

Application Guidance Notes: Technical Information from Cummins Generator Technologies

## AGN 008 – Vibration

### DESCRIPTION

Cummins Generator Technologies manufacture ac generators (alternators) to ensure compliance with **BS 5000, Part 3**.

***BS 5000-3:2006.** Title: Rotating electrical machines of particular types or for particular applications. Generators to be driven by reciprocating internal combustion engines. Requirements for resistance to vibration.*

Cummins Generator Technologies expect its alternators to be incorporated into Generating Sets that have been designed to ensure that the in-service **vibration levels** will not damage any of the alternators component parts. The manufacturers of the engine, radiator, exhaust system, electrical control panel, etc. will all have the same expectation. The reference standards that identify acceptable vibration limits are: **BS 5000-3:2006** and **ISO 8528-9**.

### GENERATING SET DESIGN

An engine driven Generating Set is subjected to vibration generated by the reciprocating forces within the Generating Set system as shown in Figure 1 on Page 2. Alternators should be incorporated into Generating Sets that have been designed to ensure compliance with the reference standards, such as **BS 5000-3:2006** and **ISO 8528-9**, that identify acceptable vibration limits. A system designer should use vibration isolators – anti-vibration mounts - to prevent excessive vibration being transmitted to other components and the surroundings where the unit is installed. Forced or resonant vibration is of particular concern, due to impact and/or high stress fatigue that can cause the alternator to fail.

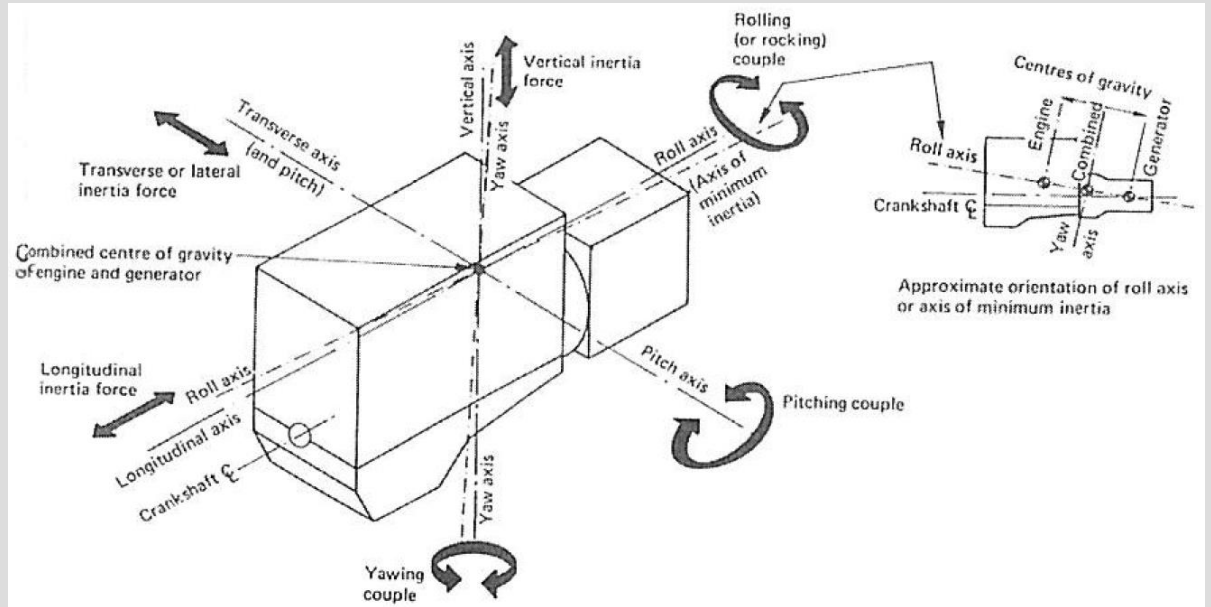


Figure 1: Six basic modes of vibratory motion of a diesel generator; three linear and three rotary motions.

