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An Overview of Methods of Reduction of Vibration for Diesel Generators

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Abstract

Mechanoelectrical devices will always vibrate because of several moving parts incorporated within them. When they are in operation, these machines usually have oscillatory motions around an equilibrium point. For generating sets, vibration is from the engines to the metal frame because vibration travels through mediums**.** Accelerometers are used to measure vibration when mounted on the generator frame where the vibratory motion is been converted into electrical signal with the use of piezoelectric accelerometer. The versatile uses of electronics make it easy to measure and analyse electrical signal. The accelerometers usually mounted perpendicular and concentric to the shaft of the rotating engine in the vertical and horizontal position. Mechanical vibrations are present in different degrees. Some vibrations are desirable, they perform useful work. Vibration is generated intentionally in component feeder, concrete compactor, eccentric grinders, ultrasonic clearing baths, rock drills and pile drivers. Excessive vibration in equipment can not only damage the equipment itself but also decrease functionality and they can cause destruction of power delivery. Minimizing vibration of generating set can both reduce the transfer of energy to building surrounding, generator equipment/component and human. This leads to longer life for generator. The rate of vibration and cost are the most important consideration before a designer can decide the methods that can effectively minimize the transmission of vibratory motion. Vibration can become a noise source. The paper discusses isolation as a means of preventing vibration from the system and damping as a means of absorbing of vibration energy from the system. Methods of reducing vibration such as elastomeric isolations, spring isolators and accelerometers are discussed.

Keywords: Accelerometer; Concentric; Damping; Equilibrium point; Isolation; Mechanoelectrical; Mediums; Oscillatorymotion vibration

Introduction

The diesel engine known as sparkless compression-ignition engine is an internal combustion engine in which the energy stored in fuel is transformed into heat when ignited. The ignited atomized fuel is been injected spontaneously to the combustion chamber at the top of the cylinder through the injector at an appropriate point in the cycle (diesel cycle) once the high ratio compressed air (14:1 to 25:1) is well above the ignition temperature (700-900°C). The compression ignition has a high thermal efficiency due to its very high compression ratio [1]. The heat is firstly converted into mechanical energy and afterwards into electrical energy. An alternator is coupled with the diesel engine and the kinetic energy of the engine is transmitted to alternator and converted into electrical energy. Alternator works on the Faraday's law of electromagnetic induction. This electrical energy is then connected to the load [2]. A cyclic motion of a body or a system, due to the elastic deformation under the action of external forces is known as Vibration. Vibration is the magnitude of force, acceleration or displacement which is mostly expressed in term of amplitude and frequency (Hz or cycles per seconds) [3]. Figure 1 shows the block diagram of working principle of diesel generation.

There are different types of vibration within a generating system. These are: torsional vibration and linear vibration. Torsional vibration is difficult to identify because they are not felt but are forces transmitted to the engine crankshaft and afterwards throughout the entire operating rotating range in combustion engine. Correct matching of the prime mover and alternator by manufacturers will eliminate torsional vibration while linear vibration is the shaking and movement of equipment we can easily see, feel and hear. It is caused by mechanical imbalance, misalignment, wear etc. (Torsion Control Products INC., 2018) [4]. To isolate all the causes of vibration is difficult because vibration varies from point to point. Vibration is usually in the system when a generating set is running. These vibrations can never be totally eliminated. The designers specify vibration isolator and recommend proper foundation design to reduce its transmission to its surroundings [5,6]. Vibration isolators can generally be thought of as interrupting the energy transmission path between a rotating machine and its environment. Most of the vibrations transferred to structures are from internal combustion engines if they are not properly fixed. The anti-vibration damper should be able to absorb both the horizontal and vertical vibrations in the system. Isolation prevents vibrations from entering into a system, whereas damping is the absorption of the vibration energy that is entering the system [7]. The generator sets come in many sizes and configurations, every application has a unique installation location, and there are several considerations that must be taken into account when determining the best method of mounting a generator set to its operating base or foundation. These are: machine location, proper sizing of isolator units, location of isolators, stability, adjustment, eliminate vibration short circuits and fail safe operation [8].

