



Electric Power Application and Installation Guide

Mounting Systems

LEBX0045



WHERE THE WORLD TURNS FOR POWER

Table of Contents

Foundations .....	.5
Soil, Gravel, or Rock Mounting .....	.5
Concrete .....	.5
Ground Loading .....	.6
Bases .....	.7
Types of Mounting Systems .....	.8
Vibration .....	.11
Mass Elastic System .....	.11
Linear Vibration .....	.13
Isolation .....	.15
Torsional Vibration .....	.20
Out-of-Balance Driven Equipment .....	.22
Alignment .....	.22
Procedures .....	.22
Torque Reaction .....	.22
Runout .....	.23
Parallel/Angular Alignment .....	.23
Bearing Clearance .....	.24
Flywheel Sag .....	.24
Thermal Growth .....	.25
Shimming .....	.25

Mounting Systems

Proper generator set installation is crucial to ensuring the efficient, long and dependable life of a system, as well as minimizing time spent on maintenance.

Caterpillar Gas Engines are rigid, self-contained structures which will operate and maintain inherent alignment unless subjected to extreme external stresses.

Due to the diversity of installation types, no one mounting system or method is universally acceptable. The engine must be mounted in a manner suited to the specific application, taking into account the characteristics of the engine, the driven loads, and the operating cycle of the machine. One or more of the following results will occur if mounting method is inadequate.

Foundations

Major functions of a foundation are to:

- Support the total weight of the generator set, which includes accessory equipment and liquids (coolant, oil and fuel)
- Maintain alignment between engine, generator and accessory equipment.
- Isolate generator set vibration from surrounding structures

The equipment foundation is not the responsibility of Caterpillar Inc., nor is the driven equipment attachment to the foundation. The customer or customer's agent familiar with local site conditions and application requirements bears foundation design responsibility. Foundation comments published herein are intended only as general guidelines for consideration. Further engine foundation general guidelines can be found in Engine Data Sheet 30.0, Form LEHQ1172.

Soil, Gravel, or Rock Mounting

Firm, level soil, gravel, or rock provides satisfactory support for single-bearing generator sets used in stationary or portable service. This support can be used where the weight-bearing capacity of the supporting material exceeds pressure exerted by the equipment package, and where alignment with external machinery is unimportant.

Soil, such as fine clay, loose sand, or sand near the ground water level, is particularly unstable under dynamic loads and requires substantially larger foundations. Information concerning bearing capacity of soils at the site may be available from local sources and must comply with local building codes.

Where support rails or mounting feet have insufficient bearing area, flotation pads can distribute the weight. The underside area and stiffness of the pad must be sufficient to support the equipment.

Seasonal and weather changes adversely affect mounting surfaces. Soil changes considerable while freezing and thawing. To avoid movement from seasonal changes, extend foundations below the frost line.

Concrete

Several basic foundations are applicable for generator sets. The foundation chosen will depend on factors previously outlined as well as limitations imposed by the specific location and application.

Massive concrete foundations are unnecessary for modern multicylinder medium speed generator sets. Avoid excessively thick, heavy bases to minimize subfloor or soil loading. Bases should be only thick enough to prevent deflection and torque reaction, while retaining sufficient surface area for support. Non-parallel units require no foundation anchoring.

If a concrete foundation is required, minimum design guidelines include:

- Strength must support wet weight of units plus dynamic loads.
- Depth sufficient to attain a minimum weight equal to generator set wet weight (only if large mass, i.e. inertia block, is specified for vibration control).
- Outside dimensions exceed that of the generator set, a minimum of 304.8 mm (12 in.) on all sides.

Before calculating the depth of the concrete foundation, certain issues must be considered:

- When effective vibration isolation equipment is used, floor concrete must only be deep enough to provide structural support of the static load.
- If isolators are not used, dynamic loads transmit to the facility floor and require it to support 125 percent of the generator wet weight.
- If generator sets are paralleled, possible out-of-phase paralleling and resulting torque reactions demand foundations that are able to withstand twice the wet weight of the generator set.

Estimate foundation depth that will accommodate generator set weight using the formula:

$$FD = \frac{W}{D \times B \times L}$$

FD = Foundation depth (m), (ft)

W = Total wet weight of generator set (kg), (lb)

D = Density of concrete (kg/m³), (lb/ft³)
(2402.8 kg/m³), (150 lb/ft³)

L = Foundation length (m), (ft)

Suggested concrete mixture by volume is 1:2:3 of cement, sand, aggregate, with maximum 100 mm (4 in.) slump and 28-day compressive strength of 20 MPa (3000 psi).

Ground Loading

Initial considerations include generator set weight and material supporting this weight.

The wet weight of the total package must be calculated. This includes accessory equipment and weight of all liquids (coolant, oil, and fuel) supported by the foundation. Engine and attachments dry weights can be found in the price list. Liquid densities are given in Table 1.

Liquid	kg/m ³	lb/U.S. gal	lb/ft ³	Specific Gravity
Water, Fresh	994.6	8.3	62.1	1.00
Water, Sea	1018.3	8.5	63.6	1.02
Water/Glycol	1024.4	8.55	64.0	1.03
Diesel Fuel	850.7	7.1	53.1	0.855
Lube Oil	909.7	7.6	56.8	0.916
Kerosene	802.7	6.7	50.1	0.807

Table 1. Densities of liquids [@ 16°C (60°F)].

Material supporting the foundation must carry the total weight (see Table 2) shows bearing load capabilities of common materials.

Material	Safe Bearing Load kPa (psi)
Rock, Hardpan	482.6 (70)
Hard Clay, Gravel and Coarse Sand	386 (56)
Loose Medium Sand and Medium Clay	193 (28)
Loose Fine Sand	96.5 (14)
Soft Clay	0-96.5 (0-14)

Table 2. Bearing load capability.

The area of load-bearing support is adjusted to accommodate surface material. To determine pressure (P) exerted by the generator set, divide total weight (W) by total surface area (A) of the rails, pads, or vibration mounts.

$$P = \frac{W}{A}$$

Where: P = pressure (kPa), (psi)

W = weight (kg), (lb)

A = area (m²), (in²)

Pressure imposed by the generator set weight must be less than the load-carrying capacity of supporting material.

Where support rails or mounting feet have insufficient bearing area, flotation pads can distribute the weight. The underside area and stiffness of the pad must be sufficient to support the equipment.

With vibration isolation between the baseframe and the floor, if the load is equally distributed over all isolators, the floor loading is:

$$\text{Floor Loading} = \frac{\text{Total Generating Set Weight}}{\text{Pad Area} \times \text{Number of Pads}}$$

Thus, floor loading can be reduced by increasing the number of isolation pads.

If load is not equally distributed, the maximum floor pressure occurs under the pad supporting the greatest proportion of load (assuming all pads are the same size):

$$\text{Max Floor Pressure} = \frac{\text{Load on Heaviest Loaded Pad}}{\text{Pad Area}}$$

Seasonal and weather changes adversely affect mounting surfaces. Soil changes considerable while freezing and thawing. To avoid movement from seasonal change, extend foundations below the frost line.

Grounding

The generator set must be properly ground before operation startup. NEC recommends maximum 25 Ohm resistance to the ground (reference ANSI/IEEE C37-101-1985 "Guide for Generator Ground Protection").

Bases

The first design consideration for an engine base is its physical dimensions. The base must provide the proper mounting holes for the engine and all other base-mounted components. The holes must also make allowance for servicing of the engine and other components. They must provide clearance and provisions for proper alignment.

Design the base to maintain the original alignment between engine and driven equipment under all operational and environmental conditions. Misalignment between an engine and driven equipment can cause vibration and

shorten the life of couplings and bearings. Bases designed and fabricated by dealers, or others, must meet design requirements of the Caterpillar supplied base to assure strength and vibration resistance.

The major cause of misalignment is flexing of the base due to lack of torsional rigidity. Other causes are poor installation methods and incorrect alignment procedures.

The base must offer rigidity adequate to oppose the twist due to torque reaction on drives where the driven equipment is mounted on the base assembly, but not bolted directly to the engine flywheel housing (see Figure 1).

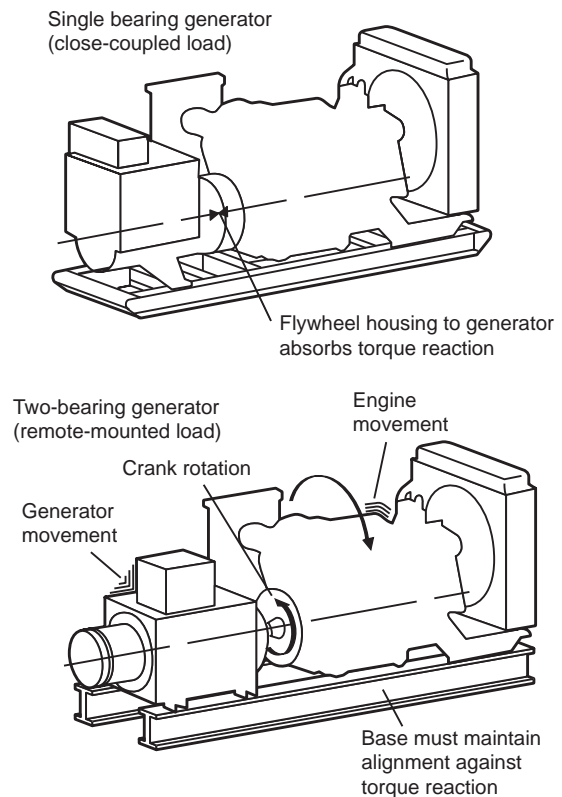


Figure 1. Absorption of torque.