### **VIBRATION CATEGORIES**

Vibration can be classified into one or more of the following categories; Periodic, Random, Resonant and Harmonic. Periodic vibration repeats itself once every time period as a result of a mass imbalance in a component or disc. Random vibration does not repeat as it is not related to a fundamental frequency e.g. shock load. Resonance is the natural frequency at which a mechanical system is inclined to vibrate. Vibrations generated by the engine are complex and contain harmonics of the fundamental frequency, which could be classified in terms as 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> ... 12<sup>th</sup> order (or harmonic).

### **SOURCES OF VIBRATION**

Typical sources of vibration produced within the alternator can be attributed to rotating system imbalance, misalignment and fan blade pass frequency. These translate into linear vibrations in the x (longitudinal), y (vertical) and z (transverse) directions. Table 1 shows the linear vibration level limits recommended for alternators in ISO 8528-9.

Engine Speed RPM (min <sup>-1</sup> )	Power Output S (kVA)	Vibration Displacement RMS (mm)	Vibration Velocity RMS (mm/s)	Vibration Acceleration RMS (mm/s <sup>2</sup> )
1300 ≤ RPM ≤ 2000	250 < S	0.32	20	13
720 ≤ RPM < 1300	250 < S ≤ 1250	0.32	20	13
	1250 < S	0.29	18	11
The broad band is taken as 10 Hz - 1000 Hz				

Table 1: ISO standard recommendations for linear vibrations.

## VIBRATION LEVELS

Alternators are designed and manufactured to comply with the continuous and short period vibration level limits referred to in the appropriate engineering standards.

### **BS5000–3:2006**

Alternators shall be capable of continuously withstanding linear vibration levels with amplitudes of 0.25mm between 5 Hz and 8 Hz, and velocities of 9.0 mm/s RMS between 8 Hz and 200 Hz, when measured at any point directly on the carcass or main frame of the machine. The limits refer only to the predominant frequency of vibration of any complex waveform.

### **ISO 8528-9**

ISO 8528-9 applies to RIC engine driven AC Generating Sets for fixed and mobile installations with rigid and/or resilient mountings. The standard explores the relationship between vibration velocity and vibration frequency. In Figure C1 (next page), example limiting curves for sinusoidal vibrations are published.

In essence; alternators incorporated in Generating Sets designed to operate for short operating periods at a Peak Standby Duty, as defined in **ISO 8528-9**, can be subjected to higher vibration levels, for these shorter periods of duration, with vibration levels < 18.0 mm/s.

To help with understanding Figure C1 of **ISO 8528-9**, the following guide is offered. This will assist with understanding why the acceptable level lines have an inverted **U** shape, and why the graph has so many axes.

- **Low** frequency vibrations, typically <10Hz are considered as **DISPLACEMENT** mm.
- **Medium** frequency vibrations 10 < 100 Hz, and this is the range most commonly encountered in an alternator / engine assembly, are considered as **VELOCITY** mm/sec.
- **High** frequency vibrations, in our industry identified as those above 100Hz, are considered as an **ACCELERATION** m/sec<sup>2</sup>.

