 5*).

(7) Modes must be sought, sympathetic to particular structures, following simple handbook guidelines; for example, back-to-back beams should be treated primarily using bending modes in the plane of anticipated spring-back. Modes perpendicular to this and those of a torsional nature will not be so effective, neither will non-resonant treatment using a DC-VSRS. Long frequency range is essential. It should be noted that the first torsional mode does very little to flat plate.

(8) Generally, the more loading patterns (modes) achieved, the greater the degree of long-term stability and accuracy[24]. This is why, in this paper, greater emphasis has been placed on to the AC-VSRS with long frequency range, rather than DC-VSRS with only 0-100Hz. Yes, the long frequency range and the increased number of modes may be an overkill in some cases, but no more than that of a standard thermal stress relief treatment. Nothing is more important than a perfect component. At least, with the vibratory process, the overkill costs an insignificant amount of time and money (fuel).

(9) Ideally, the vibrator must see itself as integral with the component. Suitable transmission media must be placed at the component/vibrator interface and extremely high clamping forces used to give stability.

(10) 'Cheapest is rarely best' applies just as much to VSR units as to anything else; over 50% of the cheap DC-VSRS supplied to India and over 80% of those supplied to the UK, since 1962, are not used. However, the lesson has been learnt in the UK; a survey shows all sales have been AC-VSRS since 1975 (see *Table 2* in Part 1 of this article).

(11) Pressure to use the VSRS for want of an alternative must be resisted. For example, in Turkey, a pressure vessel was modified by welding and then VSR treated. The vessel subsequently failed causing a fatality. This should not have occurred. It is difficult to understand how any engineer can imagine that a cold process such as VSR can change the metallurgy of the heat-affected zone as thermal treatment would. The process is no substitute for thermal stress relieving in these circumstances. Generally, however, once thermal stress relief has been applied, the VSRP can be applied later to overcome instability.

CONCLUSION

The foregoing section has in no way been an attempt to put the vibratory stress relieving world to rights: rather, it is an attempt to jolt engineers out of the simplistic complacency found in the thermal and vibration camps. There is a genuinely effective vibratory stress relieving process that, used intelligently, treats much that was thermally stress relieved. At present there is not a reliable fully automatic VSRP, nor should there be. The fully automatic thermal stress relief process severely damages thousands of components per year — a problem that could be overcome. This paper has been a genuine attempt to assist both the researcher and the practising engineer, the existing and potential VSRP user. No doubt some questions have been left unanswered and some areas of interest not covered. The author is always ready to give advice on vibratory stress relieving applications to existing equipment users and those contemplating using the process.

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