Caterpillar bases are designed to eliminate frequent, periodic realignment of the engine and driven unit. A properly installed Caterpillar base will meet the following criteria:

- Engine torque does not cause excessive misalignment.
- Flexing of the foundation or substructure under the base during operation does not cause bending of the base.

- When the engine and driven unit are mounted on a Caterpillar base, the entire package is able to withstand normal handling during transportation without permanently distorting the base or causing misalignment of the driven unit.
- A Caterpillar base is free of torsional or linear vibrations in the operating speed range of the engine.

Types of Mounting Systems

The choice of mounting method depends on the configuration and application of the generator set. Various methods are discussed in the following.

Fabricated Bases

Frequent relocation, initial installation ease, vibration isolation or isolating from flexing mounting surfaces, such as trailers, are major uses for fabricated bases. Do not rigidly connect any base to flexing surfaces.

Bases maintain alignment between engine, generator, and other drive equipment such as radiator fans. Engines with close-coupled single-bearing generators maintain alignment by mounting rails or modest bases. Two-bearing generators, generators driven from either end of the engine, tandem generators, or tandem engines, require substantial boxed bases. Bases must incorporate sufficient strength to:

- Resist outside bending forces imposed on the engine block, couplings, and generator frame during transportation.
- Limit torsional and bending movement caused by torque reactions.
- Prevent resonant vibration in the operating speed range.

Due to thermal expansion, [cast iron 5.5×10^{-6} mm/mm/1.8°C (5.5×10^{-6} in./in./1.0°F)] engines may lengthen 2.3 mm (0.09 in.) from cold to operating temperature. *This growth must not be restrained.* On single-bearing and most two-bearing generators, no close clearance dowels or ground body bolts are used to limit thermal growth. Single-bearing generators requiring extremely close alignment, use a ground body bolt at the flywheel end on one side of the engine. No other restraint is permitted.

Mounting feet of two-bearing generators can be doweled without harm. Slight expansion within the generator is absorbed in the generator coupling.

Single of Multiple Bearing

Caterpillar offers different bases for close coupled units (such as single-bearing generators) and for remote mounted units (such as two-bearing generators). The base for a remote mounted two-bearing generator must be sturdy enough to provide support and maintain alignment, meaning that it must be more rigid. The base for a close coupled single-bearing generator can be lighter because the base does not have to withstand torque reaction.

Fastening the driven unit housing to the flywheel housing eliminates the need for the base to absorb the engine torque (see Figure 1). On remote mounted units, the frame of the driven equipment tries to rotate in the same direction as the engine crankshaft. If the base were not rigid enough, engine torque would cause the base to flex excessively. The result would be misalignment proportional to the amount of load. This misalignment would not be evident during a static alignment check.

For engines with close-couple units, Caterpillar does not recommend a specific section modulus for the longitudinal girders or cross members. Usually “I” beams or channel section steel beams in a ladder type arrangement are acceptable.

Foot Mounted Engines

Caterpillar Engines and single-bearing or close-coupled two-bearing generators with mounting feet can either be mounted on a base or mounted directly on a pair of beams without a base. The mounting feet must be bolted in place. Do not weld the feet to the base or beams. If support beams are used, the beams must be flat and lie in the same plane. Use shims as necessary between feet and base or support beams so all mounting feet are in solid contact at all locations. If the mounting feet are not in equal contact with the base or beams before the anchor bolts are installed, the engine and/or generator can be stressed when the anchor bolts are tightened.

Mounting Rails

Lugs or brackets have been welded to the sides of the oil pan at the factory and hold the engine to the mounting rails. Shimming is not allowed between the engine oil pan and the mounting rails.

On engines whose mounting rails are extended to mount close-coupled driven units, these rails must not be notched or the cross braces removed to provide clearance for the driven unit. Shims are used as necessary between the mounting feet of the drive unit and the mounting rails to get correct alignment with the engine.

If the driven equipment is close-coupled to the engine, use clearance type bolts at all locations to fasten the mounting rails to the mounting blocks or base. These bolts must have a diameter 1.5 mm (0.06 in.) less than the diameter of the holes in the mounting rails.

If the driven equipment is remote-mounted, clearance type bolts should be used at all mounting locations in the left mounting rail. If a ground body bolt is to be used to control the direction of horizontal thermal growth, install this bolt in the right rail at the end of the rail next to the coupling, or at the rear of the rail if remote mounted equipment is driven from both ends of the engine. Install clearance type bolts at all other locations in the right rail. If a spot weld is to be used to control the direction of thermal growth, spot weld the right rail to the mounting block and/or shims on the side of the rail next to the coupling. Install clearance type bolts at all mounting locations in the right mounting rail. All clearance type bolts must have a diameter 1.5 mm (0.06 in.) less than the diameter of the mounting rails holes.

Each anchor bolt between the mounting rail and the base must be bolted into a mounting block. Distortion of the mounting rails will result if these bolts are fastened from the rails into the base (see Figure 2).

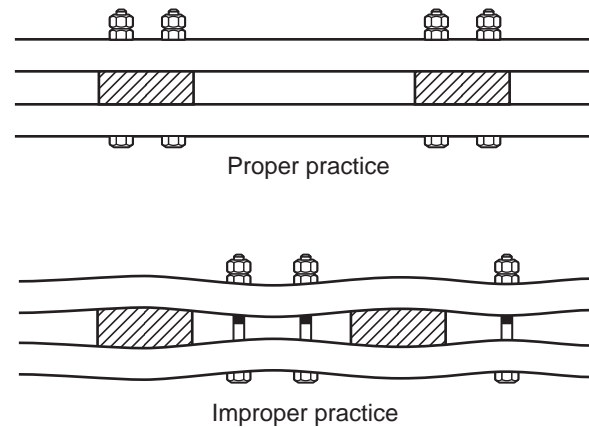


Figure 2. Bolt position.

For engines driving remote-mounted equipment, the mounting rails must be cradled between guide strips which keep the expansion of the rails always parallel to the output shaft centerline. The guide strips are welded to the top of the mounting blocks at the opposite end of the rails from the ground body bolt or spot weld.

Because horizontal thermal growth of the engine and mounting rails will always be away from the ground body bolt or spot weld, never weld stops or chocks against the opposite end of the mounting rails from the ground body bolt or spot weld. If chocks or stops are to be used, there must be a minimum of 0.13 mm (0.005 in.).

Skid Mounting

Skid mounting is a heavy duty base (see Figure 3). This mounting method is generally most suitable for the semimobile type of power unit or fixed installation which may be subject to the need for occasional relocation. The unit cannot be operated during such movement as the skid base is not supported on a machine subframe.

For these applications the auxiliary fuel tank located below the generator set will have additional wall thickness in order to withstand the handling.

Skid mounting is normally used when the engine drives pumps, blowers, generators, air compressors, or if an outboard bearing is used.

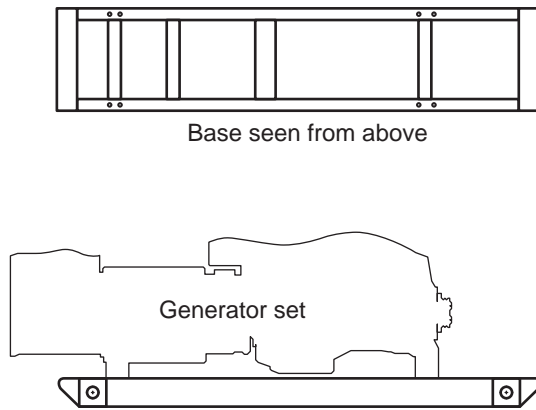


Figure 3. Skid mounting.

Three/Four Point Mounting

A Caterpillar base for remote mounted equipment is a torsionally rigid structure for mounting the engine and driven unit. The three point suspension design maintains proper relationship and alignment of all equipment by isolating external forces (see Figure 4). The three-point mounting rails can only be used for close-coupled driven units where the rails are extended for the mounting of these units.

The three-point suspension system must be used when there is a possibility the foundation or substructure supporting the base can deflect due to external forces or settling. Suspending the power unit on three points isolates the unit from deflection of the substructure. More than three mounting points can cause base distortion.

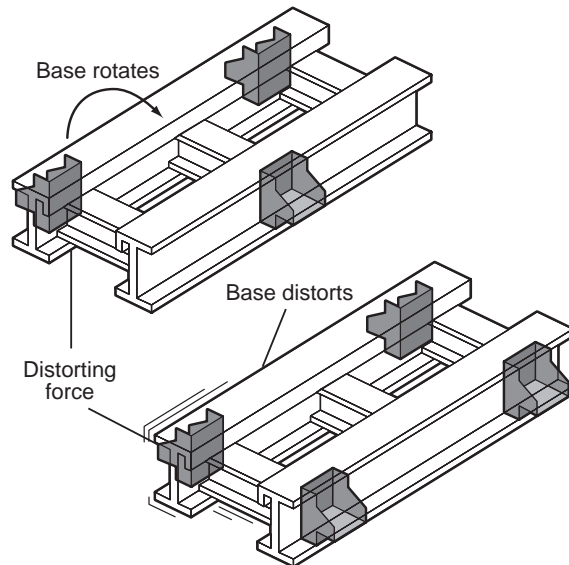


Figure 4. 3-point mounting.