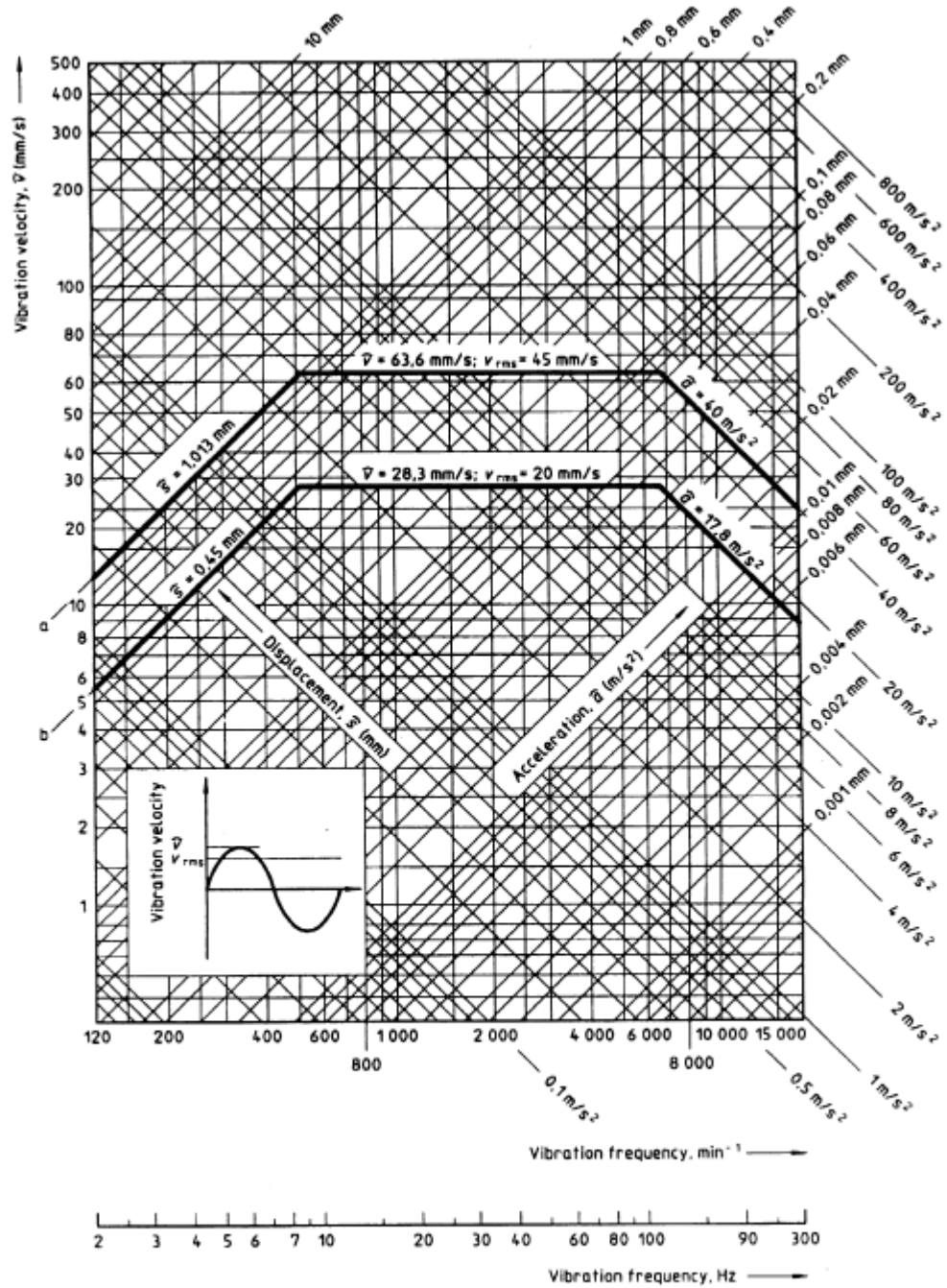
Accepting that a **Shock Load** is of a **Low** frequency and yet identified in terms of 'g' and therefore, an acceleration is somewhat contradictory to the above.

However, if  $1g = 9.81m/s^2$  it figures that the maximum allowable shock load of 3g is then  $3 \times 9.81 = 29.43m/s^2$  call it  $30m/s^2$ .

If now Figure C1 of **ISO 8528-9** is used to consider an acceleration of  $30m/s^2$  and this diagonal line is followed upwards and back towards the Y axis and considered at a frequency of 2Hz, then the actual Vibration velocity in mm/s is an horrific value, off the top of the Y axis scale.

But, for a sudden impact shock load to impart 3g, it would be a high momentary velocity that the generating set would be subjected to. Imagine the sudden deceleration when something is dropped onto a hard surface.

Remember that Figure C1 is a graph showing the limits associated with continuous operation VIBRATION levels, not extreme situation associated with a shock load.



