



ASPEC ENGINEERING PTY LTD
ABN 22 105 267 016

Level 3, 349 Coronation Drive
Milton QLD 4064

PO Box 1843
Milton QLD 4064

T (07) 3842 3114
F (07) 3371 7300

www.aspec.com.au

Introduction

Welcome to ASPEC's first newsletter for 2009. The objective of this newsletter is to share knowledge and experience gained during the course of our work. This edition contains articles on Welding Defects, Causes and Corrections as well as Vibration Acceptance Criteria. These articles emphasise the fact that "perfection" is usually not possible in engineering and we should always clearly specify some type

of acceptance criteria whether it be a description of acceptable vibration amplitudes or a description of the acceptable level of flaws in welds. We are always happy to receive suggestions from readers as to the subjects and types of articles for future newsletters.

by Frank Gatto (fgatto@aspec.com.au)

Welding Defects, Causes & Correction

Welding defects can greatly affect weld performance and longevity. Having an understanding of the various defects, their causes and remedies can help to ensure higher-quality and longer lasting welds.

Upon detection of welding defects, an evaluation should be carried out to determine its severity, and appropriate action taken. Even the most inconspicuous weld defect, can render a welded structure unfit to carry out its intended purpose.

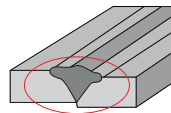
This article details some of the more common welding defects, their causes and possible preventative and corrective measures.

Geometric Imperfections

Geometric imperfections refer to certain weld characteristics such as fit-up and weld bead shape as determined by visual inspection. They are an indication of poor workmanship and may be cause for concern if they exceed the acceptable limits of the quality control code being used for the weld inspection.

• Misalignment

This type of geometric defect is generally caused by a setup/fit up problem, or trying to join plates of different thickness.

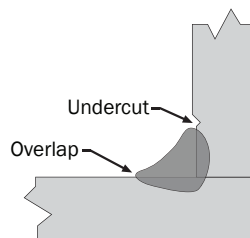


• Overlap

The protrusion of weld metal beyond the weld toe or weld root. It is caused by poor welding techniques and can generally be overcome by an improved weld procedure. The overlap can be repaired by grinding off excess weld metal and surface grinding smoothly to the base metal.

• Undercutting

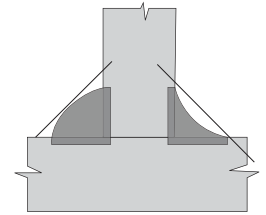
Undercutting is one of the more severe welding defects. It is essentially an unfilled groove along the edge of the weld. The causes are usually associated with incorrect electrode angles, incorrect weaving technique, excessive current and travel speed. Undercutting can be avoided with careful attention to detail during preparation of the weld and by improving the



welding process. It can be repaired in most cases by welding up the resultant groove with a smaller electrode.

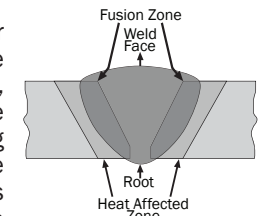
• Concave and Convex Welds

Misshaped welds are caused by a combination of incorrect electrode current and speed. Excessive concavity (lack of reinforcement), results in insufficient throat thickness in relation to the nominated weld size. Excessive convexity results in poor weld contour. In multilayer welds this can give rise to slag inclusions, while in the finished weld it provides a poor stress pattern and a local notch effect at the toe of the weld. They can be avoided by using an appropriate electrode size, current and weaving pattern. Repair by either filling with further weld material or by grinding back to the base metal on each side of the weld and re-welding.



Cracking

Cracks and planar discontinuities are some of the most dangerous, especially if they are subject to fatigue loading conditions. There are several different types of cracks and none are desired. They must be removed by grinding back (if superficial) or repaired by welding. Cracks can occur in the weld itself, the base metal, or the heat affected zone (HAZ).



Longitudinal cracks run along the direction of the weld and are usually caused by a weld metal hardness problem. This type of cracking is commonly caused by a cooling problem, the elements in the weld cooling at different rates. They can also be caused by; the weld bead being too wide, current or welding speed too high or having the root gap too large and also by shrinkage stresses in high constraint areas. Longitudinal cracks can be prevented by welding toward areas of less constraint, preheating the elements to even out the cooling rates and by using the correct choice of welding consumables. If cracks do appear they can be repaired by grinding out or cutting the members apart and re-welding.