Four-point mounting rails are used if the rails are to be secured to a base or foundation that will not be subjected to external forces that could cause distortion of the mounting rails. These rails can be used for either remote-mounted or close-coupled driven units. For close-coupled driven units, extended mounting rails are available so the driven equipment can be fastened directly to the rails.

Shims only or four drilled and threaded mounting blocks and shims can be used between the engine rails and the base at the four corner location. If mounting blocks are used, these blocks must be welded to the base. The blocks are first fastened to the bottom of the rails at the four corners. Remove bolt clearance with the rails by driving the blocks toward the end of each rail. This will provide clearance for thermal growth at operating temperature. The engine is then put in position on the base and the blocks tack welded to the base. If necessary, remove the engine to complete welding the blocks to the base.

Use shims as necessary to make sure the mounting rails are in solid contact with the mounting blocks or base at all four mounting locations. Distortion of the mounting rails will result when the anchor bolts are tightened, if the mounting rails are not in solid contact.

Non-Cat Bases

Bases not manufactured by Caterpillar must meet several design criteria. These bases must be rigid enough to limit torsional and bending forces caused by torque reaction and subbase flexing. They must prevent excessive bending forces from passing to the engine block, couplings, and driven unit during shipment. To prevent resonance, they must have a natural frequency out of the operating speed range. They must allow sufficient space for shimming so proper alignment can be accomplished.

Vibration

All mechanical systems with mass and elasticity are capable of vibration. Engines produce vibration due to combustion forces, torque reactions, structural mass and stiffness combinations, and manufacturing tolerances on rotating components. These forces may create conditions ranging from unwanted noise to high stress levels, and possible ultimate failure of engine or driven components.

The same amplitude and frequency of vibration generated by the engine could result in structural damage if a fixed installation were housed in a building, or close to sensitive instruments or equipment, such as computers.

Other influencing factors are foundation design, soil load characteristics, and other machinery operating in close proximity.

Vibrating stresses can reach destructive levels at engine speeds which cause resonance. Resonance occurs when natural system frequencies coincide with engine excitation frequencies.

Engine vibrations are produced and maintained by regular, periodic driving forces set up by unbalanced moving masses. These are called forced vibrations.

Free vibrations have no driving force. When set in motion such vibrations, is undamped, would continue indefinitely with constant amplitude and natural frequency.

If the frequency of a forced vibration is the same as the natural frequency of free vibrations,

excessive vibration results. This is called resonance and can cause serious problems.

Mass Elastic System

Engine vibration may be of the following types and causes:

1. Linear vibration — vertical and/or horizontal inertia forces due to lack of balance in reciprocating or rotating machinery.
2. Torque reaction — not a vibratory force, but may excite vibration.
3. Torsional vibration of shafting — occurs in any rotating mass elastic system (two or more masses connected by an elastic shaft) where periodic forces are present. Where these forces recur near the natural frequency of torsional vibration, resonance may develop and cause dangerous stress.
4. Axial vibration of shafting — when torques are applied to a crankshaft, it is alternately shortened and lengthened. This could be troublesome if the natural axial frequency is near a torsional frequency.

Generator sets need no isolation for protection from self-induced vibrations. However, isolation is required if:

1. Engine vibration must be separated from building structures.
2. Vibrations from nearby equipment are transmitted to inoperative generator sets.
3. System is supported on a flexible mounting surface, such as a trailer bed.

Vibration isolators prevent the transmission of possible damaging generator set vibration throughout a building. Noise is also reduced.

When an engine and generator are to be assembled to each other, vibration studies and tests must be completed to assure satisfactory, trouble-free operation on the job site. With factory assembled generator sets, the responsibility is assumed by the manufacturer. In any case, wherever assembly takes place, someone must assure the integrity of the installation from a vibration standpoint.

Vibration Measurement

Vibration measurements on large engine units should be made using the Caterpillar Vibration Analyzer, Part No. 4C-3030.

If Caterpillar measuring equipment is not available, an equivalent device capable of measuring peak-to-peak displacement at selected frequencies, overall velocity, and overall displacement should be used.

Vibration should be measured at nine points on a two bearing generator set. Comparable points on non-generator driven equipment may be important. These points are illustrated in Figure 5 and are described below.

Point 1

Horizontal direction at the front of the engine; locate the probe on the side of the block at the crankshaft centerline.

Point 2

Vertical direction at the front of the engine; locate the probe on the block top deck in the plane of the crankshaft centerline.

Point 3

Horizontal direction at the rear of the engine; locate the probe on the side of the block at the crankshaft centerline.

Point 4

Vertical direction at the rear of the engine; locate the probe on the block top deck (or rear housing) in the plane of the crankshaft centerline.

Point 5

Vertical direction at the generator front bearing; locate the probe on the bearing housing at the shaft centerline.

Point 6

Horizontal direction at the generator front bearing; locate the probe on the side of the bearing housing at the shaft centerline.

Point 7

Vertical direction at the generator rear bearing; locate the probe on the bearing housing at the shaft centerline.

Point 8

Horizontal direction at the generator rear bearing; locate the probe on the side of the bearing housing at the shaft centerline.

Point 9

Axial direction at the generator rear; locate the probe on the rear right outside edge of the generator structure (not sheet metal) at the shaft centerline.

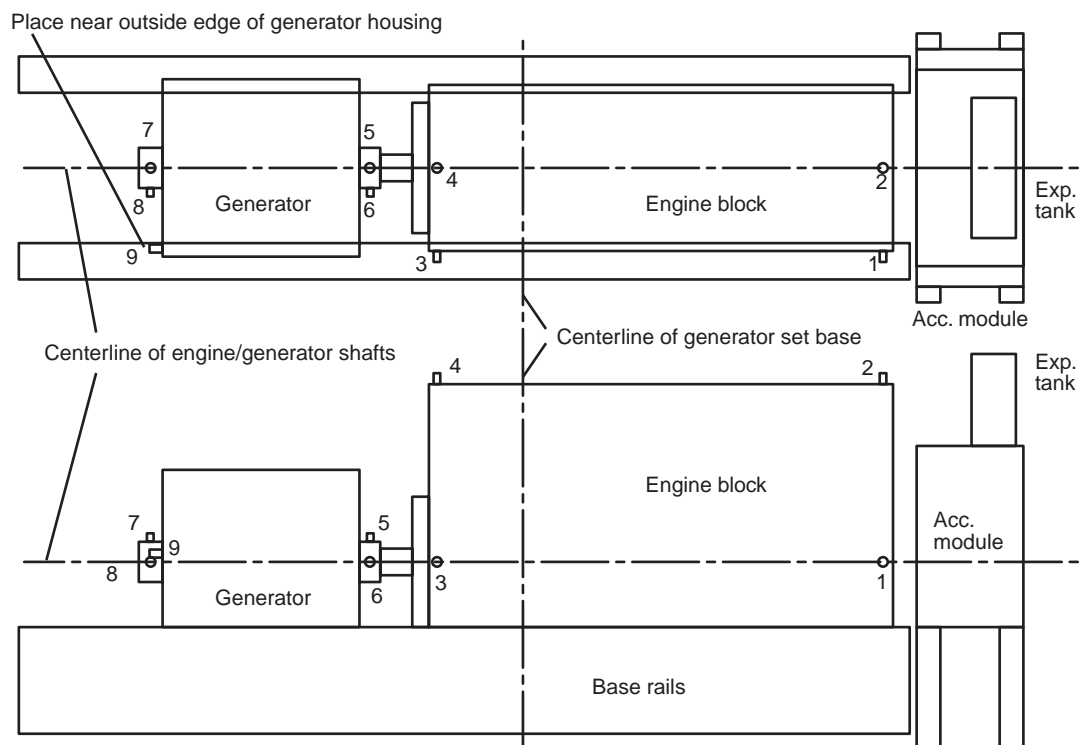


Figure 5. Vibration measuring points.

Vibration measurements must be made at the advertised driven equipment rating (100% load). If additional data is desired, it is recommended that measurements be made at 0% load, 50% load, and 75% load.

Data must be reported in terms of peak-to-peak displacement (mils) at half order frequency, first order frequency, overall velocity level (in/s) and overall displacement (mils) for each of the nine measuring locations. The chart at the end of this section can be used to record and report the measured vibration data.

Vibration Limits

The vibration levels for any load condition, at any of the nine measuring locations, must not exceed the following guideline limits:

1. Peak-to-peak displacement at half order frequency = 0.13 mm (5 mils)
2. Peak-to-peak displacement at first order frequency = 0.13 mm (5 mils)
3. Overall displacement = 0.22 mm (8.5 mils)
4. Overall velocity = 34.3 mm/s (1.35 in/s)

This is applicable to both Diesel and Gas Engines (reference: EDS 73.1, Linear Vibration).

Consult the manufacturer of the driven equipment for any such vibration limits.

If the measured vibration levels exceed the limits, contact your Caterpillar dealer representative or Caterpillar factory representative for assistance.