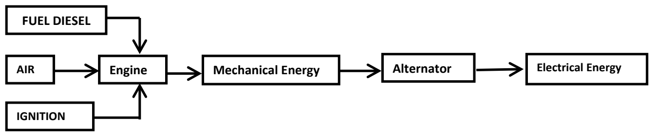

Figure 1: Flow diagram of working principle of diesel generator Source. Pavan et al., 2016

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Causes of vibration in mechanoelectrical devices:

1. Misalignment of engine and driven equipment (rotors in line not well concentric parallel and angularly inside tolerances). Shaft misalignment occurs when the centerlines of rotation of two (or more) machinery shafts are not in line with each other, or more precisely, it is the deviation of relative shaft position from a collinear axis of rotation measured at the points of power transmission when equipment is running at normal operating conditions. Misalignment causes a decrease in efficiency, and misaligned machinery is more prone to failure due to increased loads on bearings, seals, and couplings [9,10].

2. Out-of-balance or unbalance of rotating part, engine, coupling torque dampers generators rotor parts. Unbalance due to traditional unbalance not related to combustion forces. Unbalance of reciprocating parts as well as driven generator rotor parts; this can be the reason for different levels in horizontal and vertical direction or even high in axial direction. Unbalance can also cause premature failure of the mounting structure or undesirable vibration even though the unit is properly mounted and isolated from the engine.

3. Resonance from rigidity (stiffness) or weight (structural mass) body or both and all parts offering unwanted multiples of amplification of dynamic force. The vibrating component is said to be in resonance when a vibrating peak out in a narrow speed range.

4. Torque reaction of the rotor line as well as combined aggregate structure. Due to the attempt from each firing cylinder to twist the rotors with a strong turning push and the counter reaction from the stationary parts along them. This can be caused when the base is not rigid enough to withstand the forces.

5. Cylinder misfiring, for a multi-cylinder engine, all cylinders is expected to offer as precisely similar torque force as possible. A cylinder with a reduce or no existing torque force will cause not only reduced total power but also through gradually falling torque balancing functions often initiate damaging wear. Pending the level of fault, this can affect a broad train of frequencies which can start at halve the speed for a typical four stroke engines.

6. Poor maintenance, external influence, the movement of the generator set from one place to another etc. [11-14].

Figures 2-4 show vibration motion which is relatively constant over the speed rate but it exceed the accepted limit. A wide vibration motion oscilating within a narrow speed range and vibration motion increases as load is applied respectively.

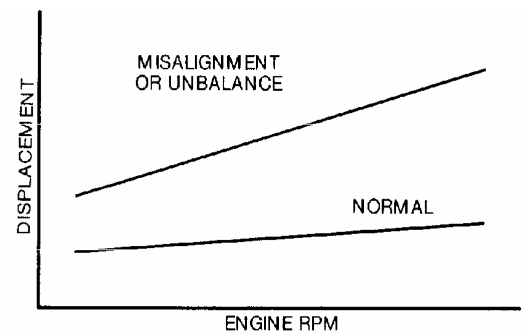


Figure 2: A vibrating motion relatively constant over the speed range but exceeds accepted limits.

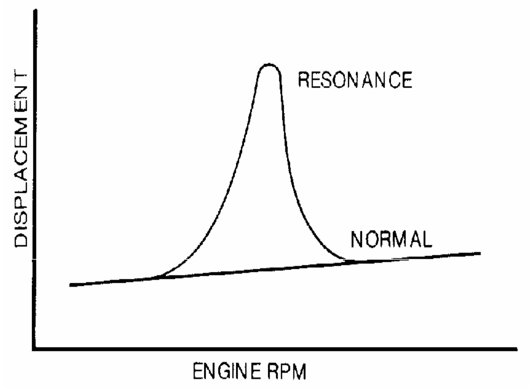
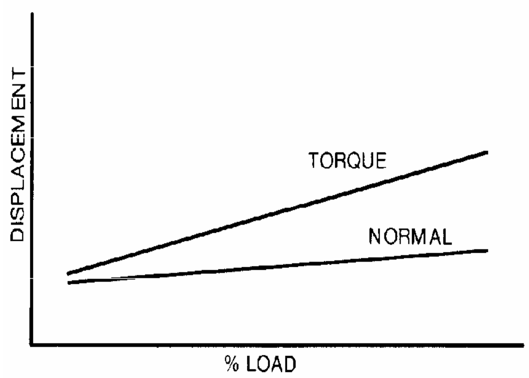


Figure 3: A large vibrating motion (amplitude) taking place within a narrow speed range.