Examples for limiting curves for sinusoidal vibrations

Curve a: Example RIC engine (see table C.1),  $v_{\text{rms}} = 45$  mm/s

Curve b: Example generator (see table C.1),  $v_{\text{rms}} = 20$  mm/s

**Figure C.1 — Relationship between vibration velocity and vibration frequency**

In **ISO 8528-9** Table C1 provides RMS values for vibration velocity, displacement and acceleration for RIC engine driven ac generator sets. This table identifies values for the allowable vibration levels in terms of Displacement, Velocity, and Acceleration.

Table C1 also provides conversion factors to change a Velocity to Acceleration or Displacement. For information; converting 3g to Velocity gives  $29.43 / 0.628 = 46.86$  mm/s and converting 3g to Displacement gives  $46.86 \times 0.0159 = 0.745$  mm.

Table C.1 — Rms values for vibration velocity, displacement and acceleration of RIC engine driven AC generating sets (see clause 10)

Declared engine speed $\text{min}^{-1}$	Rated power output of the generating set ( $\cos \varphi = 0,8$ )		Vibration displacement <sup>a</sup> , $s_{\text{rms}}$			Vibration velocity, $v_{\text{rms}}$			Vibration acceleration <sup>a</sup> , $a_{\text{rms}}$		
	kVA	kW	RIC engine <sup>b c</sup> mm	Generator <sup>b</sup>		RIC engine <sup>b c</sup> mm/s	Generator <sup>b</sup>		RIC engine <sup>b c</sup> $\text{m/s}^2$	Generator <sup>b</sup>	
				value 1 mm	value 2 mm		value 1 mm/s	value 2 mm/s		value 1 $\text{m/s}^2$	value 2 $\text{m/s}^2$
$\geq 2\ 000$ but $\leq 3\ 600$	$\leq 15$ (1-cylinder engine)	$\leq 12$ (1-cylinder engine)	—	1,11	1,27	—	70	80	—	44	50
	$\leq 50$	$\leq 40$	—	0,8	0,95	—	50	60	—	31	38
	$> 50$	$> 40$	—	0,64 <sup>d</sup>	0,8 <sup>d</sup>	—	40 <sup>d</sup>	50 <sup>d</sup>	—	25 <sup>d</sup>	31 <sup>d</sup>
$\geq 1\ 300$ but $< 2\ 000$	$\leq 10$	$\leq 8$	—	—	—	—	—	—	—	—	—
	$> 10$ but $\leq 50$	$> 8$ but $\leq 40$	—	0,64	—	—	40	—	—	25	—
	$> 50$ but $\leq 125$	$> 40$ but $\leq 100$	—	0,4	0,48	—	25	30	—	16	19
	$> 125$ but $\leq 250$	$> 100$ but $\leq 200$	0,72	0,4	0,48	45	25	30	28	16	19
	$> 250$	$> 200$	0,72	0,32	0,45	45	20	28	28	13	18
$> 720$ but $< 1\ 300$	$\geq 250$ but $\leq 1\ 250$	$\geq 200$ but $\leq 1\ 000$	0,72	0,32	0,39	45	20	24	28	13	15
	$> 1\ 250$	$> 1\ 000$		0,29	0,35		18	22		11	14
$\leq 720$	$> 1\ 250$	$> 1\ 000$	0,72	0,24 (0,16) <sup>e</sup>	0,32 (0,24) <sup>e</sup>	45	15 (10) <sup>e</sup>	20 (15) <sup>e</sup>	28	9,5 (6,5) <sup>e</sup>	13 (9,5) <sup>e</sup>

NOTE The relationship between vibration velocity and vibration frequency is shown in Figure C.1.

<sup>a</sup> The values of  $s_{\text{rms}}$  and  $a_{\text{rms}}$  are determined from the following equations by using the values given in the table for  $v_{\text{rms}}$ .  
 $s_{\text{rms}} = 0,0159 \times v_{\text{rms}}$   
 $a_{\text{rms}} = 0,628 \times v_{\text{rms}}$

<sup>b</sup> In the case of flange housing coupled generating sets the values measured at point 5 [see Figure 1 a)] shall meet the values for generators.