Warning: It is not an acceptable practice to lower the package vibration levels when operating at stable conditions by tightening the snubber bolts on the Caterpillar vibration isolators. This practice will only hide vibration problems.

Linear Vibration

Linear vibration is exhibited by noisy or shaking machines, but its exact nature is difficult to define without instrumentation. Human senses are inadequate to detect relationships between the magnitude of vibration and period of occurrence. A first order ($1 \times \text{rpm}$) vibration of 0.254 mm (0.010 in.) displacement may feel about the same as third order measurement of 0.051 mm (0.002 in.).

Vibration occurs as a mass is deflected and returned along the same place and can be illustrated as a single mass spring system (see Figure 6). With no external force imposed on the system, the weight remains at rest and there is no vibration. But when the weight is moved or displaced and then released, vibration occurs. The weight travels up and down through its original position until frictional forces cause it to rest. When external forces, such as engine combustion, continue to affect the system while it vibrates, it is termed *forced vibration*.

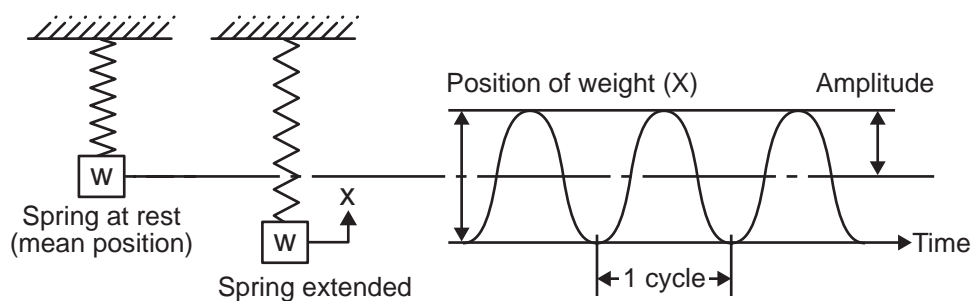


Figure 6. Mass-spring system.

Time required for the weight to complete one movement is called a period (see Figure 7).

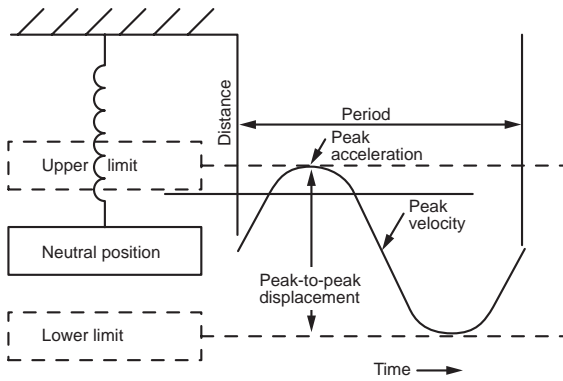


Figure 7. Illustration of a period.

Maximum displacement from the mean position is amplitude; interval in which the motion is repeated is called the cycle.

If the weight needs one second to complete a cycle, the vibration frequency is one cycle per second.

If one minute, hour, day, etc., were required, its frequency would be one cycle per minute, hour, day, etc. A system completing its full motion 20 times in one minute would have a frequency of 20 cycles per minute, or 20 cpm.

Establishing vibration frequency is necessary when analyzing a problem. It allows identification of engine component or condition causing the vibration.

Total distance traveled by the weight, from one peak to the opposite peak, is peak-to-peak displacement. This measurement is usually expressed in mils, one mil equaling one-thousandth of an inch [0.025 mm (0.001 in.)]. It is a guide to vibration severity.

Average and root-mean-square (rms) are used to measure vibration (rms = 0.707 times the peak of vibration.) These terms are referred to in theoretical discussions.

Another method to analyze vibration is measuring mass velocity. Note that the example is not only moving but changing

direction. The speed of the weight is also constantly changing. At its limit, the speed is "0". Its speed or velocity is greatest while passing through the neutral position.

Velocity is extremely important; but because of its changing nature, a single point has been chosen for measurement. This is peak velocity normally expressed in inches per second.

Velocity is a direct measure of vibration and provides best overall indicator of machinery condition. It does not, however, reflect the effect of vibration on brittle material.

Relationship between peak velocity and peak-to-peak displacement is compared by:

$$V \text{ Peak} = 52.3 \times D \times F \times 10^{-6}$$

Where:

V Peak = Vibration velocity in inches per second peak.

D = Peak-to-peak displacement, in mils (1 mil = 0.001 in.).

F = Frequency in cycles-per-minute (cpm).

Acceleration is another characteristic of vibration. It is the rate of velocity change. In the example, note that peak acceleration is at the extreme limit of travel where velocity is "0". As velocity increases, acceleration decreases until it reaches "0" at the neutral point.

Acceleration is dimensioned in units of "g" (peak), where "g" equals the force of gravity ($980 \times 6650 \text{ mm/s}^2 = 386 \text{ in./s}^2 = 32.3 \text{ ft/s}^2$).

Acceleration measurements, or "g's", are used where relatively large forces are encountered. At very high frequencies (60,000 cpm), it is perhaps the best indicator of vibration.

Vibration acceleration is calculable from peak displacement

$$g \text{ Peak} = 1.42 \times D \times F^2 \times 10^{-8}$$

Machinery vibration is complex and consists of many frequencies. Displacement, velocity, and acceleration are all used to diagnose particular problems. Displacement measurements are better indicators of dynamic stresses and are, therefore, commonly used. Note that overall, or total peak-to-peak displacement, described in Figure 8, is approximately the sum of individual vibrations.

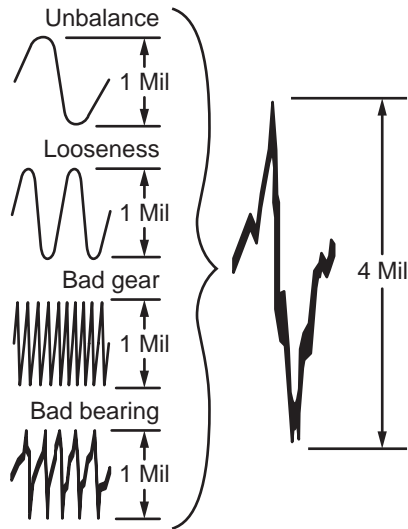


Figure 8. Peak-to-peak displacement.

Isolation

Generator sets need no isolation for protection from self-induced vibrations. They easily withstand any vibrations which they create.

However, isolation is required if engine vibration must be separated from building structures, or if vibrations from nearby equipment are transmitted to inoperative generator sets. Caterpillar Generator Sets with isolation mounts between the generator set and base already satisfy these requirements. Running units are rarely affected by exterior vibrations. Methods of isolation are the same for external- or self-generated vibrations.

Isolation Location

Several commercial isolators provide various degrees of isolation. Generally, the lower the natural frequency of the isolator, the greater the deflection (soft) and more effective the isolation. Weight of generator sets can be unequally balanced within the limits of the isolators. However, overloading will eliminate isolator benefits. Isolators are most effective when located under generator mounting and engine front support (see Figure 9). If additional support is desired, place an isolator midway between front and rear mounts and under radiator.

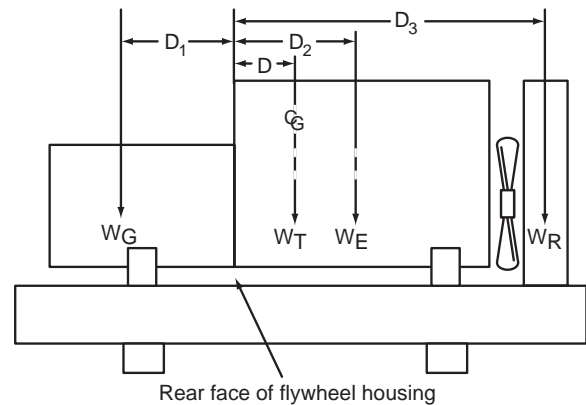


Figure 9. References for distances.

To apply isolators, wet weight and center of gravity of the assembled unit must be established. Assuming engine and generator are assembled to a base, wet weight (W_T) and assembled center of gravity can be calculated. A common reference is needed (see Figure 9). In this case, use the rear face of the flywheel housing. Because measurements are to both sides of the reference, one direction can be considered negative.

$$W_T (D) = W_E (D_2) - W_G (D_1) + W_R (D_3)$$

$$D = \frac{W_E (D_2) - W_G (D_1) + W_R (D_3)}{W_T}$$

W_T = wet weight

W_E = engine weight

W_G = generator weight

W_R = radiator weight

$D_{1,2,3}$ = distances

If additional equipment is added, the process is repeated to determine a new center of gravity.

Having established center of gravity for the total unit (see Figure 10), loading on each pair of isolators is determined by:

$$S_1 = W_T \frac{B}{C} \qquad S_2 = W_T \frac{A}{C}$$

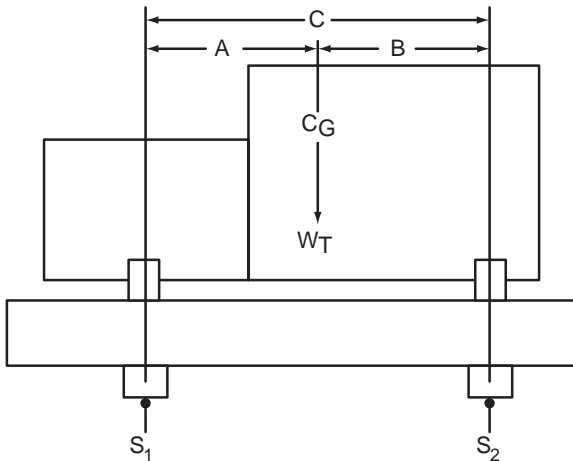


Figure 10. Determination of isolator location.