Source: Arne , 2006; Caterpiller, 2008.

Figure 4: The vibrating motion increases as load is applied.

Remedy

1. Calculate the generating set parameter using the manufacturers' data or experimental modeling to determine it vibration rate, mass, stiffness and damping method.

2. Misalignment problem can be minimized at the design and installation steps. Proper alignment between the prime mover, alternator and mounting frame are the most important consideration when assembly a generating set. If the alignment is difficult to accomplish, a suitable flexible coupling method should be used. Figure 5 shows direct flexible coupling, Figure 6 shows local way of checking the alignment of the prime mover and the alternator by using their shafts concentric point as an advantage.

3. Unbalanced and reciprocating part can be control by correct mounting and coupling by the use of vibrator isolator. No mounting method is so special but due to the different installation methods which create different mounting style in order to suit its application putting the characteristics of the prime mover and alternator into consideration.

4. Due to thermal expansion the engine fixing should have clearance.

5. Resonance vibration levels can be reduced by changing the natural frequency of the resonant parts and reduction of the force of excitation.

6. Torque reaction problems are not found with close-coupled generators. The rigid coupling method can withstand torque. Figure 7 shows rigid coupling.

7. The complete installation of the generator should allow easy transportation to site of use without tampering with the generator alignment as shown in Figures 5-7.

Effects of Vibration on Generators

The effects of vibration on Generators are: direct vibration of diesel generator on human body with time can seriously affect body organ and can also have negative effects on human sight, body balance / concentration [15]. Vibration greatly reduces reliability, life span and output power [16]. Installation of sensitive equipment and heavy machinery not possible in same workshop where vibrating machine is installed [17]. It makes buildings and machineries not safe from earthquake. (www.exportersindia.com, 2010). Misalignment can lead to malfunctioning or total breakdown of the engine crankshaft and bearing [18]. They are undesirable because they will increase; the stress of the engine, sound level, wearing of the parts, material fatigue, losses in the engine, load on the bearing. With time all these can cause mechanical failure or total breakdown [3].

Figure 5: Direct flexble coupling.

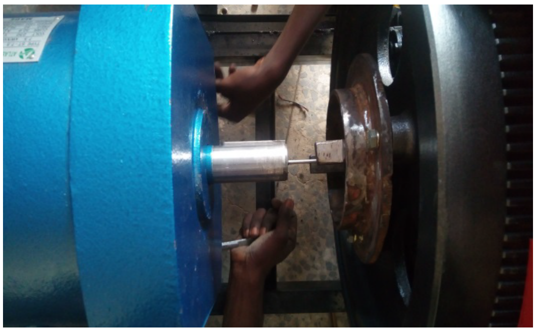


Figure 6: local way of checking the alignment of the prime mover and the alternator.

Figure 7: Shows rigid coupling.

Methods of Vibration Reduction

The two most common methods of vibration reduction are: Elastomeric and spring isolators are very effective at limiting the transfer of vibratory energy to foundation structures and other components.

Elastomeric isolators (Neoprene or rubber or pad)

Elastometric isolators reduce vibration and sound whereas metals radiate sound [19]. Rubber isolator applications are sufficient in places where the control of vibration is minor. They generally do not have a high load capacity as spring isolators, but they are ideal for dampening smaller masses on the generator set. Since their compliance (movement) is in the vertical direction, they have a high resistance to shear loading and consequently resist misalignment forces in flex-plate-coupled generator sets. Elastomeric isolators are especially effective at dampening high-frequency vibrations and containing unanticipated upward forces also tend to offer lower levels of deflection (typically between 2.5 mm-8 mm). Neoprenes are mostly the inner isolator mounted by the manufacturer. They have up to 90% isolator efficiency which is adequate for most of the installations. The increased levels of damping and higher levels of stiffness offered by rubber mounts provide increased control of the Generator, particularly during start-up, shut down, or if resonance occurs. This increased damping and control however come at the expense of the vibration reduction which is typically lower than a spring mounting; rubber mounts are available with captive restraints to ensure a fail-safe design for mobile applications [6].