A transverse crack is a crack in the base metal beginning at the toe of the weld. They are caused by transverse shrinkage stresses, and often indicates a brittleness problem in the heat

INSIDE THIS ISSUE

Introduction	
Welding Defects, Causes and Corrections.....	p.1
Vibration Acceptance Criteria.....	p.3

Every effort has been made to ensure that the information contained in this newsletter is correct. However, Aspec Engineering Pty. Ltd. or its employees take no responsibility for any errors, omissions or inaccuracies.

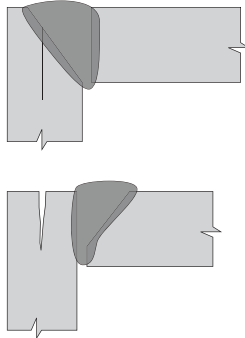
For any enquires regarding this newsletter including adding or removing your name from the newsletter distribution list please email: ksmithcottrell@aspec.com.au

affected zone. To prevent them it may require an increase in pre-heating or the use of a more ductile filler material. Underbead cracks are cracks in the unmelting parent metal of the heat affected zone and can be caused by hydrogen embrittlement (a process by which various metals become brittle and crack following exposure to hydrogen). To prevent these cracks use hydrogen controlled electrodes or preheat the elements being welded. These cracks can be repaired by gouging out and re-welding, but can only be found using non destructive testing (NDT).

Cold cracking occurs after the weld metal has had the chance to completely solidify. They are caused by highly restrained welds, shrinkage and discontinuities. Cold cracks can be prevented by preheating the weldments, welding towards areas of less constraint as well as using more ductile weld metal. They can be repaired by removing and rewelding the elements together.

• Lamellar Tearing

Lamellar tearing is a type of defect that is most likely to occur below a welded joint at points of high stress concentration. It is created by non-metallic inclusions being rolled into the hot plate metal during fabrication. These tears occur when weld metal is deposited on the surface of a joint where there is high restraint. Special joint design is one way to minimize this defect but the best precaution is to specify materials of adequate quality and test at the receiving inspection.



Inclusions

Inclusions are generated by extraneous material such as slag, tungsten, sulfide and oxide inclusions becoming part of the weld. These defects are often associated with undercut, incomplete penetration and lack of fusion in welds. Insufficient cleaning between multi-pass welds and incorrect current and electrode manipulation can leave slag and unfused sections along the weld joint. Slag inclusions not only reduce cross sectional area strength of the joint but may serve as an initiation point for serious cracking. This defect can only be repaired by grinding down or gouging out and re-welding.

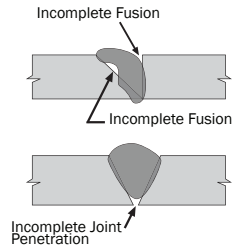
Porosity

Porosity is a collective name describing cavities or pores caused by gas and non-metallic material entrapment in molten metal during solidification. There are many causes which include contamination, inadequate shielding, unstable arc, arc gap too short and poor welding technique in general. Porosity can be minimized in many different ways - by the proper selection of electrodes and/or filler materials, improved welding techniques, more attention to the work area during weld preparation and a slower speed to allow gasses time to escape. The effects of porosity on performance depend on quantity, size, alignment, and orientation to stresses. When clustered at the weld's center, porosity is not considered a dangerous fatigue promoter, or detrimental to fatigue resistance, although it may reduce the static stress carrying capacity of the weld.



Incomplete Fusion/Penetration

Incomplete fusion or penetration is an internal planar discontinuity that is difficult to detect and evaluate, and very dangerous. It occurs when the weld metal does not form a cohesive bond with the base metal or when the weld metal does not extend into the base metal to the required depth, resulting in insufficient throat thickness. These defects are usually caused by incorrect welding conditions such as current too low, insufficient preheating, welding speed too fast, incorrect edge preparation, short arc length, insufficient electrode size or the arc was not in the centre of the seam. This type of defect can only be repaired by grinding/gouging out the defective area and re-welding.