Isolators are sized to have natural frequencies far removed from engine exciting frequencies. If these frequencies were similar, the entire unit would resonate. The transmissibility chart in Figure 11 depicts this condition. It also shows the significant improvement caused by decreasing the mounting natural frequency to allow a ratio increase above $\sqrt{2}$, or 1.414.

Isolation Methods

Vibration is reduced by commercially available fabricated isolators or bulk isolators. Both techniques utilize static deflection, with increased deflection resulting in greater isolation. Although internal damping of various materials cause performance differences, the vibration chart in Figure 12 describes the general effect deflection has on isolation. By using engine rpm as the nominal vibration frequency, magnitude of compression on isolating materials can be estimated.

The unit can be separated from supporting surfaces by these *soft* commercial devices, i.e., those which deflect under the static weight. Mounting rails or fabricated bases withstand torque reactions without uniform support from the isolators.

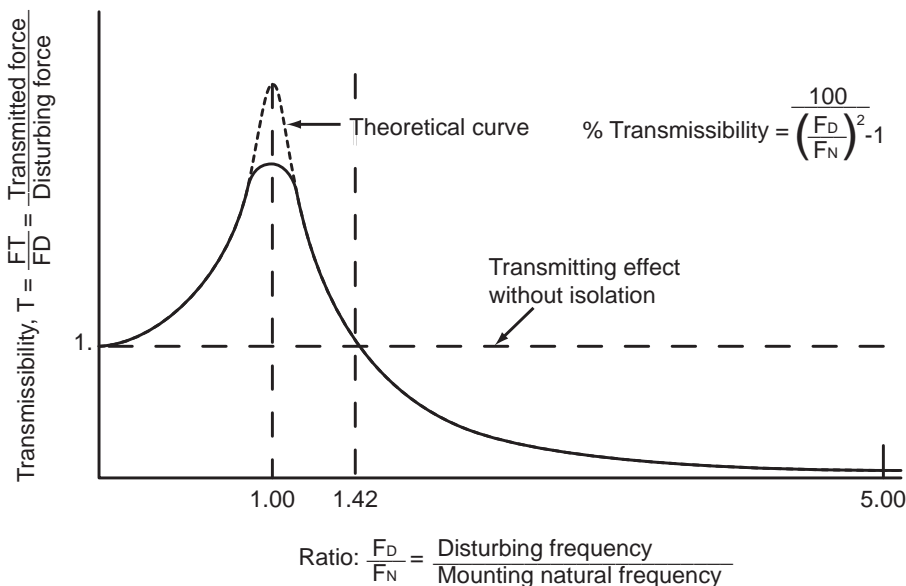


Figure 11. Transmissibility chart.

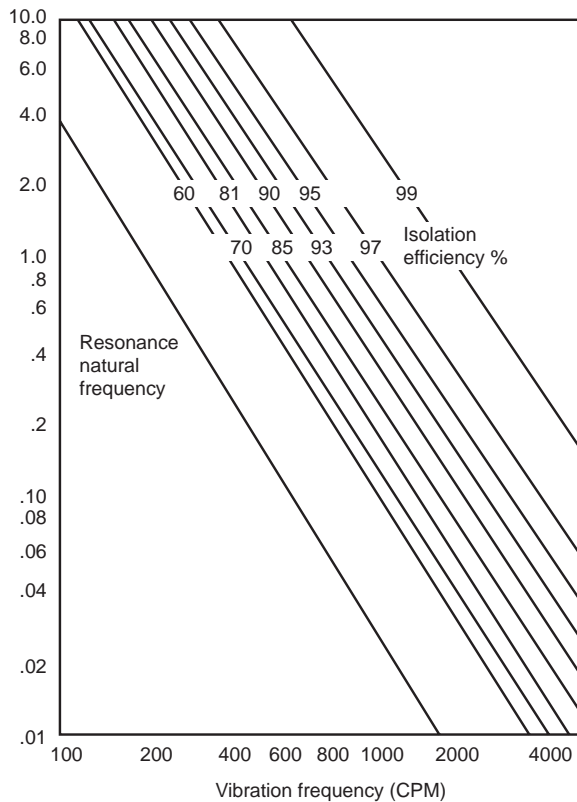


Figure 12. Basic vibration chart.

Piping connected to generator sets requires isolation, particularly when generator sets mount on spring isolators. Fuel and water lines, exhaust pipes, and conduit could otherwise transmit vibrations long distances. Isolator pipe hangers, if used, should have springs to attenuate low frequencies, and rubber or cork to minimize high frequency transmissions. To prevent buildup of resonant pipe vibrations, support long piping runs at unequal distances (see Figure 13).

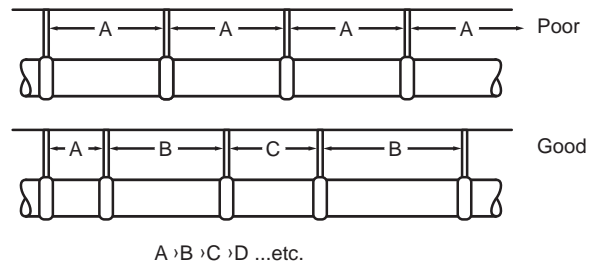


Figure 13. Pipe runs support.

Rubber

Rubber isolators are adequate for applications where vibration control is not severe. By careful selection, isolation of 90% is possible. They isolate noise created by transmission of vibratory forces. Avoid using rubber isolators with natural frequencies near engine excitation frequencies.

Adding rubber plates beneath spring isolators block high frequency vibrations transmitted through the spring. These vibrations are not harmful but cause annoying noise.

Spring

The most effective isolators are of steel spring design. They isolate over 96% of all vibrations and noise transmitted from rotating machinery to the foundation or mounting surface. Conversely, isolators can absorb disturbances generated by *adjacent* machinery and prevent damage from being transmitted to idle equipment.

Spring-type linear vibration isolators are available as attachments (not installed) for all generator sets to be used in stationary applications. These isolators permit mounting the generator set on a surface capable of supporting only the static load.

A detail of a spring-type isolator shows the addition of thrust blocks to restrict lateral movement without interfering with the spring function (see Figure 14).

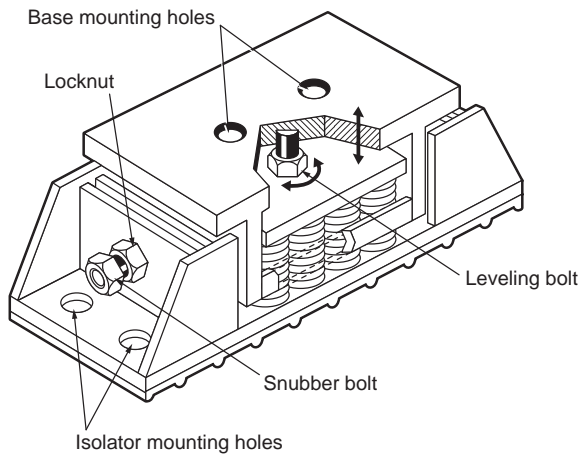


Figure 14. Vibration isolator.

No allowance for torque or vibratory loads is required. As with direct mountings, no anchor bolting is usually required. However, when operating in parallel, vertical restraints are recommended and the isolator firmly fastened to the foundation. Spring isolators are available with snubber for use when engines are side loaded or located on moving surfaces.

Gravel or Sand

Bulk isolating materials are used between the foundation and supporting surface but are not as foolproof as spring or rubber types.

Isolation of block foundations may be accomplished by 200 to 250 mm (8 to 10 in.) of wet gravel or sand in the bed of the foundation pit (see Figure 15). Sand and gravel can reduce engine vibration one-third to one-half. The isolating value of gravel is somewhat greater than sand. To minimize settling of the foundation, gravel or sand must be thoroughly tamped before pouring the concrete block. Make the foundation pit slightly longer and wider than the foundation block base. A wooden form the size and shape of the foundation is placed on the gravel or sand bed for pouring the concrete. After the form is removed, the isolating material is placed around foundation sides, completely isolating the foundation from surrounding earth.

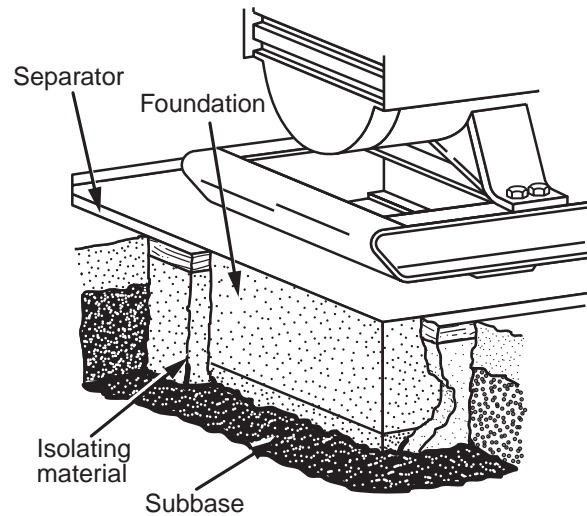


Figure 15. Bulk isolation.

