HEAT TREATMENT
OF METALS
1991.2 P.53-59

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

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Part 1: Research, Equipment and Processing

The benefits, limitations and application of vibratory stress relieving are reviewed in a two-part article. In this first part, the author casts a critical eye over research into the efficiency of the technique before describing equipment development and processing procedures. He concludes by discussing some of the questions commonly asked about the treatment.

INTRODUCTION

With the exception of the practice of "ageing" of castings, the traditional method of stabilising engineering components has been to treat them thermally. This involves many hours in a furnace with its associated high-energy costs, pollution and delays in manufacture. Reduction in component rigidity can occur along with distortion due to heating For over fifty years, engineers have been attempting to obtain equivalent or better stability with diverse vibratory treatments.

Based on the paper "Vibratory Stress Relief Process applied for Component Stabilisation" presented by the author to the 22nd International School of Welding, organised by the Welding Research Institute of Czechoslovakia, on 13-20 October 1990

In the sixties and early seventies, the need was partly met by DC rotating-mass vibrator systems (DC-VSRS), which largely gave way to AC rotating mass vibrator systems (AC-VSRS) in the seventies. Where available, these dominated the eighties, especially when requirements called for extreme accuracy and stability, coupled with a wide application range. The superiority of AC-VSRS has become widely accepted by industry and researchers alike.

Currently, VSRS treatment of castings, welded fabrications and bar components, from under 1kg to over 100 tones, is commonplace (Fig 1). Treatment times are shorter than thermal treatment by a factor of approximately fifty, with no discoloration, even on near finished components, thus giving rise to extreme accuracy and stability. Capital cost is very little.

New enhanced force/frequency ranges, introduced for the nineties, mean that many of the traditionally difficult areas, even for AC-VSRS, can be tackled, further reducing the role of thermal stress relief. Modern AC-VSRS also provide valuable design data with respect to component frequency response.

This paper traces the development of vibratory stress relieving techniques and equipment with reference to industrial use, academic research and twenty-one years of personal experience.

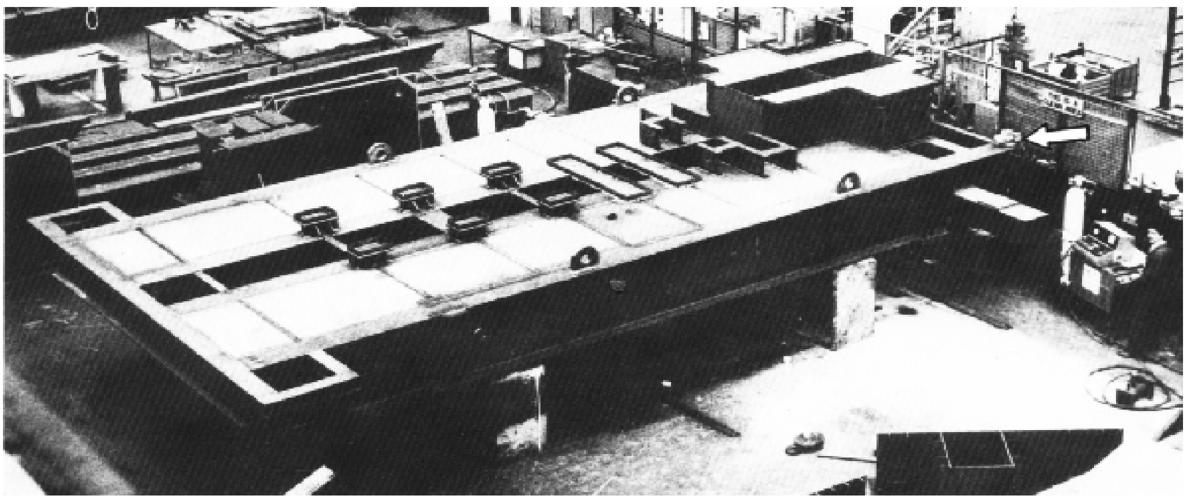

Fig .1. Vibratory stress relieving being applied to an 18-ton bedplate. The vibrator (arrowed) is mounted at the top right hand corner. (Courtesy: Ingersol Rand)

RESEARCH

Many attempts have been made to establish what happens inside material during vibratory processes. Conclusions include: "nothing", "cyclic versions of a simple stress overload" and "beneficial effects of vibration on the distorted crystal lattice of the material".