Weld Damage

• Hammer Marks & Arc Strikes

Arc strikes appear as localized spots of remelted metal. Hammer strikes are small dints or nicks. They are caused by excessive force when using a chipping hammer, careless handling of the welding electrode holder and from inadvertent or careless arc manipulation. They must be avoided, and any traces removed. These imperfections can lead to small cracks in the heat-affected zone of the weld metal and can cause localised stress concentrations.

Craters

Craters are visually inspectable depressions that indicate improper weld terminations, usually with the presence of radial cracks. They should be avoided if possible, the best way to do this is to ensure that correct welding techniques are used.

Spatter

Metal drops expelled from the weld that stick to surrounding surfaces. Spatter can be minimized by correcting the welding conditions and should be eliminated by grinding when present.



Welding defects can greatly affect weld performance and longevity, early detection and correction is important to ensure that welds can carry out their designed purpose.

Detection techniques need to be sensitive enough to detect harmful or rejectable discontinuities but not to the point where all defects are rejected. It is only necessary to repair defects that are considered to be detrimental to the structural integrity of the structure. Welds don't have to be perfect, this is too costly and time consuming to achieve - simply within the acceptable working limits as specified by the quality control code being used during the weld inspection.

by Leigh Baughurst (lbaughurst@aspec.com.au) & Grant Voznaks (gvoznaks@aspec.com.au)

Leigh is an undergraduate student studying structural engineering who is currently doing work experience with Aspec. Grant is a structural engineer with an interest in welding. He is a qualified boilermaker who now designs steel structures for others to build.

Vibration Acceptance Criteria

The effects of vibrating loads on structures can often be significantly greater than the effects of static loads of equal or greater magnitude. These effects can include: fatigue damage such as cracking and breakage, damage to operating equipment due to excessive ambient vibration and human discomfort, among others.

Traditionally, structures subjected to dynamic loads have been designed by trying to ensure that the major natural frequencies of the structure are not close to the frequency of the applied forces. While the calculation and study of the structure's natural frequencies presents a guide to the behaviour of the structure, it does not give the complete picture. Generally, the overall response of the structure to applied vibration forces should be determined and compared to defined acceptance criteria. Similarly, where vibration may be causing problems on existing structures, the overall response should be measured with appropriate equipment, and compared to acceptance criteria.

This article outlines the details of the codes/standards defining the acceptance criteria for vibration, particularly for vibration of industrial structures.

Structural Integrity

The German Standard DIN 4150 Part 3 provides vibration velocity guidelines for use in evaluating the effect of vibration on structural integrity (see Table 1). The guideline limits presented in the standard are based on experience, and are defined as 'safe limits' up to which no damage due to vibration effects has been observed for a particular class of building. "Damage" is defined by DIN4150 to include even minor non-structural damage. For continuous long term vibration, 10 mm/s peak vibration velocity is seen as a safe limit for structural integrity in industrial buildings.

Although these limits are defined in the code as being for vibration in the horizontal direction at the top floor of a building, ASPEC's experience with vibration studies at a number of Australian industrial plants has shown that these limits are effective for local vibration levels as well. Structural damage has been observed on members whereby the vibration velocity exceeds approx. 20-40 mm/s.

Table 1: Safe Limits for Structural Integrity for Long Term Continuous Vibration (DIN4150)

	Type of Structure	Guideline values for velocity in mm/s, of vibration in horizontal plane of highest floor, at all frequencies
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	10
2	Dwellings and buildings of similar design and/or occupancy	5
3	Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g. listed buildings under preservation order)	2.5

These guidelines are very useful as a first pass to determine the suitability of vibration levels. Where there are significant structural integrity concerns however, a detailed vibration and fatigue analysis, often using Finite Element methods (FEA), may be required. Again this analysis should consider the full response of the structure to the applied vibration forces, and the resulting loads and stresses developed in the structure.

Equipment Serviceability

High levels of vibration can adversely affect the life of operating equipment and can increase the frequency of breakdowns, leading to excessive maintenance. A great deal of work is often conducted to measure the balance and vibration of individual pieces of equipment, but often the level of ambient vibration transmitted through the supporting structure can have a significant effect on the life of equipment.

