individual pump and nozzle for each cylinder, commonly called a *unit injection,* or a multicylinder pump that maintains a high pressure in a common fuel line connected to each injection nozzle. The latter is normally called the *common rail system.*

ENGINE INSTALLATIONS

Foundation The correct foundation, mounting, vibration isolation, and alignment are most important to the success of any engine installation. All stationary engines require a foundation or mounting base. There are many variations, but all basically serve to isolate the engine from the surrounding structures and absorb or inhibit vibrations. Such a base also provides a permanent and accurate surface upon which the engine and usually the pump may be mounted.

To meet these requirements, the foundation must be suitable in size and mass, rest on an adequate bearing surface, provide an accurately finished mounting surface, and be equipped with the necessary anchor bolts.

The size and mass of the foundation will depend upon the dimensions and weight of the engine and the pump (if a common base is considered). The following minimum standards should be followed:

1. Width should exceed the equipment width and length by a minimum of 1 ft (0.3 m).
2. The depth should be sufficient to provide a weight equal to 1.3 to 1.5 times the weight of the equipment. This depth may be determined by the following formula:

In USCS units

$$H = \frac{(1.3 - 1.5)W}{L \times B \times 135}$$

In SI units

$$H = \frac{(1.3 - 1.5)W}{L \times B \times 2162}$$

where H = depth of foundation, ft (m)
W = weight (mass) of equipment, lb (kg)
L = length of foundation, ft (m)
B = width of foundation, ft (m)
135 = density of concrete, lb/ft^3 (2162 kg/m^3)

The soil-bearing load in pounds per square foot (kilograms per square meter) should not exceed the building standard codes. It may be calculated by the formula

$$\text{Bearing load} = \frac{(2.3 - 2.5)W}{B \times L}$$

Foundation or anchor bolts used to hold the equipment in place should be of SAE grade No. 5 bolt material or equivalent. The diameter, of course, is determined by the mounting holes of the equipment. The length should be equivalent to a minimum embedded length of 30 times the diameter plus the necessary length for either a J or an L hook. An additional 5 to 6 in (13 to 15 cm) should be provided above the top surface of the foundation for grout, sole plate, chocks, shims, equipment base washers, and nuts, plus small variations in the surface level. Around the bolts, it is a good practice to place a sleeve of iron pipe or plastic tubing to allow some bending of the bolts to conform with the mounting hole locations. This sleeve should be about two-thirds the length of the bolt, with its top slightly above the top surface of the foundation to prevent concrete from spilling into the sleeve.

Sole plates running the length of the equipment are recommended for mounting directly to the foundation. Made of at least $\frac{3}{4}$-in (19-mm) hot- or cold-rolled steel and a width equivalent to the base-foot mounting of the equipment, they will provide a level means of mounting and will avoid variations in the level of the concrete. These plates should be drilled for the mounting holes and drilled and tapped for leveling screws, which will permit the plates to be leveled and held during the pouring of grout.

Alignment Although the alignment will vary with the type of engine and the pumping equipment, the basic objective remains the same. The driven shaft should be concentric with the driver shaft, and the centerlines of the two shafts should be parallel to each other. Rough alignment should be made through the use of chocks and shims. A dial indicator should be used to check deflection by loosening or tightening the anchor bolt nuts until there is less than a 0.005-in (0.13 mm) reading at each bolt. Shims should be added or removed to arrive at this point. A final check should be made with all the conditions “hot,” as the engine and its driven equipment expand at the rate of 0.000006 in/°F (0.27 μm/°C) above ambient hot to cold. Although the coupling, or driving member between the engine and the pump is not discussed in this section, it must be considered in the final alignment.

Vibration Isolation It is desirable to isolate the engine, and at times the pumping equipment, from the building structure because of vibrations. Cork (Figure 13) is used in the larger and heavier installations. A combination of cork and rubber pads may be used at each mounting hole on small- or medium-size installations, and spring isolators may be used on a complete installation if flexible hoses are used for fuel, water, and air connections where required. The manufacturer of the engine and the pumping equipment should be consulted in the use of any isolating material or device.

Vibrations are closely associated with the driving and driven equipment, couplings, and other connections. These linear vibrations may be caused by improper supports of the unbalanced parts, which produce a *torsional* vibration. An understanding of this vibration is important because its elimination is the responsibility of the engine and the driven-equipment manufacturer. It is complex and cannot be detected without the use of calculations and special instruments.

The basic concept involves an elastic element, such as an engine crankshaft, which tends to twist when any firing impulses are applied. When these forces are removed, the elastic body will try to return to its original position. The driven mass and the connecting elements tend to resist these external impulses. The natural elasticity of the crankshaft and its connecting system allows a small amount of torsional deflection and tends to

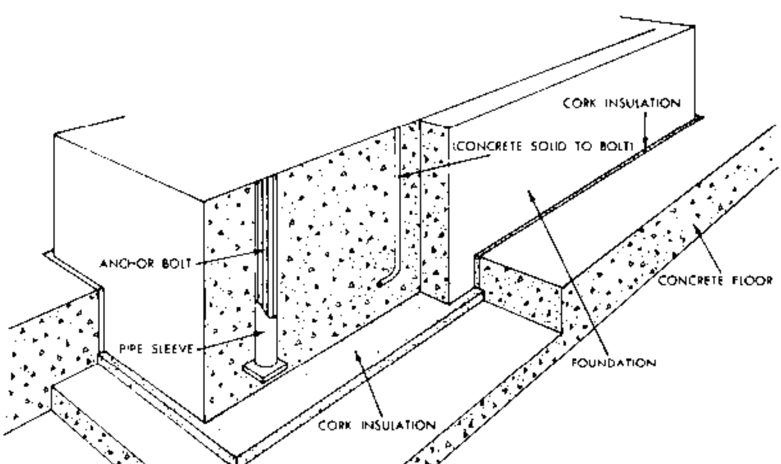

FIGURE 13 Engine foundation installation (Waukesha Motor)

reduce the deflection as the external impulses reduce in force. Other reciprocating forces in the engine and external forces in the driven equipment may excite vibrations in the entire system. When all these forces come into resonance with the natural frequency of the entire system, torsional vibration will occur. This vibration may or may not be serious but, being complex, cannot be solved hastily.

The engine and pump manufacturer designs and constructs the product so critical harmonic vibrations will not be present under normal speeds and loads. However, there is no way to control the combination. An analysis of the complete system should be made. This requires a study of the mass elastic system of the combination, involving the mass weight and radius of gyration of all rotating parts. This study should be made either by the engine or pump manufacturer or by a torsional-analysis specialist.

FURTHER READING

Gunther, F. J. "Gas Engine Power for Water and Wastewater Facilities." *Water & Sewerage Works,* **112** and **113** (November 1965 to July 1966).