Figure 8 represents an elastomeric isolator between the generator foot and the base which minimizes the transfer of energy to the base. Figure 9 represents several elastomeric isolator mount types have steel shells to enhance lateral stiffness and prevent oil or solar degradation of the elastomeric. Figure 10 represents different shapes of rubber anti-isolator.

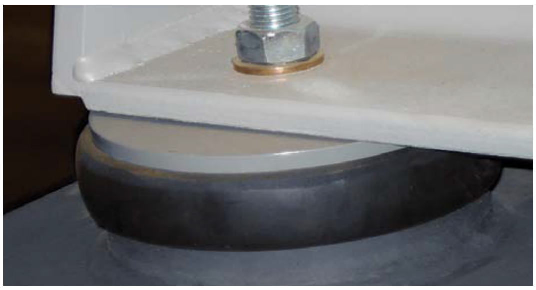
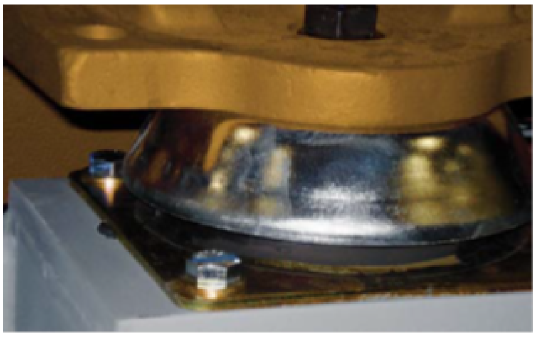


Figure 8: An elastomeric isolator between the generator foot and base minimizes the transfer of energy to the base.

Spring isolators

They can isolate above 95% of all vibratory motions and noise transfer to the mounting surface or foundation through the parts rotating in the machine. Generally, isolators can absorb waves produce by adjacent machineries and prevent it from been transfer to idle equipment. Spring isolator is used when the installation of the generating sets is higher than its grade and avoid over compensator of the spring. Local codes should be consulted by the designer to know if the spring isolator is necessary. Spring mountings have a comparatively lower level of damping compared to rubber mounts and generally provide high levels of deflection (typically 25 mm, but can be up to 50 mm). This high level of deflection results in extremely low natural frequencies; result in high levels of vibration reduction of up to 99%. However the low stiffness of these products can cause issues during start-up, shut down, resonance and mobile applications. Additional snubber or restraint can be incorporated to control movement which could otherwise harm the spring mountings and any flexible connections [5,6].



Source: Onsite Energy, 2013.

Figure 9: Several elastomeric isolator mount types have steel shells to enhance lateral stiffness and prevent oil or solar degradation of the elastomeric.

Figure 10: Different shapes of rubber anti-isolator.

Figure 11 represents different types of spring isolator. The reasons for frequent vibration monitoring are: vibration monitoring increases safety through identification of dangerous vibration condition including steady state and transient state. It avoids major secondary damage by way of early failure identification. The maintenance expenditure through localization and diagnosis of the vibration and optimization of maintenance by means of consideration of the current engine condition and It helps in engine control when its malfunction. Some mechanical faults which can be detected and diagnosed by vibration monitoring are: deteriorations, high pressure and ice build-up, Spoil blade or dirty blade, buffeting, instability due to malfunctioning, rub, loose joint, misalignment, bearing failure/broken bearing and inspect the reciprocating ability of the generation.

Figures 12-14 represent mounting of deflecting gauge, putting color water in transparent bottle and placing level on a table respectively.