Other Isolation Methods

Fiberglass, felt, composition, and flat rubber do little to isolate major vibration forces. The fabric materials tend to compress with age and become ineffective. Because deflection of these types of isolators is small, their natural frequency is relatively high compared to the engines. Attempting to stack these isolators or apply them indiscriminately could force the system into resonance.

Cork is not effective with disturbing frequencies below 1800 cps and, if not kept dry, will rot. It is seldom used with modern generator sets, but is used to separate engine foundations and surrounding floor because of resistance to oil, acid, or temperature changes between -18° and 93°C (0° and 200°F).

If no isolation is required, the generator set may rest directly on the mounting surface. Factory assembled units are dynamically balanced and theoretically there is no dynamic load. Practically, the surface must support 25% more than the static weight of the unit to withstand torque and vibratory loads. Unless the engine is driving equipment which impose side loads, no anchor bolting is required. This normally applies to all non-parallel generator set mountings. Thin rubber or composition pads minimize the unit's tendency to creep or fret foundation surfaces.

Stationary equipment isolators are used when the package will not be transported, (with isolators attached), or will not experience seismic shock. The isolators contain thrust blocks to control lateral movement.

External Isolation

Piping connected to generator sets requires isolation, particularly when generator sets are mounted on spring isolators. Fuel and water lines, exhaust pipes, and conduit could otherwise transmit vibrations long distances.

If isolator pipe hangers are used they should have springs to attenuate low frequencies, and rubber or cork to minimize high frequency transmissions.

To prevent buildup of resonant pipe vibrations, long support piping should run at unequal distances (see Figure 13).

Mobile Equipment

Isolation from a movable platform is desirable to:

1. Reduce vibration.
2. Reduce noise.
3. Prevent torque loading on generator sets caused by platforms or trailer beds.

Mobile equipment isolators have the same features as the stationary equipment isolators. They also have built in restraints capable of withstanding a + 2 G vertical load and + 3 G horizontal load under low cyclic conditions (see Figure 16). They are suitable for use with mobile platforms, but are not generally intended to handle seismic shock.

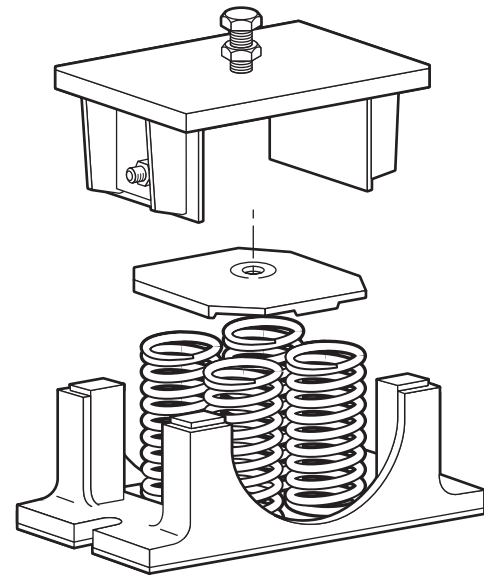


Figure 16. Isolator for mobile equipment.

Vibration carried throughout an enclosure causes early failure of auxiliary equipment. Relays, switches, gauges, and piping are adversely affected.

Noise, while normally only annoying, can attain levels objectionable to owners and operators. If operating near property lines, noise could exceed local ordinances.

Perhaps the most important reason to isolate mobile equipment is to avoid bending of the generator set by movement of the subbase. Unless the platform or trailer bed is extremely rigid, the generator set must not be bolted to it. Deflection of the bed would be transmitted to the engine, causing block bending and possible crankshaft and bearing failures.

Lateral movement of the generator set must be minimized as the trailer is transported. This can be achieved simply by blocking the unit off the isolators during the move. If not practical, snubbers can confine vertical and horizontal movement.

Trailer Units

Lateral movement of the generator set must be minimized as the trailer is transported. This can be achieved simply by:

- Blocking the unit off the isolators during the move
- Using snubbers to confine vertical and horizontal movement

A spring-type isolator with the addition of thrust blocks will restrict lateral movement without interfering with spring function.

Seismic Vibration

Seismic shocks are insufficient to harm generator sets resting on the floor. However, isolation devices, particularly spring isolators, amplify small movement generated by earthquakes to levels which would damage equipment. Special isolators incorporating seismic restraining or damping devices are available, but exact requirements must be reviewed by the isolator supplier. Isolators anticipating seismic shock are bolted to the equipment base and the floor. Positive stops are added to limit motion in all directions. Attached piping and auxiliary equipment supports must also tolerate relative movement.

Torsional Vibration

Torsional vibrations occur as subjects, such as an engine crankshaft, twist and recover. Standard generator set components withstand normal stresses caused by combustion forces and torque reactions. A generator set must prevent the natural frequency of the drive train from approaching the unit's operating speed. Failure of crankshaft, couplings, gears or bearings may result without this attention.

Torsional vibrations originate with the piston power stroke. The simplified drive train in Figure 17 illustrates relationship of shaft diameter, length, and inertia on the natural system frequency.

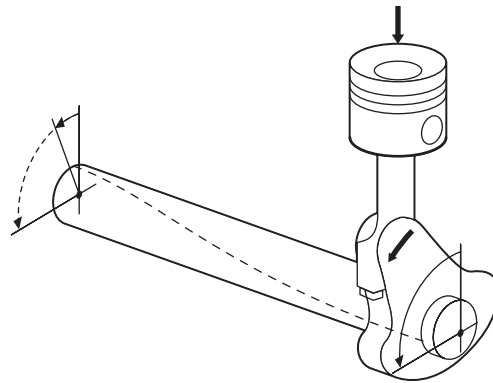


Figure 17. Torsional vibrations.

Even though generator sets, factory packaged on Caterpillar designed bases, avoid critical speeds where resonant conditions occur, all applications, whether packaged by Caterpillar or others, require a torsional vibration analysis. This assures compatibility of the engine and driven equipment. It must be performed by either the customer or by Caterpillar, depending on the customer's preference. Customer performed analyses are subject to Caterpillar review and approval and Caterpillar does not assume responsibility for analysis performed by others without the approval. Without the approval, no warranty can be claimed from Caterpillar. For Caterpillar-performed analyses, a complete set of technical data (see below) must be submitted to Caterpillar before calculations are undertaken. The report will include a mathematical determination of the natural frequency, critical speeds, relative amplitudes of angular displacement, and approximate nodal locations of the complete elastic system (both engine and driven equipment). See the TIR section of the price list for ordering information.

Note: Consult factory on compound installations. There may be additional charges for analyses of applications where more than one engine drives a single load. A separate torsional analysis is also required for each engine with different driven equipment in multiple engine installations.

Technical data required:

1. The operating speed range.
2. Load demand curve on generator sets which have a load dependent variable rigidity coupling.
3. General arrangement drawing or sketch of complete system, including data on equipment driven from front of engine.
4. With driven equipment on both ends of the engine, the power demand of each end is required. In addition, simultaneous front and rear power (maximum engine load) is required.
5. Make, model WR^2 (rotational inertia), and torsional rigidity on all couplings used between the engine and driven equipment.
6. WR^2 of each rotating mass. Weight of each reciprocating mass.
7. Torsional rigidity and minimum shaft diameter or detailed dimensions of all shafting in the driven system whether separately mounted or installed in a housing.
8. The ratio of the speed reducer or increaser. The WR^2 and rigidity submitted for a speed reducer or increaser should state whether or not they have been adjusted to engine speed.
9. For reciprocating compressor applications, a harmonic analysis of the compressor torque curve under various load conditions. If not available, a torque curve of the compressor under each load condition through one compressor cycle. The WR^2 of all available flywheels for the compressor.

Couplings

A coupling must be torsionally compatible with engine and driven load so that torsional vibration amplitudes are kept within acceptable limits. A mathematical study called a torsional vibration analysis should be done on any combination of engine-driveline-load for which successful experience doesn't already exist. A coupling with the wrong torsional stiffness can cause serious damage to engine or driven equipment.

All couplings have certain operating ranges of misalignment, and the manufacturers should be contacted for this information.

Some drives, such as U-joint couplings, have different operating angle limits for different speeds.

As a general rule, the angle should be the same on each end of the shaft (see Figure 18). The yokes must be properly aligned and sliding spline connections should move freely. If there is no angle at all, the bearings will brinell due to lack of movement.

Cyclic Irregularity

Cyclic irregularity is a nondimensional ratio describing degree of crankshaft twist occurring between two successive firings of cylinders during steady-state operation. Formulas to represent this movement were derived before modern instrumentation allowed measurement. The ratio is expressed as:

$$\text{Cyclic irregularity} = \frac{\text{rpm (maximum)} - \text{rpm (minimum)}}{\text{rpm (average)}}$$

System speed varies with connected rotating mass. Cyclic irregularity differs, therefore, for a basic engine, one driving a generator, or additional equipment.