With few exceptions, up to the mid-eighties, research at universities was carried out using laboratory tensile test machines, rotary/bending fatigue rigs or oscillatory electro-magnetic vibrators. Some closely simulated a VSRS; others bore no relationship at all. Erroneously the results were referred to as vibratory stress relieving and this caused misunderstandings.

At best, an old VSRS, totally non-representative of the state of the art, was used – as Sedek [1]. Other methods had speeds nowhere near the resonant frequencies of the components. Quite notable establishments ridiculed the vibratory stress relieving process (VSRP) as a means of stabilising components, based on work using: cams flexing a finger test piece, having no freedom to creep; or specimens placed in a deburring barrel as Hallet[2, 3] or incredibly, a stretched testpiece strapped to a foundry knockout shaker ram[2, 3]. None had any bearing on VSRP and only served to confuse the casual observer and the reviewer seeking abstracts concerning the process. However Dawson[4] successfully used laboratory equipment to shed light on the fundamentals. This has been ignored by subsequent research – Wahlstrom[5] and current work in the USA. Experimenting with inappropriate testpieces has served only to waste sponsor's money and tarnish the VSRP image. So many research groups including recent Dutch university work for the EC, wasted time and effort by repeating past mistakes

We are all guilty at one time or another of reading technical papers superficially and not seeing the basic flaws contained in the body of the report. When researchers and reviewers themselves fall into this trap, the problems are compounded and misinformation results. Two classic examples are an article by Brogden[6] in 1968 and one by Parlane[7] in 1978. The former changed his views in 1969 when he found that hundreds of companies in the UK were successfully using a vibratory method. The latter did not bother to seek data from leading experts in the vibratory stress relieving field, even when introduced to them during the preparation for his article. Parlane misquoted the Battelle report[8] and questioned the effectiveness of the VSRP. No doubt many engineers read the article thinking it to be authoritative, contained as it was in a usually reliable publication.

On the positive side, many research projects have shown significant stress reductions; i.e. greater than 30%. A proprietary aerospace report showed 40% reduction with titanium 685 bar. Strachen[9] demonstrated 80% with mild-steel welded specimens and 60% reduction in stainless-steel welded specimens. Zveginceva[10] reported over 40% and Zubchenko[11] approximately 73% reduction with large mild-steel welded bedplates, while Weiss[12] substantiated Strachen's findings using small components. All excited the components in one or more resonances but unlike Zubchenko, Weiss did not use proprietary equipment as he needed between 100 and 120Hz for resonance to occur. Only DC-VSRS were available and then, as now, they were limited to 100Hz.

More recently, with the advent of the 5-200Hz range of VSRS, both private research (CEGB and National Power) and other papers (Jesensky[13] , Bonthuys[14], Ohol1[15] and Sagalevich[16]) showed reductions ranging from 40-80%, all using the resonant approach

Table 1. Summary of recent experimental investigations (updating table 2.2 contained in Dawson's thesis *4*)

Ref. No.	Author	Date/origin	Material	Specimen	Method of stress induction	Method of cycling/ Resonance or non resonance	Strain measurement method	Results† Instability	Results† Residual stress
1	Sedek	1989/Poland	Mild steel	Mill equipment	Welding	DC-VSRS Res./non-res.	Non-stability	A	Compressive: B Tensile: B
5	Wahlstrom	1976/Sweden	Mild steel	Tube flange & plate	Welding	DC-VSRS Non-resonance	RSG*	B	B
13	Jesensky	1988/Czecho.	Mild steel	Welded beam	Welding	AC-VSRS Resonance	RSG	A	Compressive. A Tensile: A
14	Bonthuys	1989/USA	Mild steel	Plate & bed	Welding	AC VSRS Resonance	RSG	–	Compressive. A Tensile. A
10	Ohol	1988/India	Mild steel	Bed plate	Welding	AC-VSRS Resonance	RSG	A	Compressive. A Tensile. N
15	Ohol	1988/India	Stainless steel/mild steel	Centrifuge bowl	Welding	AC VSRS Resonance	RSG	A	–
16	Sagalevich	1979/Russia	Mild steel	Welded beam	Welding	Simulated Resonance			Compressive. A Tensile. A
20	Murthy	1981/India	Mild steel	Plate & bed	Welding	DC-VSRS non-resonance	X-ray diffraction		Compressive. N Tensile. A
21	Bouhelier	1988/France	F 26 4	Gearbox	Welding	DC-VSRS Res./non-res.	X-ray diffraction	A	Compressive: A/B Tensile: A
23	Ananthagopal	1986/India	Mild steel	Gearbox	Welding	AC VSRS Resonance	Non stability	A	
24	Rudder	1971/Belgium	Mild steel	Machine frame	Welding	Vibrating table Resonance	–	A	–
25	Burck	1977/USA	A36 steel	Test rod	Mechanical	Fatigue machine Non resonance	Instability	–	Both B at low cycles