Discussion

The accelerometer signal generated is transferred to the instrument that will convert it to velocity signal based on the waveform of the velocity spectrum. A velocity spectrum is gotten from a velocity waveform through Fast Fourier Transform (FFT), a calculation in mathematics. Accelerometer result can be used to identify and diagnose the vibration cause considering the continuous changes of the amplitude after reaching defined operational condition. Piezoelectric accelerometers have been the traditional method used to detect vibration. These give exact and reliable value but are associated with some natural problems viz; mass-produce difficulty and high impedance source, which means careful amplification of their signals are important. Also, traditional piezoelectric accelerometer for the collection of multiple data are impracticable because the associated electronic signal cost and the cost of the instrument itself. Piezo-resistive accelerometer is another type of vibration measuring instrument which resolution is limited and it is only used for low and medium frequencies. Low resolution is also a demerit of electro-dynamic accelerometer. Low resolution and ability to break easily are the demerits of capacitive type accelerometer. There are different types of accelerometers by different manufacturers all over the world. Piezo-electric accelerometer which has integrated circuit (ICP) can not exactly measure non-stationary impulsive response of structures all the time in vibration measurement test and accurate measurement can be gotten from charge-type piezoelectric accelerometer [20,21]. A data acquisition system consisting of single accelerometer (which record a unidirectional exacted force), double

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Figure 11: Different forms of spring isolator.

Figure 12: Mounting of deflecting gauge.

Figure 13: Putting colour water in a transparent bottle.

Figure 14: Placing of spirit level on table.

axis accelerometers or trial axis accelerometer. Each accelerometer is connected to the digitalizing unit with the use of a coaxial cable. Then the digitalizing unit will be connected to the computer system. The set up of this is shown in Figure 14. The displacement measurements are better indicators of dynamics stress [22]. Figure 15 is the setup of affixed accelerometer to the generator, the laptop and data acquisition apparatus. The vibration waveform consists of the magnitude of different frequency component which makes its signal fairly noisy. In order to get data that can be analyzed, the time-dependent vibration signal must be subjected to a special analysis, which processes it and separate it into frequency component. The spectrum graphs are two dimensional plots with amplitude on the vertical axis and frequency on the horizontal axis. The amplitude is a peak-hold, displaying the maximum displacement for that particular frequency and time, unless otherwise stated. Different number of tests should be conducted with the generator. Pulses modulation, phase modulation, Peak and peak-to-peak amplitudes of each oscillation can only be seen in the time-domain [23]. After the FFT analysis in frequency level, the spectrum is the analyzed time signal which values are displaced as either peak or root mean square values (RMS). Every peak in the spectrum is an excitation from the engine. It is necessary to know the frequencies of a vibrating engines, this will assist in knowing the movement of the machine and how to solve some problem because it will give the idea of where the problem lies [24]. Data should be taken during start up before loading the generator electrically, when the generator is running after adding load and after shutdown. The accelerometer should be mounted in the horizontal and vertical axis perpendicular and concentric to the rotation of the prime mover and alternator shaft.

Figures 16 and 17 shows spectrum of a typical vibrating signal before adding anti vibration isolator and after adding anti vibration isolator respectively.

The accelerometer should be mounted as close as possible to the bearing, attached firmly and on substantial surface, oriented correctly, same location when taking different test, properly taking care of for safety and long life span [25].

Equipment Needed for Vibration Test

This does not endorse the equipment and instrumentation trademark or trade name used as the best for this application. These are the equipment that will be needed in the nearest future when the real experiment will be carried out in order to ascertain the level of vibration and methods of reduction are determined.

7.5kVA diesel Generator: 2200 RPM (revolutions per minute).

Accelerometer Dytran: Series 3030B, Frequency response (2 to

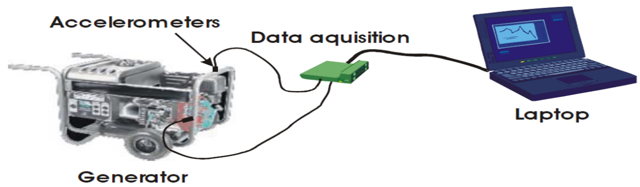

Figure 15: A data acquisition system consisting of accelerometers connected to both horizontal and vertical axes used to record forces exerted in both directions (test setup).