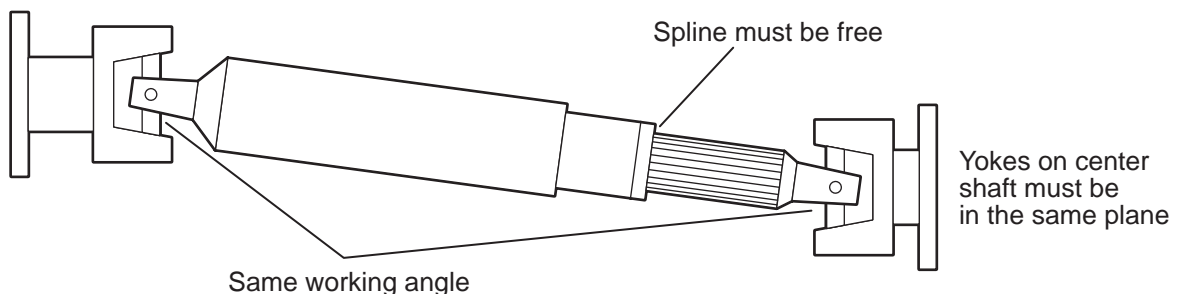


Figure 18. Universal joint shaft drive.

This ratio compares merits of large slow speed engines which were custom made, but has little value applied to modern medium speed engines.

Out-of-Balance Driven Equipment

The engine itself is designed and built to run very smoothly. Objectionable vibration generally arises from either poor driveline component match to the engine or unbalance of the driven equipment. Reciprocating equipment with large imbalances, for example, can cause premature failure of the mounting structure or undesirable vibration even though the unit is properly mounted and isolated from the engine.

Even though the engine and the driven load are in balance, it is also possible to encounter undesirable and damaging vibration as a result of the driving or connecting equipment having a misalignment or out-of-balance condition. Long shafts, drives, gear assemblies, clutches, or any type of coupling where misalignment, out-of-balance, or mass shifting may occur, are probable sources of vibration.

Alignment

An unsatisfactory engine mounting nearly always results in alignment problems between the engine and the driven machinery. Assuming that failure of the driven equipment does not occur first, the forces or loads transmitted to the engine in the form of pounding, twisting, flexing, or thrust could result in engine crankshaft and bearing failure. Costly failures of this nature can be avoided if, at the design and installation stage, the importance of proper alignment between the engine and driven load and adequate mounting to maintain alignment is considered.

If this is possible, a suitable flexible coupling must be incorporated into the drive train to compensate for misalignment.

Good alignment practices include proper shimming, correct torque on hold-down bolts, accurate dial indicator usage, allowances for bearing clearances, thermal growth, and accounting for other characteristics of the engine.

Procedures

Perform final alignment after all major equipment has been installed on the base. Engines should be filled with oil and water and ready to operate. The temperature of the engine and driven equipment must be equalized.

Complete step-by-step alignment procedures are described in Caterpillar Service Special Instructions, Form No. SEHS7073, *Alignment of Two-bearing Generators* or SEHS7654, *Alignment-General Instructions*.

Place driven equipment in its final position as closely as possible without taking indicator readings. There should be a minimum of 0.76 mm (0.031 in.) and a maximum of 1.5 mm (0.060 in.) of shims under each mounting surface of the driven equipment.

Position driven equipment, using the leveling and alignment screws.

For cold alignment, the generator is mounted higher than the engine to compensate for thermal growth, bearing clearances, and flywheel droop.

Torque Reaction

The tendency of the engine to twist in the opposite direction of shaft rotation and the tendency of the driven machine to turn in the direction of shaft rotation is torque reaction. It naturally increases with load and may cause a torque vibration. This type of vibration will not be noticeable at idle but will be felt with load. This usually is caused by a change in alignment due to insufficient base strength allowing excessive base deflection under torque reaction load. This has the effect of introducing a side to side centerline offset which disappears when the engine is idled (unloaded) or stopped.

Runout

Inaccurate flanges cause apparent misalignment and make accurate alignment impossible.

Face runout refers to the distance the hub face is out of perpendicular to the shaft centerline (see Figure 19).

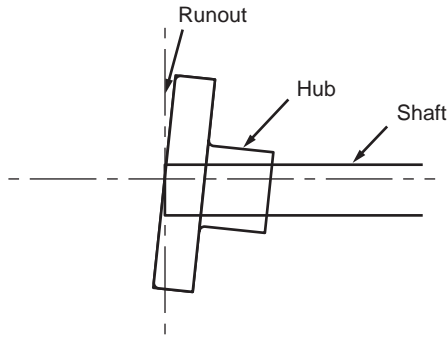


Figure 19. Face runout.

Bore runout refers to the distance the driving bore of a hub is out of parallel with the shaft centerline (see Figure 20).

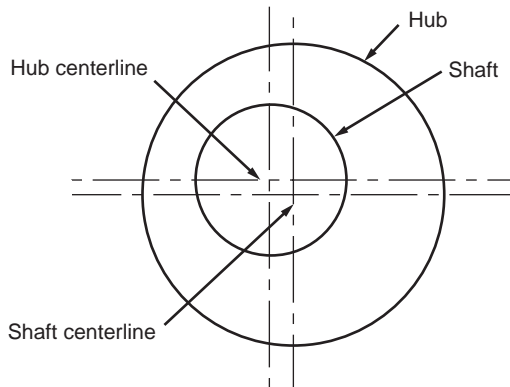


Figure 20. Bore runout.

The face and bore runouts of flywheel, clutch or coupling, driven members, and hubs must be checked when inconsistent alignment results occur. Face or bore errors must be corrected. Bore-to-pilot diameter runout error should not be more than 0.05 mm (0.002 in.) on the flywheel and 0.13 mm (0.005 in.) on adapters bolted to the flywheel. Flange face runout should not be more than 0.05 mm (0.002 in.).

Parallel/Angular Alignment

Parallel or bore misalignment occurs when centerlines of driven equipment and engine are parallel but not in the same plane (see Figure 21).

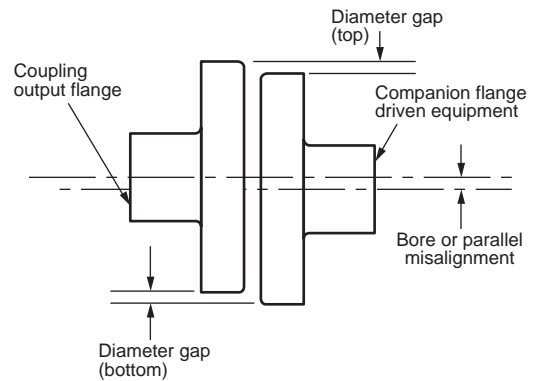


Figure 21. Parallel misalignment.

Angular or face misalignment occurs when centerlines of driven equipment and engines are not parallel (see Figure 22).

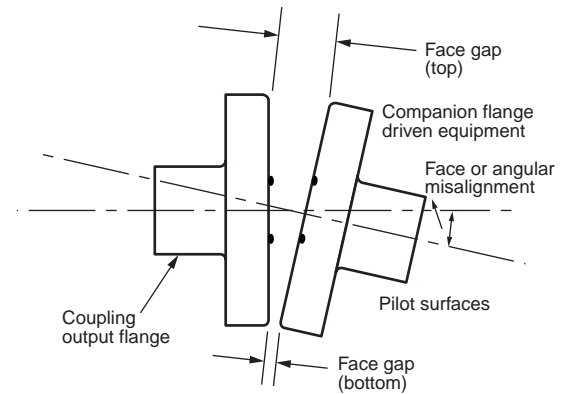


Figure 22. Angular misalignment.

Figure 23 illustrates that misalignment can occur in more than one plane. For this reason, alignment readings must be taken at 90 degree intervals as the units are rotated.

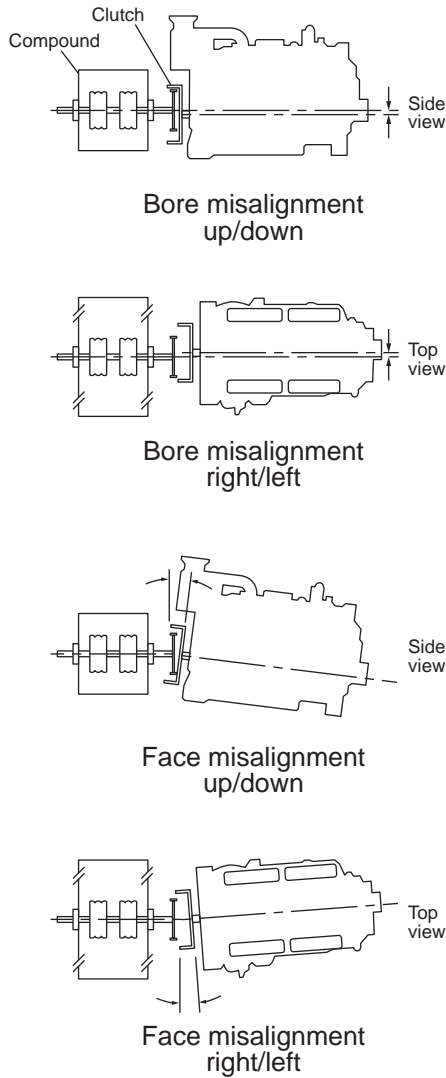


Figure 23. Misalignment.