<sup>c</sup> The stated values for RIC engines are applicable for engines with power outputs of more than 100 kW. For smaller engines with power outputs below 100 kW, no typical values exist.

<sup>d</sup> These values are subject to agreement between the manufacturer and customer.

<sup>e</sup> The values given in parentheses are applied to generators mounted on solid concrete foundations. In these cases the axial measurement for points 7 and 8 in Figure 1 a) and b) shall be 50 % of the values given in parentheses.

These lines can be superimposed onto the graph; Figure C1, and then considered against the recommended maximum shock load levels 1 and 2.

## SHOCK LOADS

Vibration may be considered to be continuous shock loading that is present at all times when the Generating Set is operating. Shock Loads are considered as momentary one-off conditions resulting from rough handling, or extraordinary - very low frequency - vibration resulting from an event external to the Generating Set and its base frame.

### Maximum Shock Loads – Level 1.

STAMFORD and AvK alternators are designed to tolerate shock acceleration levels in the order of 3g in any of the three planes. This condition should be an abnormal situation rather than continuous and can therefore, be considered to be stressful without being destructive, providing the frequency of such events are not part of the normal continuous duty cycle.

If the Generating Set is likely to be subjected to shock loading levels above 3g, then it is expected the design of the Generating Set base frame will incorporate anti-vibration mounts that restrict the full effect of these events to ensure the generator shock loads are below the stated 3g level.

## Maximum Shock Loads – Level 2.

For infrequent transient shock load occurrences STAMFORD and AvK alternators will tolerate a level of 6g radially, but still only 3g axially.

Following any such severe event it would be prudent to:

- Establish the condition of the bearings by monitoring their operating vibration levels and if possible assessing the results by comparing with historical maintenance data for the equipment package.
- Inspect the coupling assembly for signs of distress.
- Inspect the structure of the generating set for evidence of relative movement or structural distress.

## MEASURING VIBRATION

A basic overall value vibration meter is used for quick vibration measurement to determine the current state of the machine using overall vibration values that can be correlated to the **ISO 8528-9** recommendation or monitoring the change in trend. It does not provide the detailed information about the cause of the vibration.

Relevant to the **ISO 8528-9** recommendations, the measuring system should provide the RMS values of displacement, velocity and acceleration. The RMS value is the most relevant measure of amplitude, because it both takes the time history of the wave into account and gives an amplitude value that is directly related to the energy content, and therefore the destructive abilities of the vibration.

Pure displacement measurements have a tendency to be biased to low frequencies, and acceleration measurements tend to be biased towards higher frequencies. By measuring the overall RMS vibration velocity over the range of 10-1000 Hz gives the best indication of a vibration's severity. This is because a given velocity level corresponds to a given energy level, so that vibration at low and high frequencies are equally weighted from a vibration energy point of view.

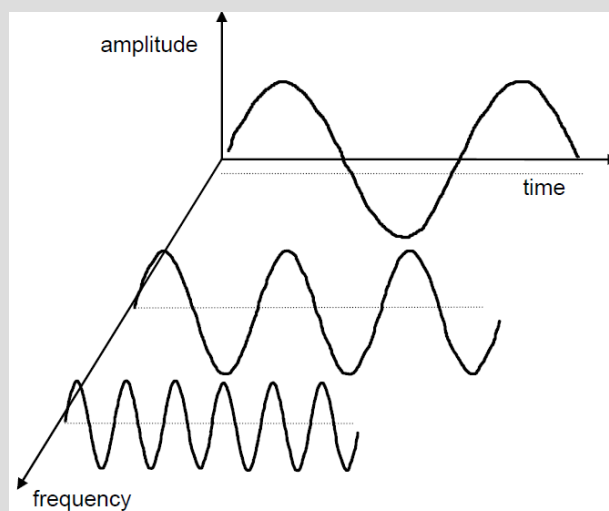


Figure 2: Example of a complex time waveform components.