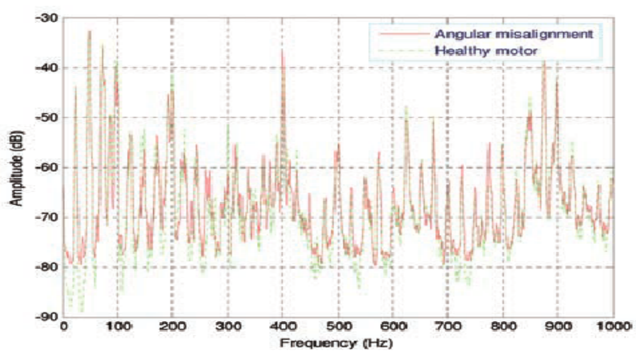

Figure 16: Spectrum of a typical vibrating signal before adding anti vibration isolator.

10,000 Hz ± 5%), Range full scale (±500 G), Sensitivity (@ 100 Hz 1G, RMS, 10.0 ± 5% mV/G), Linearity at FS (±1%), Resonant frequency (30 kHz), Equivalent noise floor (0.007 G, RMS).

Digitizing System Sound Technology, Inc: Model ST191, 32 bit PC link.

Computer system: 3GHz processor, 1GB RAM.

Analysis Software Sound Technology, Inc.: LAB432 Enterprise, Version 19

Calibration Exciter Rion Co., Ltd.: Model VE-10, Vibration frequency (159.2 Hz ±1%), Acceleration (10 m/s2 RMS)

Types of Accelerometer

1. Digiducer 333D01 USB digital accelerometer is the first fully integrated and ruggedized packaging of a high-resolution, broad-frequency piezoelectric accelerometer with integrated internal digital data acquisition. When used in conjunction with multi-instrument software, the setup allows you to take reliable and quality vibration measurements as simply as plug & play. Hardware activated multi-Instrument pro software license (the software will be automatically activated with the USB accelerometer connected to the computer). If necessary, you can purchase upgrades of the license to include multi-instrument add-on software modules such as spectrum 3D Plot, vibrometer and data logger at any time. No external power supply, data acquisition hardware, driver installation and manual entry of sensor sensitivity are required. It is a truly hassle-free portable vibration test and measurement solution. It works with Windows, IOS, Linux, Android, and Mac OS. It has low-hassle vibration measurements in the palm of your hand. It has a magnetic mounting base. This USB digital accelerometer allows users to take professional grade vibration measurements right from a PC, smartphone, or tablet, turning any device into a portable, handheld vibration meter spectrum analyzer. The simplicity of model 333D01 opens the door to those just starting out in vibration, while still providing the accuracy and range needed by the experts. Based on piezoelectric sensing technology, Model 333D01 has a wide frequency range. The ± 5% range is from 2 Hz to 8 000 Hz (120 CPM to 480 000 CPM). The unit comes in a rugged, stainless steel, hermetically sealed package to survive harsh environments. With an optional magnetic mounting base and a cable length of almost 10 feet (2.9 m), taking measurements is quick and easy, even in the most difficult to reach places. Model 333D01 USB digital accelerometer delivers accurate, useful vibration testing in a package you can trust [26]. The software can also be downloaded from www.virtins.com/MIsetup.exe. Figure 18 show digiducer 33D01 accelerometer and its connection to laptop through USB port respectively.

2. AS63A, TV-260, VM-6320 accelerometer which gives their output in digital form.

Technical specifications for accelerometers

(a) Sensitivity is the ratio of the electrical output (voltage per unit acceleration) of the accelerometer to its mechanical input. The specification of sensitivity is enough for instrument which produces its own voltage, independent of an external power source. The sensitivity of an instrument needs an external voltage given in term of output voltage per unit supplied voltage displacement, acceleration or velocity. e.g. mv/g of acceleration.