Bearing Clearance

The generator rotor shaft and engine crankshaft rotate in the center of their respective bearings, so their centerlines should coincide. Alignment is made under static conditions while the crankshaft is in the bottom of its bearings. This is not its position during operation. Firing pressures, centrifugal forces, and engine oil pressure all tend to lift the crankshaft and cause the flywheel to orbit around its true center (see Figure 24).

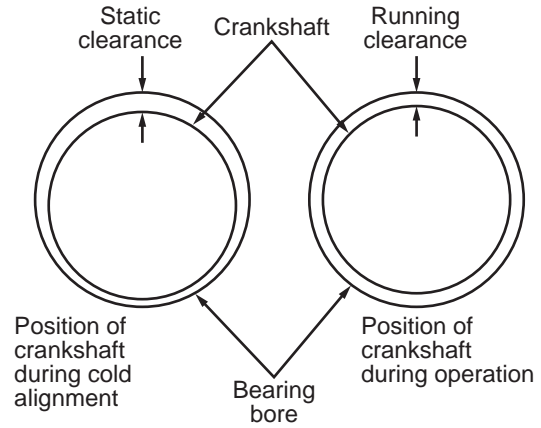


Figure 24. Bearing alignment.

Generally, driven equipment will have ball or roller bearings which do not change their rotational axis between static and running conditions.

Flywheel Sag

With the engine not running, the flywheel causes the crankshaft to bend. The weight of the coupling increases the bending. This results in the checking surface (pilot bore or outside flywheel diameter) rotating below centerline of the crankshaft bearings. For this reason, Caterpillar recommends alignment checks be performed with the coupling in place (see Figure 25).

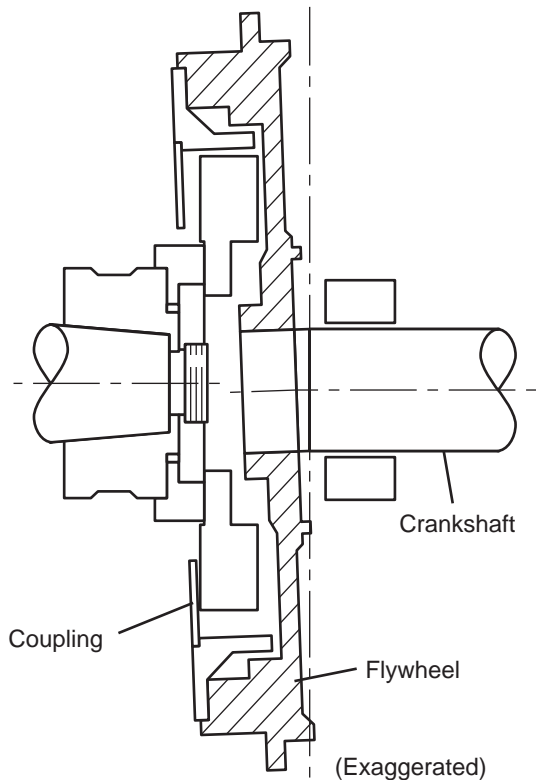


Figure 25. Crankshaft bending.

The values for the maximum crankshaft side loads for the specific engine can be found in TMI.

To calculate the actual load on the shaft, proposed multiple direction drive loads must be resolved into one single direction and load by vector addition.

Side Load:

$$P_{SL} (N) = \frac{kW \times 19099000}{rpm \times pd}$$

$$P_{SL} (lb) = \frac{hp \times 126000}{rpm \times pd}$$

Where:

P_{SL} = force of side load (N), (lb)

pd = pitch diameter of drive sprocket or main belt diameter

D = distance from front or rear side load center to index location (rear face of flywheel housing unless otherwise specified)

Note: The calculated side load must not exceed the side load limit found in the selected drive type data set for the distance (D) calculated.

Thermal Growth

The change in distance between mounting holes due to thermal growth of the engine must be considered when designing the base.

Cast iron has a coefficient of expansion of 0.0000055, and that of steel is 0.0000063. This means that the block of an engine 238.8 cm (94 in.) in length will grow 0.197 cm (0.0776 in.) if its temperature is increased from 10°C (50°F) to 98.8°C (200°F). Using 0.0000063 as the plate steel coefficient of expansion, a steel weldment of 238.8 cm (94 in.) will grow 0.226 cm (0.089 in.) through the same temperature range. The small difference in growth between the block and the lubricating oil pan is compensated for in the design of the engine by making the holes in the flange of the attached component (rails) larger than the attaching bolts.

Due to the growth resulting from thermal expansion, the engine must not be dowel located in more than one location. Failure to do this will cause unnecessary stresses in the engine and base as the engine tries to grow due to temperature changes. It is recommended that a dowel locator be used on one engine mounting rail located at the end with the driven equipment. This will force all thermal growth away from the engine coupling. Clearance between the mounting bolts and the mounting brackets on the base will then allow slip to compensate for thermal growth.

Shimming

Shims can be used to get correct alignment between the engine and the driven unit (see Figure 26). Depending on the application, shims are required under the engine, under the driven unit, or under both the engine and driven unit.

Shims should be of nonrushing material. The most commonly used shim materials are metal and poured resin shims.

Under no circumstances should lead be used as a shim material. Lead is easily deformed under weight and vibration and has poor support characteristics.

Handle shims carefully. Use only complete width and length shims. Do not use partial shims trimmed to fit. After alignment, each mounting surface must carry its portion of the load.

All mounting points must bear equally on the mounting structure. To determine if shims are required, set the engine on the mounting structure but do not attempt to secure it by bolting it in place. Using a feeler gauge, check all mounting points for clearance between the mounting point and the base. If clearance exists which exceeds 0.127 mm (0.005 in.) compensation must be provided.

If the mounting base is a rigid steel structure, the areas where the engine mounts make contact may be machined to bring them all into a true plane. If this is impractical, shims should be used.

Shim packs under all equipment should be 5 mm (0.2 in.) minimum thickness to permit later corrections requiring the removal of shims, if necessary.

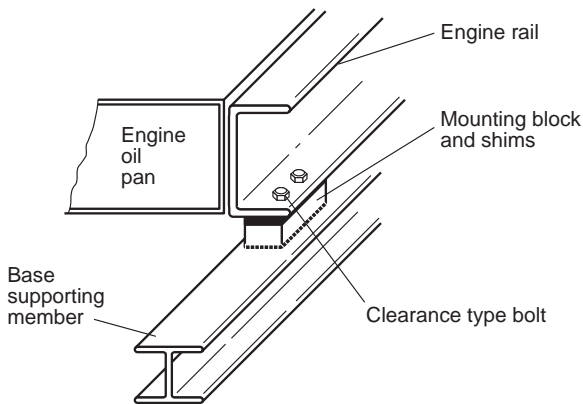


Figure 26. Mounting with shims.

Before the engine and driven equipment can be aligned, each foot must carry its portion of the load. Failure to do this can result not only in misalignment, but also in springing of the substructure causing resonant vibrations, high stress in welds or base metal, and high twisting forces in the engine or generator.

This same requirement for a true plane (flat) mounting is also necessary for most driven equipment. If specific instructions are not provided by the driven equipment manufacturer, the same principles as recommended for the engine can be applied.

Important: When metal shims are used between the mounting pads or feet and the base or mounting surface, the mounting surfaces must be flat, free of burrs, and parallel to the bottom surface of the mounting pads or feet.

Poured Resin Shims

After the engine and the driven equipment have been aligned, poured resin shim material can be used between the mounting pads of the engine mounting rails and the engine bed. When using poured resin shim material, always follow the manufacturer's installation recommendations.

Follow these guidelines:

- Use foam rubber strips of the appropriate thickness to form the dams for pouring the shim material.
- Do not pour shim material inboard of the machined pad on the bottom of the mounting rail.

Shim material can be poured the full length of the mounting rail (a continuous pour) or it can be poured only at the mounting pad locations (an interrupted pour). If an interrupted pour is used, the minimum area of shim material must be 29,000 mm² (45 in.²) per mounting bolt. If the mounting rails have mounting pads only at the bolt hole locations, foam rubber strips must be installed on both sides of each pad on all pads forward of the flywheel housing to provide for expansion. These expansion strips permit thermal expansion of the mounting rails at operating temperature. On engines whose mounting rails have full length mounting pads, no expansion strips are necessary.

Note: When realigning an existing installation, full length foam rubber strips for a continuous pour can often be difficult because of limited access. It is recommended that a full length continuous pour be used only for new installations where the engine can be raised to install the foam rubber strips.

Do not pour the shim material thicker or thinner than the manufacturer's recommendation. Use steel spacers if the clearance between the bottom of the mounting pad and the top of the engine bed is more than the maximum allowable thickness of the shim material. The spacers must be a minimum of 29,000 m³ (45 in.²) in area per mounting bolt.

Before pouring the shim material, install all anchor bolts finger tight. Put sealing material around the bolt at the bottom of the mounting pad to prevent the shim material from filling the bolt holes in the mounting rails. If shim material is allowed to enter the bolt holes in the mounting rails, thermal expansion of the rails will be prevented.

After the shim material has sufficiently hardened according to the manufacturer's specification, the anchor bolts can be tightened to a torque of 490 N•m (360 lb-ft). Use two nuts on each bolt.



www.cat-engines.com

© 2000 Caterpillar
All rights reserved.
Printed in U.S.A.

LEBX0045 (04-00)

Materials and specifications are subject to change without notice.