Equipment manufacturers may provide information on acceptable levels of ambient vibration; however where this information is not available, AS2625.1 and AS2625.2 provide guidelines for evaluating the effect of ambient vibration on the life of equipment.

Depending on the class of the equipment (e.g. small, medium, large etc), AS2625 defines RMS vibration velocity limits corresponding to different qualitative evaluation zones (see Figure 1). The four zones are defined in the standard as:

- **GOOD (Zone A):** The vibration of newly commissioned machines would normally fall within this zone.
- **ALLOWABLE (Zone B):** Machines with vibration within this zone are normally considered acceptable for unrestricted long-term operation.
- **JUST TOLERABLE (Zone C):** Machines with vibration within this zone are normally considered unsatisfactory for long-term continuous operation. Generally, the machine may be operated for a limited period in this condition until a suitable opportunity arises for remedial action.
- **NOT PERMISSIBLE (Zone D):** Vibration values within this zone are normally considered to be of sufficient severity to cause damage to the machine.

These guidelines are especially useful where sensitive equipment is required to operate in the vicinity of highly vibrating equipment.

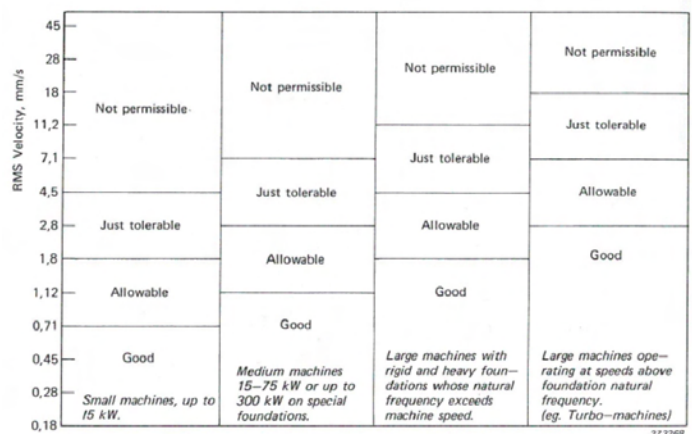


Figure 1: Machine Vibration Criterion Chart (AS2625)

Human Body Perception & Response

The human body can detect magnitudes of vibration lower than those which would normally cause mechanical or structural problems. The "discomfort" or "annoyance" produced by whole body vibration is a very influential factor and may be the one of the limiting parameters in the design of the structure.

Data on human exposure to vibration has been incorporated into AS2670: Evaluation of human exposure to whole-body vibration. Vibration exposure limits are given as a function of:

- Direction of motion, either horizontal or vertical.
- Frequency of vibration.
- Acceleration of the oscillations.
- Exposure time.

The method prescribed in AS2670.2 for vibration between 1 and 80 Hz, is to compare the magnitude of RMS vibration (acceleration) to established base curve levels which are approximately equal to a level of significant human annoyance and/or complaints about interference with activities (see Figure 2). A more complicated analysis is required for vibration below 1 Hz.

Depending on the type of building these base curves are multiplied by a factor to determine an acceptable level of vibration (see Table 2).

For example the level of acceptable vibration in industrial buildings (workshop) is generally of the order of 0.1 m/s² (at approx 20 Hz or 1200 RPM), which is much greater than that of residential buildings (0.013 m/s² at night) etc. This is taken from the base curve value at 20 Hz in Figure 2 multiplied by the appropriate working environment factor (8), shown in Table 2.