(b) Frequency range which is the operating range which the sensitivity of the transducer that does not vary more than a stated percentage from the rated sensitivity. Limitation of the range may occur as a result of mechanical or electrical features of the transducer or by other equipment incorporated to it to aid its functions.

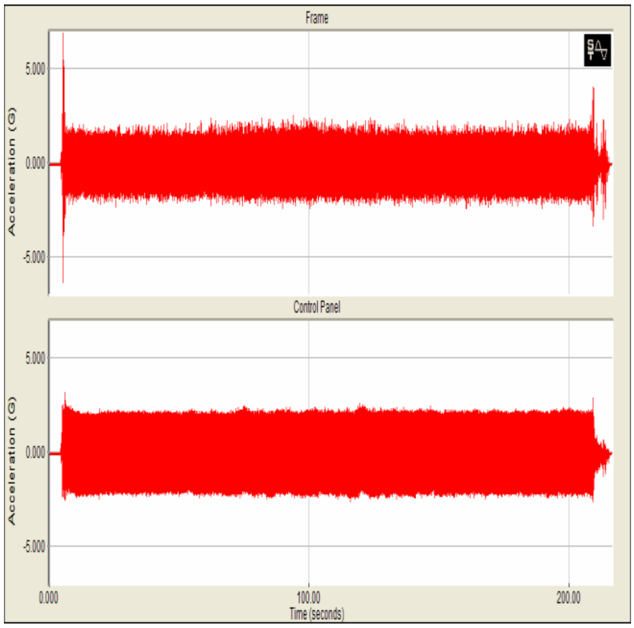

Figure 17: Spectrum of a typical vibrating signal after adding anti vibration isolator.

Figure 18: Digiducer 333D01 USB digital accelerometer.

(c) Amplitude range which gives the maximum level that an accelerometer can measure acceleration.

(d) Shock limit which gives the maximum range of acceleration the accelerometer can withstand without any damage to the unit.

(e) Linearity shows the exactness of the acceleration amplitude measured within the corresponding level of frequency.

(f) Natural frequency that is showing the measuring frequency level indirectly. In an accelerometer, higher natural frequency allows higher measuring range of frequency [23].

Conclusion

This paper involves the research on generation vibration, finding its causes, effects and methods of reducing it. The most effective and efficient remedy to the problems of vibration is to avoid at every steps of installation through intelligent designs. Vibrations in diesel generators are undesirable because they can increase: stress, level of sound, wears, bearing loads, material fatigues and energy loss. With time all these can cause engine malfunctioning or total breakdown. Vibration reduction clearly improved engine efficiency, as well as reduced breakdown costs is the greatest benefits. Vibration spectrum analysis the range of motion and resonance of a vibrating engines should be carried out in order to have the complete result, take both the vertical axis and horizontal axis measurement for both front and rear vibration at the: (i) start up, running and shutdown stage. (ii) Initial stage before adding anti vibration and final stage after adding anti vibration (isolator).

Recommendations

The following recommendations are made for further improvement in order to reduce vibration and noise level.

1. The future diagnostic and prognostics measuring device will be extended by the use of artificial intelligence for pattern recognition.

2. The major secondary damage should be avoided by way of early failure identification, maintain expenditure through localization and diagnosis of the vibration and optimization of maintenance by means of consideration of the current engine condition, helps in engine control when its malfunction etc.

3. Dampers should be used in between the frame and the generating sets (primemover and alternator). Although, damping is difficult to model out.

4. Sensitive equipment and electronic devices on generating sets should be isolated from vibrations

5. Mounting of a generating set on its own isolated concrete slab also helps to minimize any transfer of energy to the main building structure.

6. Generator vibration should be frequently monitored because this increases safety through identification of dangerous vibration condition including steady state and transient state.

7. Proper mounting must be provided to reduce the engine vibrations.

8. Vibration monitoring analysis can be used to identify basic problems like bearing failure etc.

9. Accelerometers should be used to practically measure vibration level of the generating set and appropriate reduction methods be utilized such as elastomeric isolator and spring isolator.