If the vibration root cause needs to be identified in more detail, a minimum requirement will be to use FFT (fast Fourier transform) capable vibration equipment. The FFT method involves taking a real-world, time-varying signal and splitting it into components, each with an amplitude, a phase, and a frequency. Three waveforms as shown in Figure 2 (previous page) are plotted in a 3-D grid of time, frequency and amplitude.

Figure 3 shows how a complex multi-spectral vibratory signals can be separated out into its component frequencies. This, combined with knowledge of the system components, can then be used for diagnosis/identification of root causes or areas of concern. A complex transient waveform can be decomposed into its component frequency spectra (below) using FFT, thereby allowing diagnosis of system faults.

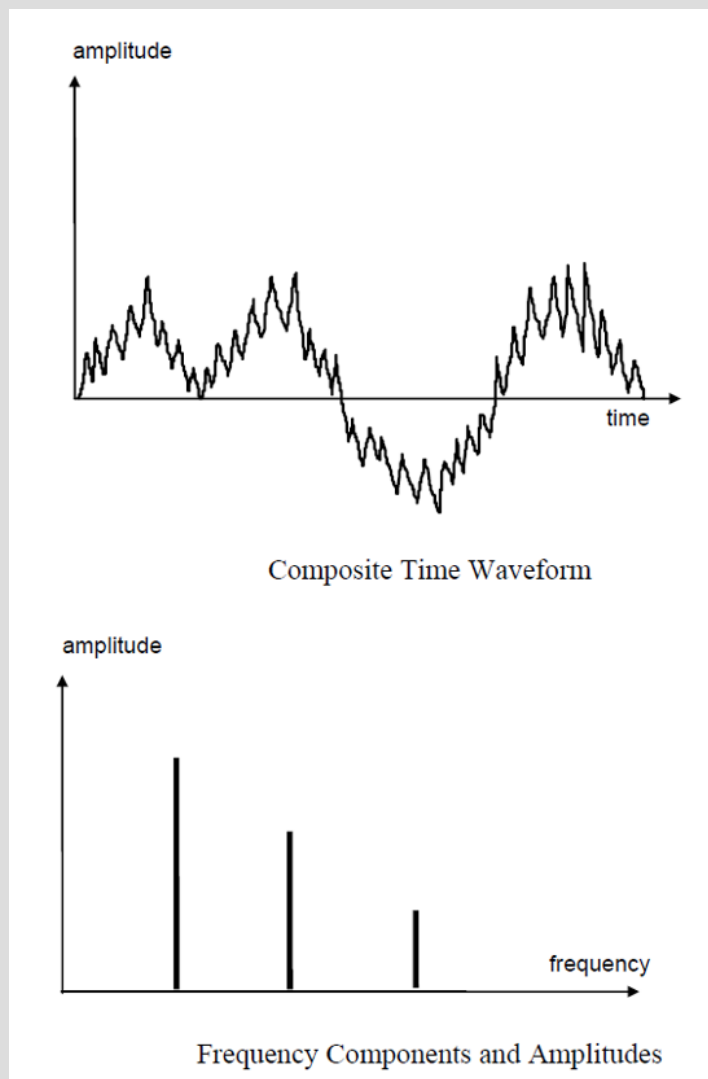


Figure 3: Time and frequency components of a complex time waveform components.

If additional root cause analysis is required using ODS (operating deflection shape) data, speed sweep, etc., then higher specification vibration equipment will be required. As well as selecting the correct type of data acquisition system, consideration of sensor type and size will need to be reviewed. Examples of accelerometer methods with respect to frequency range can be seen in Table 2 (next page). Accelerometer temperature range and size should be considered based on parts being tested.

Method	Frequency Limit
Handheld	500Hz
Magnetic	2,000Hz
Adhesive	2,500Hz to 5,000Hz
Stud	> 6,000Hz

Table 2: Frequency Limits for vibration measurement equipment.

