For several years, strict attention has been paid to good grouting materials and installation techniques, particularly with the development of epoxy grouts. In more recent years, the vital role of anchor bolts is recognized as being just as important as the grout under the machine. An analysis of the part that each play points out that they really are equal partners.

It is the function of a good machinery grout to provide a strong, stable bed for the machine base or sub-base, such as a sole plate and chock. The base should remain at a precise elevation within 0.001 in. (0.025 mm) over the life of the machine. The grout prevents any downward elevation changes. The anchor bolt prevents the machine base from moving upward. Upward deflections are just as harmful as downward deflections, so the anchor bolt and its proper maintenance (as will be discussed later) are every bit as important as the grout.

WHAT CONSTITUTES A GOOD ANCHOR BOLT

Fortunately, there are excellent ASTM specifications that detail various strength bolting systems, which comprise the bolt or stud, the nuts, and the washers. This makes it easier to know that you are getting an anchor bolt system that will provide the design load capability.

We will discuss later how the actual design load is calculated. Knowing what that load is will allow you to choose a bolting system made from 60,000 psi (4137 bar) steel, as specified in ASTM A307, or a higher strength steel (such as Grade B7) of 105,000 psi (7239 bar) yield strength, as called for under ASTM A193. Since the size of the hole in the equipment through which the anchor bolt must fit has usually been decided by others, choosing a bolting material of a higher strength specification is often the only way a proper design load or hold-down capacity can be achieved. When upgrading old anchor bolts, which is discussed at the end of this article, the use of a replacement bolt of higher tensile strength allows for the correction of an inadequate hold-down system.

Because of the importance of the anchor bolt and the damage it can cause if it breaks, choosing a bolt from a vendor who manufactures to ASTM specifications is extremely important, and one who is willing to supply certified material test reports (MTR). Be sure the nuts and washers are also made to the appropriate ASTM specifications.

While the strength of the steel itself is important, there are several other things that also must be taken into account. These items, which we will call “enhancements,” can improve the bolt’s performance dramatically.

For instance, it is a well-known fact that a sharp notch in a steel member causes a stress concentration point that will fail first under heavy loading. Since cut threads are nothing but a series of sharp notches, the use of rolled threads has been found to reduce failure in the threaded portion of a bolt or stud, which is where they almost always fail. Be sure to specify for rolled threads, which is one reason a bolting system made to A193 specifications can take greater loads.

A further enhancement to augment the use of rolled threads is to have the threaded portion, as well as the shank, shot-peened to an appropriate specification, such as Mil Spec. No. S-13165-C. This reduces any stress on the surface of the steel from machining or rolling and is an extra factor of safety. Almost all critical fasteners used by the US military and the US space program are shot-peened to get the highest strength and performance possible. Shot peening can also reveal a poorly formed thread!

An off-center load occurs when an anchor bolt is not perfectly straight, or becomes slightly off-center when a long engine or compressor grows thermally. This causes the nut to apply an unequal load to one side of the bolt or stud. Self-aligning steel washers, consisting of matching concave-convex surfaces that are made of steel (Figure 1) and matching the hardness of ASTM F436 (if used with an ASTM A193 specifications bolt), allow the off-center line load to be corrected; an inexpensive solution to a vexing problem.

Now we come to an enhancement that embodies a concept often very hard to understand. This is the frangible section or a section that has been machined to a lesser diameter than the original bolt diameter (Figure 2). While not always applicable, there are times when a frangible section will enhance the performance of a bolt. Perhaps the following example will put this in better perspective.

If a 1.5-in. (38.1-mm)-diameter bolt is being used where
the clamping force it exerts is only 20,000 lbs. (9072 kg) and
the bolt is made of high-strength steel conforming to ASTM
A193, Grade B7, the anchor bolt would only be loaded to
13% of its total load capacity. A 1-in. (25.4-mm) bolt, made
to the same specification and loaded to 20,000 lbs. would be
loaded to 31% of its capacity.

It is a quirk of bolting that the more lightly loaded 1.5-
in. bolt is more likely to break than the 1-in. bolt.5 Bolts
need to be loaded to at least 50% of their capacity to get
enough stretch to keep the nut from backing off. Because
of equipment limitations, if for some reason a higher load,
say of 50,000 lbs. (22,680 kg) clamping force, can’t be used,
then a reduced cross section or frangible section is one way
of compensating for this. It seems strange to remove good
steel, but there are times when it makes good sense.

PRELOAD

Preload, as its name implies, is the load that is put into a
bolt as it stretches while being tightened. The preload plus
the static weight of the equipment add up to give the total
clamping force at each anchor bolt. The clamping force has
to be high enough so that the downward holding force al-
ways exceeds any upward force the machine creates. It also
must clamp with enough force so that the friction resistance
to a horizontal load will prevent sideways movement. The
higher the clamping force, the greater the resistance to lat-
eral movement.

The old rule of thumb was that the total clamping force
should equal four times the equipment weight. Dividing by
the number of anchor bolts gives the clamping force each
bolt must exert, and from that, the preload can be calculated
easily by simply subtracting the proportion of the equip-
ment weight. This is too inaccurate for today’s low-speed or
high-speed compressors, so guidance from the compressor
original equipment manufacturer (OEM), or field experience,
should be used.