10. This paper should be improved by the use of accelerometer to practically measure the level of vibration and methods of its reduction as stated in this work be implemented in the nearest future.

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References

1. Mark L (2011) Energy Industrial Power Diesel Service and Supply. Brighton Colorade 67: 521-600.
2. Pavan KB, Basavaraj Y, Nandeesh C (2016) Vibration Based Condition Monitoring for Generator. Inter J Res Eng Tech 4: 1-8.
3. Swapnil PB, Gawade SS (2017) Internal Combustion Engine Vibrations and Vibration Isolation. Inter J Sci Eng Res 8: 243-247.
4. Torsion Control Products INC (2018): Vibration - Linear vs Torsional. 530 E maple, Troy, Michingan 48083-2805.
5. Onsite Energy (2013) Vibration Isolation used on Engine Generator Sets, Central power system and services.
6. William B (2013) Controlling generator set vibration to minimize dynamic loading on building structures. A Rolls-Royce Power Systems Company.
7. Ahirrao NS, Bhosle PS, Neheta D V (2017) Dynamics and Vibration Measurements in Engines. Elsevier BV, 2nd International Conference on Materials Manufacturing and Design Engineering, Scholar, M.I.T, Aurangabad, India.
8. Beranek L (1992) Noise and Vibration Control Engineering, John Wiley and Son, Pp: 429-450.
9. Hines JW, Jesse S, Kuropatwinski J, Carley T, Kueck J, et al. (1997) Motor Shaft Alignment versus Efficiency Analysis, P/PM Technology Conference, Dallas, TX.
10. Stephen JJ, Wesley H, Andrew E (2015) Motor Shaft Misalignment Bearing Load Analysis. The University of Tennessee, College of Engineering, Maintenance and Reliability Center. Dan Nower, Conputational Systems, Inc.835 Innovation Drive. Knoxville.
11. Arne L (2006) Diesel Generator Set Vibrations Analysis and Mitigation.
12. Caterpillar (2008) Application and Installation Guide (vibration). SEHS7654: Special Instruction Alignment, REHS0423: Special Instruction Alignment of Two Bearing Generators, REHS0177: Special Instruction–Alignment of Close Coupled Two Bearing Generators and NENG2500: Tool and Shop.
13. Caterpillar (2012): Application and Installation Guide (mounting); SEHS8700: Special Instruction Installation of Flexible Mounting Groups, SEHS9162: Special Instruction Spring Isolator.
14. Mike R (2015) Causes And Control Of Electrical Machine Vibration. EE Publisher.
15. Brüel, Kjær (2014) Introduction to the measurement of vibration. Denmark.
16. Avanindra (2016) Vibration greatly reduces reliability, life span and output power.
17. Eugene R (2018) Stiffness and Damping in Mechanical Design.
18. http://dannysengineportal.com/crankshaft-thrust-bearing-failure/
19. Sabu T, Geethamma VG, Asaletha R, Nandakumar K (2014) Vibration and Sound Damping in Polymers. Resonance 19: 821-833.
20. Albarbar A, Mekid S, Starr A, Pietruszkiewicz R (2008) MEMS accelerometers! Are they suitable for machinery condition monitoring? Int J Sensors 8: 784-799.
21. Albarbar A, Sinha J, Starr A (2009) Performance evaluation of MEMS accelerometers. J Meas 42: 790-795.
22. Arthur L (2007) Portable Generator Vibration Measurements. U.S. Consumer Product Safety Commission, Directorate for Engineering Sciences.
23. Albarbar A, Teay SH (2017) MEMS Accelerometers: Testing and Practical Approach for Smart Sensing and Machinery Diagnostics. MEMS Pressure-Flow-Temperature (PQT) Sensor for Hydraulic Systems.
24. Johannes O (2014) Vibration guideline for large diesel engines, Supervised by: Rintanen K, Saine K, Mechanical and Production Engineering, Vaasa, Specialization: Mechanical Construction Systems.
25. https://reliabilityweb.com/articles/entry/how_is_vibration_measured
26. Virtins Technology (2015) Digiducer 333D01 USB Digital Accelerometer + Multi-Instrument.