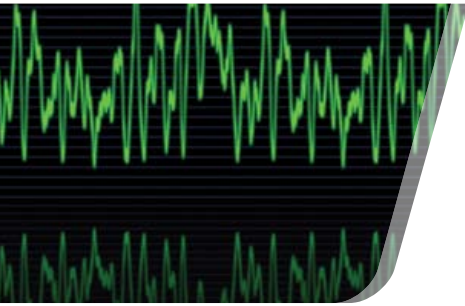


CONTROLLING GENERATOR SET VIBRATION TO MINIMIZE DYNAMIC LOADING ON BUILDING STRUCTURES

Understanding the sources of vibration and employing proper isolation methods can lead to longer generator set component life as well as less impact on building structures and occupants.



By **William Bloxson, Ph.D., P.E.**
Mechanical Engineer
MTU Onsite Energy
Mankato, Minnesota

Designing a generator set for proper vibration isolation has far-reaching consequences. Vibration induced into the building surrounding a power system can adversely affect sensitive equipment and cause tactile sensations in humans that contribute to fatigue. Vibration may also become a noise source or induce other structures to emit noise. Plus, vibration is a significant contributor to a generator set's dynamic loading on its supports, which, in turn, affects the generator/base combination's interface with the rest of the structure. Minimizing generator set vibration can both reduce the transfer of energy to building structures—that is, the dynamic loading of the building by the generator set—and lead to longer life for generator set components.

Vibration in generator sets is caused by the rotational imbalance and power pulses in the reciprocating engine-generator combination. Good engine design minimizes these imbalances, but they can never be totally eliminated. However, generator set manufacturers have been able to reduce residual vibration to acceptable levels for most applications by employing vibration-isolation mounting hardware and recommending proper foundation design.

There are two major components to vibration isolation. The first involves the isolation of the engine and generator from the remainder of the generator set assembly. The second component involves isolating the entire generator set from its mounting platform and the way in which this base connects to the building structure. Any vibration-isolation design choices then should serve to reduce the dynamic loading imposed by the generator set on its foundation, the building and ultimately its occupants.



ISOLATING THE GENERATOR SET FROM THE BASE FRAME

Generator set manufacturers routinely use elastomeric vibration isolators to isolate engines and alternators from the base frame. Additionally, elastomeric bushings are used to mount various electronic components and enclosures to the frame. These “non-spring” isolators reduce the transmission of vibration to other components by dissipating the mechanical energy in the elastomeric compound.

Vibration isolators can generally be thought of as interrupting the energy transmission path between a rotating machine and its environment. They also isolate sensitive equipment from vibrations and are typically used to mount electronic devices on generator sets. Although most individual electronic components have good shock and vibration survivability, the sheer number of these smaller components and their importance to proper performance of the generator set justifies additional vibration isolation as a prudent engineering design measure.

Elastomeric isolators generally do not have as high a 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.

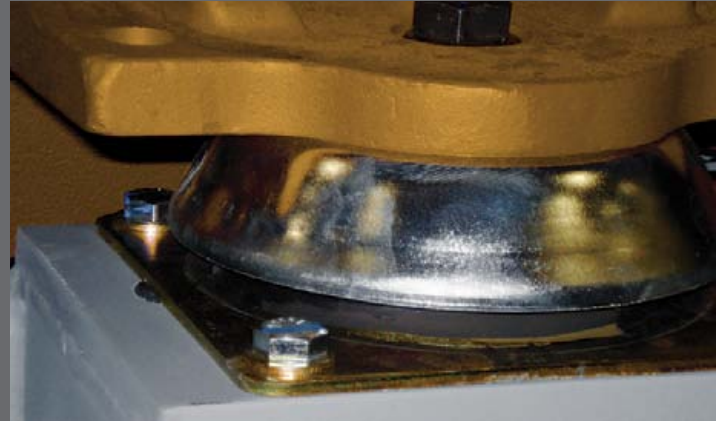
When sizing elastomeric mounts for a generator set under 500 kW, generator set manufacturers first determine the load on each isolator by dividing the unit weight by the number of mounts. The mounting points are determined with full knowledge of the location of the center of mass of the engine in order to make the loading on each mount close to equal. Manufacturers will select elastomeric mounts with a maximum load capability greater than the load applied by the component because, as a general rule, the applied load should not deflect the elastomeric mount by more than 75 percent of its rated maximum.

On generator sets of 650 kW and larger, the engine and alternator are typically rigidly mounted to the base frame. This **rigid mounting** is necessary on generator sets with two-bearing alternators where the engine and alternator are connected through a power transmission coupler. In this case, the alignment of the engine crankshaft and the alternator shaft is crucial for a long service life. These rigid connections are only possible because of the smooth operation of modern large-displacement, high-cylinder-count engines. If a large engine is paired with a single-bearing alternator connected by a flex plate, elastomeric isolators may be used in certain applications.