While calculations and experience are important in decid-
ing the proper preload, the preload at each anchor bolt should
also be used to size epoxy chocks, which are typically limited
to a load of 400 or 500 psi (28 to 34 bar), and steel or ma-
chined solid composite chocks that are designed to 1000 or
1200 psi (69 to 83 bar) load. With studies in the machine tool
field indicating that chock loading of up to 2000 psi (138 bar)
is a better conductor of shaking forces from the machine into
the concrete foundations, quite possibly the gas compressor
industry also will go to higher bolt preloads.

The design preload, often overlooked in the past, is a very
important consideration. A corollary to this is that knowing
the preload in the field is also very important. It is important
to have gas in a car but also important to know how much.

In the distant past, when a new compressor or engine was
installed, the anchor bolts were simply tightened, often with
a box wrench and sledge hammer. While the bolt was “tight,”
how tight was not known. As pointed out, less tightness can
be worse than too much tightening, up to a point.

Later, it became field practice to use a torque wrench,
which does give an approximation, maybe ±20% of what the
tensile load actually is, if a good conversion chart is used.5
This is still a big improvement and is the most popular meth-
od of measuring the tightness of a bolt today because of its
low cost.

Because a torque wrench is not the most accurate way of
measuring the actual tension load, other methods are used as well, but certainly not to the extent of torque wrenches. Other methods are:

- ultrasonic
- load washers (strain gauges)
- crushable washers pre-calibrated for a set load
- measuring the change in length of the bolt as it is stretched by tightening
- turn of nut method
- patented load monitor called “RotaBolt” (Figure 3).

The latter is probably the most economical, practical method of the several alternatives to a torque wrench, since any loss of tension can be detected by trying to turn the RotaBolt cap by hand. However, no matter what method is used, checking the tightness of the anchor bolts for loss of preload in conjunction with crankweb deflection checks should be a part of regular maintenance.

This brings up a question as to why bolts lose at least part of their preload after their initial tightening. One reason is that the entire anchor bolt system, from where it is anchored 4 to 5 in. (102 to 127 mm) below in the concrete block up through any mating surfaces such as sole plates, chocks, engine frame, and even the threads on the nuts, tends to relax slightly as the surfaces “seat” with each other. Also, there may be some creep or deflection from the epoxy grout and epoxy chocks if used. All of these factors can add up to cause a measurable loss of preload.

A good practice is to re-torque in conjunction with running a hot crankweb after the first seven days of running, and then again at 21 days. If a crankweb deflection check is not being done at the same time, a dial indicator should be used to measure any abnormal frame movement at each bolt as it is tightened. If there is a weak link in the support system, (for example, a poor-quality grout), then the downward deflection of the frame could affect the crankweb alignment.

Any pull down beyond 0.004 in. (0.102 mm) should be treated with suspicion, calling for a more detailed alignment check. Certain machines may not tolerate even that much elevation change. Maintaining the preload of the anchor bolt system is an important matter. Simply adding a locknut or double nut after the initial tightening will lead to a false sense of security.

**FREE LENGTH**

It is evident that as a bolt is tightened, it stretches. In fact, the stretch is directly proportional to the load, as expressed by the modulus of elasticity. To allow for the bolt to stretch, it has become the practice in recent years to put a sleeve around the top portion of the bolt. The sleeve prevents the grout and concrete from bonding to the anchor bolt. Usually the depth of the sleeve is a minimum of 10 to 12 times the bolt diameter, but many engineers are specifying full-length stretch, using a unique anchor bolt concept call a “Canister Anchor Bolt,” as illustrated in Figure 4.

**ANCHOR BOLTS CAN BE POST-TENSIONERS**

As the use of full-length, long canister anchor bolts has become a “best practice,” this has led to an innovation in new gas compressor concrete foundation design. The concept consists of moving the load transfer point either lower in the gas compressor foundation pedestal or into a lower underlying concrete mat or pile cap. The value in post-tensioning the concrete foundation, including the interface between the block and the mat, has been recognized by civil engineers as beneficial in reducing concrete cracking from compressor shaking forces.

Keeping cyclic tensile forces from fatiguing the concrete is just now being recognized for its importance, and post-tensioning the foundation can help in this regard. Additionally, extending the anchor bolts into the mat will help prevent movement at the foundation mat interface when there is a large overturning movement from the action of the machine. A third advantage is that an anchor bolt terminating in the mat is more likely to remain truly vertical when concrete for the block is poured, even if the rebar cage shifts during placement. The minimal extra cost for long anchor bolts is money well spent.

**UPGRADING ANCHOR BOLTS**

More often, anchor bolts break from too little tightening rather than too much. There are times, though, when the original design clamping force needs to be increased. The original anchor bolts, such as those made of merchant-grade steel, may not have enough tensile load carrying capacity. These bolts can usually be upgraded in much the same way as anchor bolts are repaired, by using a high-strength, 4140, heat-treated coupling nut and new high-strength alloy steel top bolt (ASTM A194, Grade B7). However, since the new top section is stronger than the old steel, additional anchor-
Figure 4. View Of A Proprietary Canister Anchor Bolt Showing Full Stretch Length And Variable Projection

The repair method is easier to make than trying to dig out and replace the entire anchor bolt, particularly on bolts in the center of a large block. The new top section should be long enough to have proper free length, and with the bottom anchored properly, its full load capacity can now be used.

Anchor bolts are indeed a complex item with a very simple purpose.

ABOUT THE AUTHOR

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REFERENCES