*RSG = Rosette strain gauge.

† Key to results. A = decrease (beneficial), B – no change (ineffective); N – no data

While the high imposed cyclic stresses are elastic and kept well within safe limits by the natural damping of the component, they do not permit the imposed strains to add to the residual strains and cause local plasticity at points or areas of stress concentration.

Following a series of such resonances each with a different imposed strain pattern, very substantial lowering and redistribution to low levels of the overall stress field is achieved [17]. Dawson did not get this far as he only used plain bar, not weldments.

When resonance has not been obtainable, or only partially so, due to the limitations in the "g" tolerance of DC vibrators, etc. (see Sedek[1], Nokleby[18], Leide[19], and Wahlstrom[5]), results have been very poor indeed. There are inevitably maverick results, notably Murthy et al[20] and Bouhelier et al[21]. Both used DC-VSRS, both measured stress by X-ray diffraction and both claim stress reductions of up to 100%, which seems unbelievable, particularly given dynamic stress levels as low as 1.5Mpa. Although both reports are flawed (both obviously and in technical detail), on the surface they may appear convincing; however, subsequent to the HAL report[20], unsolicited, their company has purchased three AC-VSRS 5-200Hz systems at yearly intervals.

Many reports include well-documented strain measurements using either strain gauges or X-ray diffraction methods [1,9,11,13-15,21,22]. From these and other works, it appears that non-resonant treatment is most effective when high tensile stresses predominate, whereas resonant treatment is equally effective whether the stress field is highly tensile, or compressive, or both.

Table 1 reviews the results of some recent papers. For stability to exist after machining and under service loads, it is obvious that both tensile and compressive stress peaks must be reduced; in fabrications and castings, these peaks can be of yield value. Research with AC-VSRS tends to be at resonance, resulting in stability, as it does in practice. Stability is, after all, the engineering requirement for which VSRP is applied; actual stresses are rarely measured. Where researchers have obtained resonance, stability matches that of thermal stress relief [1,13,15,21,23,24] (see table 1).

Generally, academic and industrial research confirms the author's practical experience. It indicates that where AC-VSRS are applied and, for extreme accuracy and stability applied a second time at near finish-machined size, the results have been better stability and accuracy than is achieved using thermal stress relief (Hrivnak[26], Claxton[27,28]). Obviously the modern VSRP has the advantage over thermal stress relieving that it does not reduce rigidity or other material properties (Jesensky[13]) and is able to attack machining stresses just prior to component finishing. In practice, accuracy is only limited by the accuracy of the machining producing the part, and research is at last beginning to show why.

EQUIPMENT

For over fifty years, rotating-mass vibrators have been used for vibratory stress relieving systems. For a time it was thought that oscillatory vibration might be effective. Components were treated strapped to rams of oscillatory vibrators, but these were of fixed frequency (as well as being non-portable) and results were inconsistent.

Early rotary equipment was limited by poor speed range and bulky vibrators and control equipment meant that units were not portable. Portable consoles were a product of the sixties; when small high performance DC motors had eccentric weights added to their spindles and were called vibrators, a simple DC-VSRS was launched. Surprisingly one such system, with few developments, is still available but the area of successful application is limited.

Next, commercial lightweight DC vibrators, driven by portable consoles, became available but, progressively, components were being redesigned to be stiffer, many being made of fabricated mild steel not cast iron. These highlighted the deficiencies in the frequency range of DC-VSRS such as Formula 62 and Martin. In response, Winterburn's unit (an offshoot of Lodding, USA) stretched the standard DC motor beyond 80Hz, to pass through more resonances, but reliability suffered. In 1970, a London based company associated with B&K produced a 5-150Hz DC system (Omega 70) but this failed prematurely; the vibrators could not endure the rigours of higher forces and frequencies.