**Measuring Points.**

Depending on the type of vibration analysis required, measurement location can vary drastically. However, based on the **ISO 8528-9** recommendations, the measurement locations are always taken on the main solid structural parts of the Generating Set. Figure 4 shows the basic vibration measurement points in the x, y and z directions of an alternator. Care should be taken to ensure that measurement techniques and sensors being used reasonably represent the true alternator vibrations and do not include any amplification of cable noise, incorrect sensor selection and poor mounting.

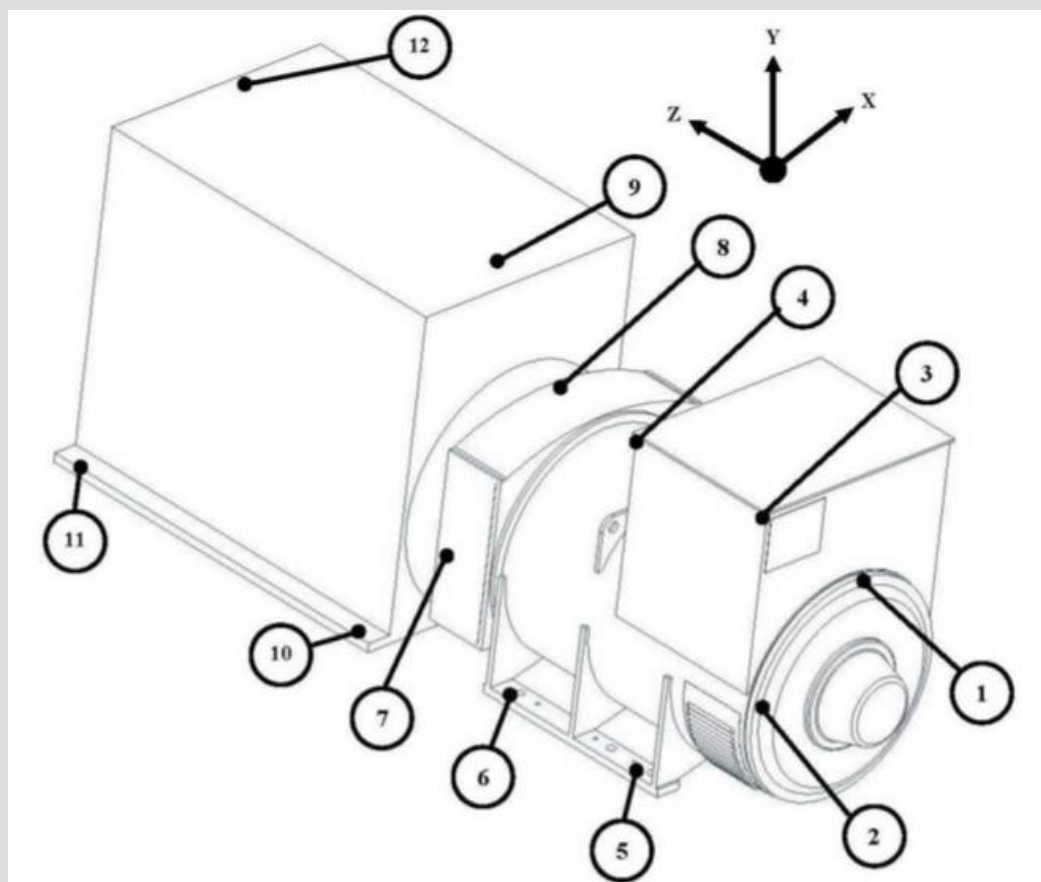


Figure 4: Position of vibration measurement equipment.



## Vibration Isolation.

Vibration isolation is a process of reducing the vibration of the Generating Set transmitting to and from the foundation. A suitable method of vibration isolation is required in the Generating Set design to minimise the effect of reciprocating forces. Anti-Vibration Mounts (AVMs) are installed between the alternator foot and Generating Set bed frame to reduce the vibration that is transmitted to the surroundings. The Generating Set manufacturer may install adjustable dampers between the engine and the base frame, to dampen out cyclical vibration created by the engine. He may use different combinations of coupling and mounting techniques and he may use other vibration isolation techniques to reduce system vibration, as shown in Figure 5.