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



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



Aligning bolts on the alternator foot are used when a coupler connects the engine to a two-bearing alternator.



ISOLATING THE GENERATOR SET/ BASE FROM THE SUPPORTING STRUCTURE

Because generator sets come in many sizes and configurations and every application has a unique installation location, 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.

In some applications, a generator set can be installed away from occupied structures. These power systems are often simple, single-set standby systems that can be mounted on massive, dedicated concrete pads. In these applications, the generator set can be bolted directly to the concrete pad, generally with thin elastomeric pads between the mating surfaces. This popular type of mounting is not detrimental to either the concrete or the generator set, and any vibration transmitted into the ground will be absorbed by the mass of the concrete and the surrounding earth.

However, in many situations the generator set cannot be placed outside of a building or spatially isolated from sensitive equipment or occupants inside the building. In these situations, even if the generator set is mounted on a dedicated concrete pad, it may be necessary to further reduce ground vibration (dynamic loading) by placing the generator set on spring vibration isolators.

When a generator set is ordered with vibration-isolation mounts, an application engineer sizes the spring isolators based on the total weight of the unit and the type of location, such as ground floor, isolated concrete pad or rooftop. The spring isolators are sized so that the weight applied to each is not more than 60 to 70 percent of the isolator's capacity. The standard spring isolation mount is not suitable as a seismic mount and, therefore, is not applicable in all geographic locations. Some geographic locations require mounts with a high shear rating, and these must employ a seismic-qualified mount.

Typical spring isolator mounts, standard or seismic, will transmit only about 5 to 10 percent of the generator set vibration energy to the supporting surface. In all but the most sensitive environments, this level of vibration reduction is satisfactory. There are, however, unique applications that require a higher level of isolation.

Hospitals, data centers, rooftop installations and large, multi-genset installations are examples of applications that require higher-than-normal levels of vibration attenuation. If these requirements are communicated when ordering a generator set, the application engineer can assemble a vibration-isolation package that will eliminate 98 to 99 percent of the generator set vibration energy transmitted to the base.

In rare cases where virtually all vibration must be isolated from the supporting surface, it is possible for vibration transmission to be reduced to a fraction of a percent. This level of isolation requires a double-isolation system. The easiest way to achieve this double isolation is to mount a diesel fuel tank under the generator set frame rails. In this way, the generator set can be spring-isolated from the tank and the tank can be mounted to the base with elastomeric pads between the mating surfaces. The primary expense of this arrangement is the second set of isolators, but when vibration has to be all but eliminated this is a very successful solution.

Regardless of whether the generator installation will be outside a building or inside, the generator set mounting surface or concrete pad should be engineered locally. If the unit is to be mounted within a commercial or public building, local building codes will probably require the design of the supporting system be approved by a licensed professional engineer. In other locations, concrete pads may not need to be approved by a licensed professional engineer but should be built according to local codes with regard to soil density, seismic risk and wind loading requirements.

Some installations, either because of the building's purpose (i.e., mission critical) or its geographic location within a known seismic zone, require generator sets to conform to IBC (International Building Code) seismic guidelines. When generator sets have been tested and qualified as meeting IBC seismic standards, they are equipped with spring-vibration isolators that also meet IBC seismic requirements.

In applications where generator sets are mounted on their fuel tanks, spring isolation should be installed between the generator set and the fuel tank rather than between the fuel tank and the supporting surface. With this type of installation, the size of the vibration mounts can be smaller. The effectiveness of the spring isolation system is not affected by fuel-level variations (and thus weight variation) in the tank.



California-approved seismic spring isolators dissipate generator set vibrations while preventing lateral and vertical movement associated with earthquakes.

SUPPORTING STRUCTURE CONSIDERATIONS

When the base for a generator set must be designed to comply with local codes, the licensed professional engineer will need to know the “dead weight” and the “dynamic loading” of the unit. The engineer will also want to know the physical footprint of the unit as well as the number and location of the vibration isolators. Other values that might be relevant include the magnitudes and frequencies of the primary modes of vibration associated with the generator set. This information is available from the generator set manufacturer.