Meanwhile, DC-VSRS manufactures in the USA emphasized sub-resonant vibration at relatively low frequencies and high forces *during* welding; they did not need to exceed the 80Hz threshold, there was no increase in noise peaks and vibration during welding required more vibrators for longer periods! This method had some merit as it reduced distortion, lowered stresses, refined the weld material, improved dilution, reduced cracking, increased deposit rates but lowered the bead profile.

In 1978/4, a French company developed an AC-VSRS, the P3V, with a vibrator that attained 100Hz. A second vibrator attained 200Hz but output force was unacceptably low. Although reliable, the P3V required a heavy generator to produce three-phase variable-frequency supply to the vibrator, rendering the unit only semi-portable. Several units sold in quick succession in France and the UK but then developments elsewhere halted production.

In 1972, in response to the Battelle report (which highlighted the inadequacies of DC-VSRS) and practical experience with the P3V system, development began on an all-electronic AC-VSRS with help from the Stanley Research (SERC). The development team conducted trials with a Formula 62, P3V, Winterburn, two different Martin units and an Omega 70. All available research papers were studied

The culmination of a three-year program was the introduction of the VCM80 equipment – the first fully portable AC-VSRS. Two three-phase variable-voltage variable-frequency vibrators were powered from a 220/240V single-phase mains supply via a custom-built electronic drive package, to give an overall frequency range of 5-200Hz. After overcoming early drive problems, the system was very reliable. The robust and uncomplicated design of its AC vibrators meant that the equipment did not suffer brush faults/bounce, fatigued connections or failed springs, nor did field windings or commutators burn out as they regularly had with DC vibrators when worked hard. In terms of tolerance to acceleration forces (g), the DC vibrators only tolerated 8-10g whereas AC ones of the VCM80 system tolerated up to 50g.

The problem throughout with DC vibrators was that they did not like being vibrated as severely as effective stress relieving dictates, so manufactures had introduced self-protecting features. In addition, they had to site the vibrator where it would not draw too many amps, rather than where it would best excite the component. The self-protecting features were wide-ranging: the "triangle of amplitudes" of the Formula 62; the "scan method" of Martin VSR; the "sub-resonant treatment zone" of Meta-lax and more recently, the novel "Fourier Scan" method of VSR Eng. These systems all rely on the avoidance of resonant peaks, high "g" forces, the need to stretch their speed range and the use of DC motors. These shortcomings and occasionally inappropriate testpieces have meant little success for DC-VSRS research projects.

Unless the frequency range is doubled, the situation is unlikely to alter, despite the newer DC systems changing over to stepper motors and servo-drives to achieve better accuracy and tighter feedback loops.

At this point, it is worth expanding a little on the sub-resonant approach – an example being the Meta-lax Process. Their literature has been claiming even greater success and more widespread use than ever. They claim to measure successful treatment by small changes in resonant frequency and, although most VSRPs notice this phenomenon, it is not a reliable sign of successful treatment. This is just one of the many puzzling contradictions inherent in the process. Outside the USA, little of the research on VSRP has dealt with sub-resonant treatment. Bonal's meta-lax process claims to have the backing of some American researchers but the project they cite have not reappeared in any independent research paper known to the author. Much of what they say seems contradictory but, given their extraordinary claims and increasingly high profile, it seems fair to mention the process in the hope that this may bring forth some independent research.

Meanwhile, a good example of an AC-VSRS is the VCM80 system. It embodied a British-made drive module dedicated to vibratory stress relieving applications, bringing the normal ±1% frequency stability near to absolute.

The benefits to both conventional vibratory stress relieving applications and the spin-off, frequency-response testing, were considerable.