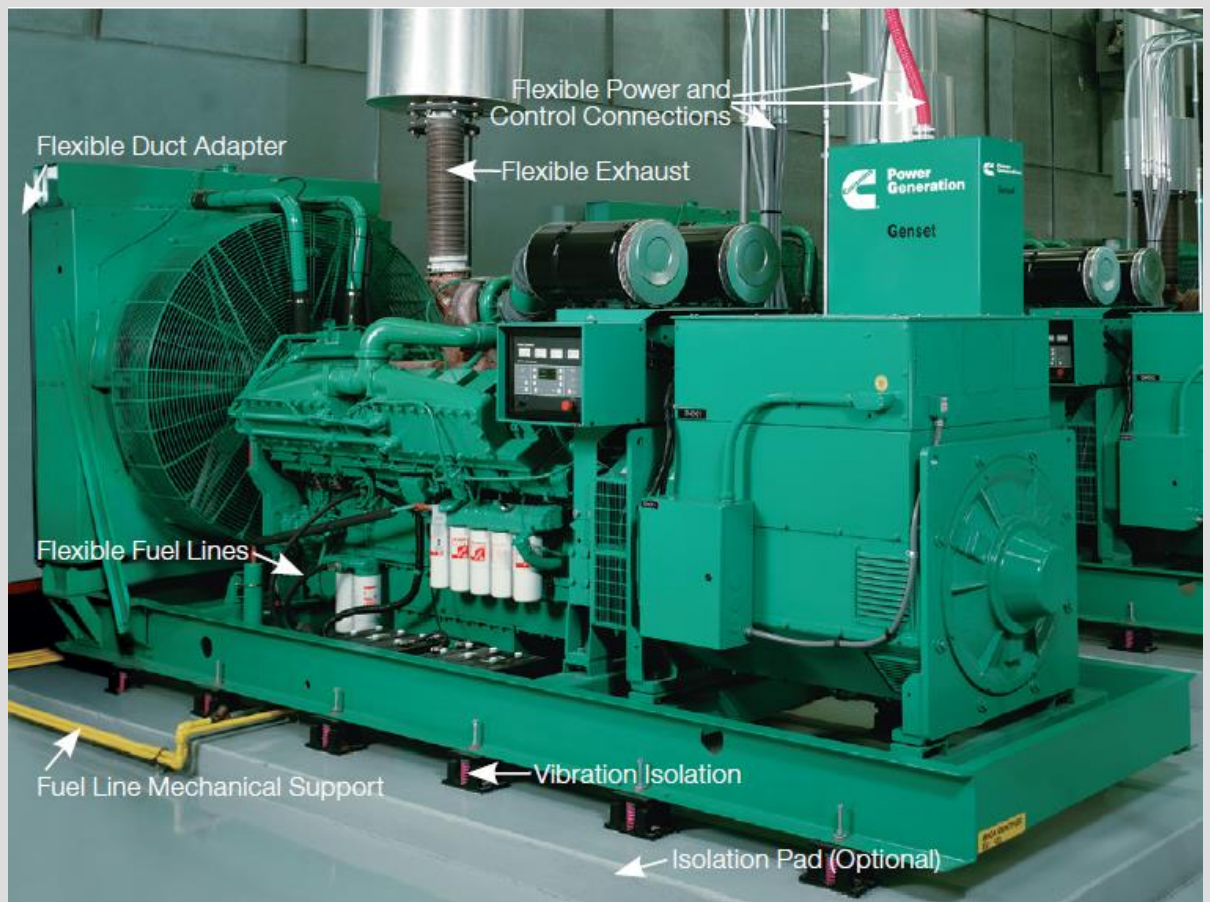


Figure 5: Examples of flexible connections required for installations in susceptible areas.