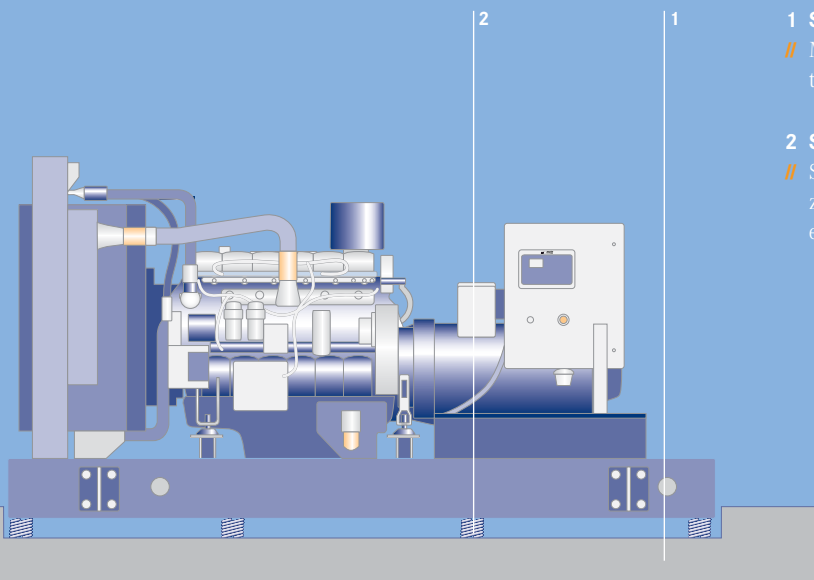
The supporting structure must support both the static loading and the dynamic loading of the generator set. Static loading is simply the “dead weight” of the object. Dynamic loading is the force applied to the floor or foundation by the operating engine-generator combination. The engineer designing or analyzing the substructure on which the generator set will rest must evaluate both the static and the dynamic loads. In general, the dynamic force is the static force multiplied by a factor (greater than 1) due to the operating vibration/motion of the object.

Ascribing a dynamic loading factor to a particular generator set is more complicated than simply providing its weight. The total weight of a generator set is the combination of all the component weights and can be approximated to within 1 or 2 percent even before any of the components are assembled. The dynamic loading factor, on the other hand, must be determined during operational testing and may be unit-specific. Dynamic loading is the total vertical force applied to the substructure when the unit is operating. The dynamic force represents the maximum magnitude of the mass of the unit times the combined accelerations of the vibration and gravity.

The masses of the concrete substructure and the generator set mathematically combine to become one when “hard-mounted” (no vibration isolation) directly to a concrete substructure. The issues at the interface of the two masses are friction and the shear-loading due to the different rates of thermal expansion and motion. These issues are mitigated by the insertion of quarter-inch-thick elastomeric pads at the mounting points. While the vibration energy of the entire assembly will remain the same as that of the generator set alone, the resulting motion of the combined masses will be significantly reduced by the addition of the mass of the concrete substructure. The soil below and alongside the concrete pad will become the “sink” for that energy.

The engineer will typically employ a large dynamic load factor to ensure a generous safety margin when designing a concrete pad poured partially in the ground and used to support a “hard-mounted” or vibration-isolated generator set. Other factors such as wind loading, freeze-depth of ground and soil stability are also taken into account in the concrete design and material specification. It is often easier to over-design the concrete supporting structure than it is to collect all of the exact data and do detailed calculations, add in a safety factor, and have exacting structural requirements. The dollar value of the time spent collecting and analyzing data is frequently more than the cost of the additional concrete in an over-designed pad.

However, there are conditions that do not allow the engineer to simply install an over-designed substructure. There are many occasions when vibration-isolated generator sets are mounted on the roofs or the upper floors of buildings. Some are moved onto the ground floor of an existing building where the floor/foundation must be partially excavated so that a separate substructure can be re-engineered to accommodate the unit. Under these circumstances, size and weight constraints as well as the use of structural steel rather than concrete become limiting factors in the structural design. In these situations it is often expedient for the engineer to gather as much accurate information as possible.



1 Separate concrete slab

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

2 Spring isolators

Spring isolators (or seismic certified isolators in earthquake-prone zones) are helpful in attenuating from 90 to 95 percent of the vibration energy that would otherwise be transferred to the foundation.



CONCLUSION

While many of these concepts about vibration isolation will not be regular issues when selecting and installing a generator set, it is important to recognize that the selection and use of vibration-isolation devices should be a conscious decision by the specifying engineer to minimize dynamic loading. Vibration that is induced into a building structure can adversely affect people, and ways to reduce it should always be a consideration during installation of a generator set. Vibration that is transferred to a structure or other components may be radiated as unwanted sound and can become a secondary issue. Elastomeric and spring isolators are very effective at limiting the transfer of vibratory energy to foundation structures and other components. Flexible connectors on exhaust piping, fuel lines and conduits all help reduce the transfer of energy to other structures.

The most accurate information about dynamic loading is obtained during operational testing at the factory, where these tests yield the best estimates of total loading. Generic values for similar units (power rating and engine type) can also be used to produce numbers that are satisfactory if the specific generator set is not available for testing.

In order to control costs, it is imperative that the parameters of the application be communicated to the generator set manufacturer early in the design process so that dynamic loading is minimized and the performance of the delivered unit meets all expectations.



MTU Onsite Energy Corporation

A Rolls-Royce Power Systems Company

www.mtuonsiteenergy.com



MTU Onsite Energy is a brand of Rolls-Royce Power Systems AG. It provides diesel and gas-based power system solutions: from mission-critical to standby power to continuous power, heating and cooling. MTU Onsite Energy power systems are based on diesel engines with up to 3,400 kilowatts (kW) power output, gas engines up to 2,150 kW and gas turbines up to 50,000 kW.