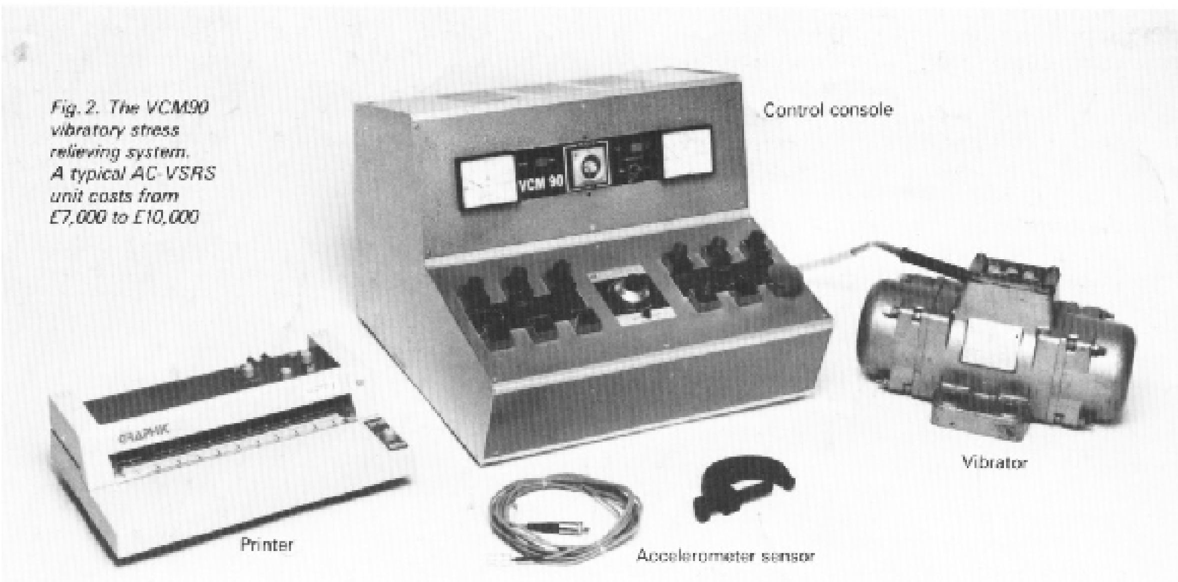

Fig. 2. The VCM90 vibratory stress relieving system. A typical AC-VSRS unit costs from £7,000 to £10,000

In the initial four countries chosen for sales (Czechoslovakia, India, Poland and UK), the VCM80 took over 85% of the market.

So, with the dawn of the nineties, there is still the choice of DC and AC systems. VSR Eng. Of Unterfeld, Germany have recently launched their Fouriermatic KD. It uses two DC vibrators to reach 80Hz and claims, via computer analysis to select frequencies in much higher ranges. Attempts to ascertain its degree of success have been met with no response from either company or independent sources. The sales literature is confusing, as it gives no proof, and many of the examples shown seem to be for the Fouriermatic's predecessor, the Martin LT120. The weight of the system could well be a problem; one vibrator weighs 38kg and the other 50kg. The 25A current requirement is a problem on many 240V supply sockets.

From AC-system builder Vibratory Stress relieving Co. of Worcester, UK, comes the VCM 90 (fig 2) with a top speed of 220Hz. This is a 10% increase over the VCM 80 specification, using two ranges of vibrators with a top force of 20g and lightweight vibrators of 24kg. A third, very low speed high force vibrator is also available for specialised applications. Of modular form, the system allows the user to supply the flat bed recorder if desired. The low cost tradition of the VCM80 continues, despite major improvements such as a new drive module having phase-phase / phase-earth output protection. Supply is 13A, 1-phase, 220/240V, 50Hz. In addition it can still be used for frequency response testing.

Because its frequency range encompasses that of the DC-VSRS, it can also be used to mimic the modus operandi of DC-VSRS with regard to scanning, sub-resonant treatment, etc. for comparative evaluation.

PROCESS PROCEDURE OVERVIEW

Both DC-VSRS and AC-VSRS systems are available and, as previously mentioned, the DC approach is quite variable. As a result, no standard vibratory stress relieving process exists. In the main, DC systems procedures have been geared towards protecting inadequate equipment while AC systems are solely orientated towards optimising component treatment. We concentrate here on the latter (AC-VSRS) because the weight of recent research indicates that these systems are more effective (see table 1). This view is also supported by industry, as indicated in *Table 2* which charts the demise of DC-VSRS.

In most cases, depending on accuracy/stability required and convenience, AC-VSRP is applied before machining. However, if greater accuracy/stability than can normally be expected of thermal stress relieving is required, VSRP can be reapplied prior to final machining. The component is supported on rubber isolators and a special-duty vibrator is attached initially on the periphery of the component. An accelerometer sensor mounted on the component will identify the different resonant conditions as the frequency range is scanned. The frequency range has been extended to 5-220Hz on the newest AC system.