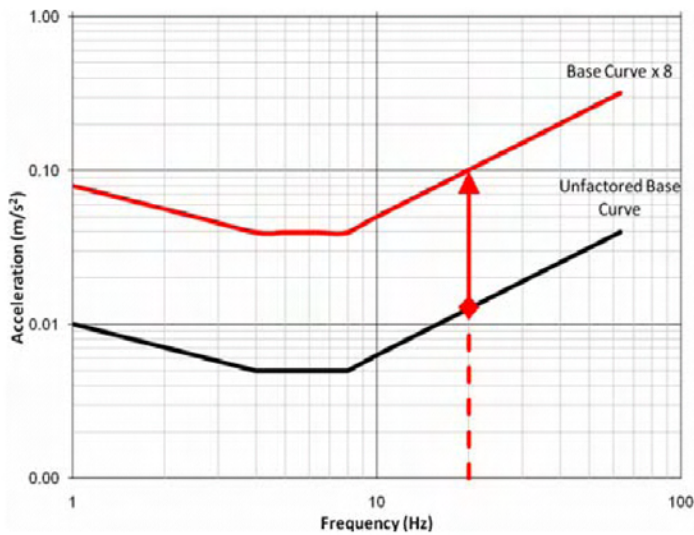


Figure 2: Vertical Axis Base Curve Acceleration for Human Comfort (AS2670)

Table 2: Base Curve Factors for Differing Working Environments (AS2670)

Place	Time	Continuous or intermittent vibration	Transient vibration excitation with several occurrences per day
Critical working areas (for example some hospital operating-theatres, some precision laboratories etc)	Day	1	1
	Night		
Residential	Day	2 to 4	30 to 90
	Night	1.4	1.4 to 20
Office	Day	4	60 to 128
	Night		
Workshop	Day	8	90 to 128
	Night		

Comparison of Acceptance Levels

To compare the acceptance levels for the discussed criteria, typical acceptance levels for an industrial building vibrating at 20 Hz (1200 RPM) are summarized in Table 3 below. As can be seen in the table, there can be significant differences in the acceptable level of vibration depending on the issue of concern. For instance, significantly higher levels of vibration can often be tolerated in areas of a building that are unoccupied, or do not house operating equipment.

Table 3: Typical Acceptable Vibration Levels at 20 Hz

Criteria & Relevant Standard	RMS or Peak?	Acceptable Limit at 20 Hz	Equivalent Acceleration at 20 Hz (m/s ²)
Structural Integrity (DIN4150)	Peak	10 mm/s	1.26 m/s ²
Machine Serviceability (AS2625)	RMS	1.8 mm/s	0.23 m/s ²
Human Comfort (AS2670)	RMS	0.1 m/s ²	0.1 m/s ²

It is also important to be clear as to the convention used to describe the vibration amplitude. Vibration acceptance levels can be expressed in Peak values or RMS values.

Peak values, or “Zero-to-Peak” values, are a direct measure of the amplitude of an oscillating signal. RMS, or “Root Mean Square” is a statistical measure of a moving set of values. Other common types of amplitude measurement include “Peak-Peak” or an “Average” value (see Figure 3). All of these values can be determined from a vibration signal.

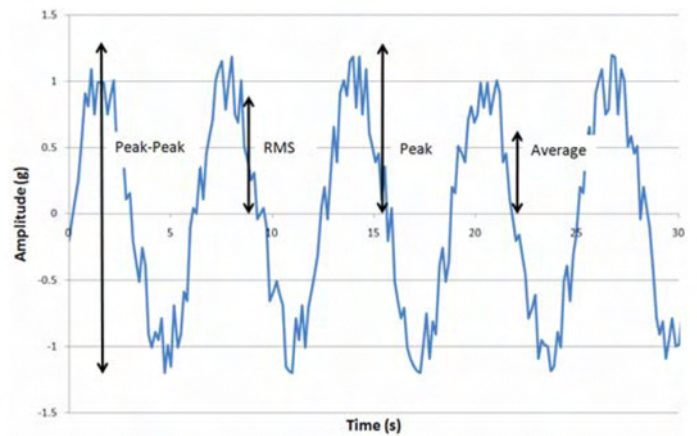


Figure 3: Example Vibration Trace with Definitions

Summary

Excessive vibration in structures can lead to a range of detrimental effects, and should be assessed against established acceptance criteria. The three main criteria (and relevant codes) that need to be considered when evaluating the effects of vibration are:

- Structural design with respect to fatigue life (DIN 4150)
- Equipment serviceability (AS2625)
- Human body perception and response (AS2670)

by Adam Mayers (amayers@aspec.com.au)

Adam is a mechanical engineer with an interest in vibration measurements and structural dynamics using finite element analysis.