Table 2. The charted demise of the DC-VSRS

This table lists all the known DC-VSR systems supplied to the UK market, totalling fourteen in all. (In addition, two different generations of Martin unit were sold to agents but neither company could find buyers). Although the two companies offering an on-site DC-VSR service ceased trading, on-site AC-VSR has flourished, with over eighteen units offering a mobile service to over nine hundred customers, of whom 10% subsequently bought the equipment. The growth continues.

CUSTOMER	MANUFACTURING SECTOR	APPLICATION	EQUIPMENT	COMMENTS
Air Log	Military equipment	Launch frame	Formula 62	Specified by US principal — used once
Ambrose Shardlow	Automotive	Forgings	Formula 62	Found unsatisfactory
Black Clawson	Paper machinery	Mild steel/stainless steel fabrications	Martin	Replaced by AC-VSR contractor
Brown Lenox	Mining/quarry equipment	Mild steel/carbon steel fabrications	Formula 62	Mediocre results*
Cameron Iron	Aerospace	Titanium fabrications	Formula 62	Not used
Dando	General fabrications	Mild steel & stainless steel fabrications	Formula 62	On-site service — ceased trading
Hennan Froude	Presses & extruders	Mild steel fabrications	Winterburn	Inconsistent results — sold*
Harris Economy	Steel scrap treatment	Presses/shears	Formula 62	Mediocre results*
Midland Stress	On-site service	Various	Formula 62	Ceased trading in the mid-1980's
Midland Stress	On-site service	Various	Winterburn	Units not satisfying many customers
Pamac	Paper machinery	Mild steel & stainless steel fabrications	Winterburn	Dissatisfied with results*
Stewart Ross	General engineering	Various	Formula 62	Dissatisfied — discontinued
Wyndham	General engineering	Mild steel fabrications & castings	Formula 62	Dissatisfied*
British Aerospace, Hatfield	Aerospace	Jigs and fixtures	Omega 70	Mechanically unreliable*
British Aerospace, Chadderton	Aerospace	Jigs and fixtures	Omega 70	Mechanically unreliable
APV Michell	Rubber machinery	Castings and stellite	Formula 62	Used occasionally for weld deposit
APV Crawley	Process engineers	Mild steel fabrications	Formula 62	Failed to stabilise test piece*

*Replaced by AC-VSR systems

A resonant peak occurs when the induced frequency of the vibrator coincides with the structure's natural resonant frequency and such peaks can be seen, felt, heard and shown on meters and recorders. A frequency scan lasts just ten minutes, in which time all the treatment conditions are established. Loose material will collect at the node lines (still areas). The optimum position for the rubber supports is beneath these lines. After the initial scan, adjustments to the positions of vibrator and supports are made. Vibrator plane and direction are also important. Each peak is then treated in turn for a period, often only a few minutes, given in the handbook related to material and component type.

The amplitude of vibration increases at resonance, to be limited eventually by the natural damping effects of the component and to a lesser extent, the supports and windage. Alteration of the induced frequency ends resonance and reduces amplitude. Treatment takes place at or near the resonant peak. High amplitude resonant vibration cause overall elastic distortion of the structure, much as mechanical loading can. The advantages of vibration is that a variety of loading patterns (modes) can be obtained in complex structures – something difficult if not impossible with a direct mechanical – loading device. As many of the natural frequencies as possible are used and, sometimes, the vibrator is repositioned in order to alter the mode shape or node position. This is the convenience of vibration at resonance as a means of mechanical stress relief. Service loading patterns may also be simulated with the benefits that this can entail.

For optimum treatment, the component has to be supported on rubber isolators, allowing complete freedom of vibration. Only high-force infinitely-variable vibration, with a minimum frequency range of 5-200Hz, using rigid clamps should be employed. A vibrator and component must be as one. The better the frequency range, the better the treatment, as more modes (loading patterns) are established[17]. A chart of conformity can be supplied. Handbooks give detailed procedures.

While overall treatment stresses are imposed on the structure in the elastic range, points of stress concentration or fields of internal stress cause local plasticity, lowering and redistributing residual stresses. In addition, the cyclic behavior of the material is not without importance. Because the process can be applied up to and including the finish-machined stage, extreme stability results. Components are not significantly distorted and material strength is not reduced. Straightening after welding should be done before VSRP. VSRP does not normalise or anneal components. Resonance does not damage components[13] as the smallest movement at the foot of the peak starts to reduce and redistribute critically high stresses. Lower stresses are worked on as the peak is developed.

Researchers with simple test bars have often missed this important point, along with the essential requirement to allow the mean stresses to vary at will. Dawson's conclusion[4,22] that frequency is not important was of course, due to his being able to use forced vibrations. Outside the laboratory resonance is necessary.

SOME QUESTUIONS ANSWERED

Stabilisation

Those with no first hand knowledge of VSRP often ask how fabrications or castings of a more complex nature are adequately stabilised. Each resonance affects a different area of the component. The higher the resonant frequency, the more complex the loading pattern and the more uniform the treatment as panels and individual limbs are brought into resonance. DC-VSRS are less effective in this regard as their maximum frequency is usually 80hz. Special AC-VSRS have been supplied giving 5-250Hz; 5-220Hz is standard on one AC system.

What proof is there that VSRP stabilizes the component? Unfortunately, as with thermal stress relief, there is no immediate proof. Both methods rely on track record. Admittedly with thermal treatment there may be discernable metallurgical changes but neither this, nor discoloration, is proof of stability. Soak time may have been to short and stresses may have been reintroduced in the cooling cycle. With both processes, surface stresses could be measured but that is impractical and still no proof of stability

Table 3. Reference papers giving direct access to industrial examples of the acceptance of VSRP

	REFERENCE NUMBER	15	20	21	23	27	28	30	31	32	33
BREAKDOWN BY COMPONENT MATERIAL	Aluminium					●	●		●	●	
	Cast iron				●	●	●		●	●	
	Cast steel								●		
	Copper									●	
	Hardened steel								●		
	Mixed metal fabrications	●				●	●		●	●	
	Stainless steel						●	●	●	●	
BREAKDOWN BY COMPONENT TYPE/INDUSTRY	Aerospace (27)*						●				
	Regulators (17)						●		●		
	Cranes (3)					●				●	
	Fans (5)					●		●		●	
	Gearboxes (16)			●	●				●	●	
	Generating plant (4)					●				●	
	Laser systems (4)					●					
	Machine tools (25)						●		●		
	Marine (7)			●		●	●	●	●	●	
	Mining & quarrying (6)				●		●			●	
	Oil industry (5)					●				●	
	Paper industry (11)						●				●
	Plastic & rubber (7)					●				●	
	Printing (4)					●			●	●	
	Rail industry (6)					●					
	Railway (3)	●					●				
	Textiles (6)					●				●	
	Vehicle industry (25)					●				●	

*Figures in parentheses are the approximate numbers of vibratory stress relieving systems known to be used in each sector of engineering in the UK. The list is not exhaustive.

Some VSRS are claimed to indicate the progress and completion of stress reduction. This phenomenon can be observed with all types of equipment but in truth, it is heavily influenced by mechanical and electrical factors inherent in the vibrators, supports etc. In any event the phenomenon is neither qualitative nor quantitative[5,29].

Supreme Accuracy

Many engineers still look upon VSRP as something to turn to if thermal stress relieving cannot be applied, Yes, it is usually quicker, cheaper and cleaner than thermal treatment but it goes further than that; if supreme accuracy is required, VSRP can be re-applied near to, or even after, the final machining stage, thus effectively treating machining stresses. A leading military instrument builder applies his AC-VSRS to a finished mechanical assembly, then retorques the joint bolts to give better joint stiffness and stability. Rework has been eliminated. *Table 3* shows wide industrial acceptance.

Machinability

Many believe that thermal stress relief is required to improve the machinability of steel. This may apply where thick flame-cut edges are to be machined. However it is good welding practice that such items should be normalised in a furnace prior to fabricating to ensure good weldability. Thermal treatment of these small items and vibratory treatment of the finished component amounts to less in cost and time than thermal treatment of the finished whole. A good example is a gearbox with thin walls and thick flame-cut half bores.

Occasionally steel plate is difficult to machine because of chromium segregation. This condition would not be known in advance of machining, therefore standard thermal stress relieving at 600-650°c is required to anneal such steel. With VSRP an initial low-cost stress relief charge, with no transport, has to be paid, whereas thermal stress relief involves two furnace charges and two transport charges. Additionally, two thermal treatments would reduce the components rigidity.

Fatigue

Many casual observers worry that the VSRP will cause fatigue. Jesensky[13] and others[34] have shown that this is not so. It is clear that the more effective the treatment, the more remote the probability of fatigue. With the many loading patterns produced by a wide frequency range, fewer cycles per mode are required. As few as 1000cycles are needed for many components. The author knows of no failures of good welds in 21-years experience of VSRP. Failures that have occurred would not be classed as fatigue failures, as they tended to be instantaneous with loading.

Informed opinion puts these down to pre-existing microstructural damage caused by critical stressing induced during cooling of heavily welded fabrications.

There is the case of failure where little or no weld preparation is carried out and the weld bead is ground off. Vibrating plant manufactures (mining and quarrying equipment, etc.) have turned this to their advantage by using VSRP, mainly on hitherto non-stress relieved parts such as screens and deck support frames, for “fitness for purpose” testing.

As a result they have been able to extend warranties from one year to three years (e.g. Babcock Power).

Fatigue has only occurred when rules have been broken or advice ignored. In his bending tests Dawson [4,22] found that unless he eliminated the stress raiser at the point where the test bars gripped, some fatigued.

This problem does not occur with VSRP as aluminum shims protrude from under the vibrator foot or clamp point. Hawbolt [35] was told of this but ignored it, had terrible problems with fatigue and, in his report blamed VSRP.

With regard to the fatigue life of test bars, it takes between 10 and 100 times longer to achieve the same stress reduction with axial cycling as with cycling in bending. So Burck’s [25] significant stress reduction achieved after 50,000 cycles was achieved by Dawson in only 1000 cycles, otherwise the process would not be viable.

For the above reason, Buhler’s work has not been included in this paper while Jesensky’s has. Obviously thermal stress relieving confers benefits greater than VSRP with respect to fatigue properties, but VSRP is not specifically applied to enhance fatigue properties.

Metallurgical changes

Is thermal stress relief more reliable and predictable than VSRP? Certainly not! For the purpose of this paper, we took Coventry, a center of diverse engineering excellence as an example and asked companies to complete a stress relief questionnaire. The results showed year-on-year reliance on VSRP for complete stability of engineering components as diverse as any examples in this paper.

All sixteen-service units of the national on-site vibratory service network were contacted, to evaluate trends and satisfaction, and a random selection of thirty companies with their own in-house vibratory units was questioned.

Complete satisfaction in all quarters was reported. Another fact has emerged from this survey: approximately 98% of the vibratory systems in the UK are of the AC type (all but two being VCM80 systems). Only two of the ten F62 units sold in the UK are still being used, along with one each of the Martin, Omega80 and Winterburn units (see *Table 2*).

Noise

In a minority of cases, VSRP produces unacceptable noise levels, but measures can be taken to overcome this:

- For components up to say 3m x 1m x 1m, a simple rough sawn 30mm thick-wall wooden packing case placed over the component, reduces the noise to acceptable levels.

- VSRS having a long frequency range help, as noisy panel resonances can be ignored and treatment concentrated on overall structural resonances.
- With plates and frames, for a given resonance frequency, a succession of different mode patterns can be obtained by moving the vibrator, rather than going to higher frequencies.

CONCLUSION

Despite the widespread acceptance of vibratory stress relieving, there are thousands of companies worldwide that could be using VSRP with 100% surety. They are often put off by misinformation spread by engineers and academics who appear to think that VSRP is being foisted on industry to replace thermal stress relieving indiscriminately. It is not.

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The following are useful background papers, but do not necessarily represent the state of the art*: 1,4,5,8,12,16-19,22,24-26,29 and 34*

The following are typical misleading or inappropriate papers: *2,3,6,7 and 35*

The following contain genuine and useful engineering examples: *23,27,28,30-34 and 36*

The following show large stress reductions*: 9-17,20 and 21*

In the second and concluding part of this article, to be published in the next issue of HEAT TREATMENT OF METALS, the author describes various industrial applications of vibratory stress relieving and provides guidelines for its successful implementation.