# Getting the most from your machines and foundations

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Process plants around the world depend on millions of rotating machines:

- compressors
- pumps
- blowers
- fans
- presses
- generators
- mills
- mixers

and so on through a long list. The maintenance department is generally pretty busy keeping these machines together; repairing them, and making sure they are available for production.

The diagnostics of machine problems have been steadily improving since the electronics revolution, and catastrophic failures are getting fewer every year. Yet there is still a gap between the sophisticated diagnosis of vibration and alignment issues, and the understanding of how best to solve intractable and recurrent problems.

It has been stated frequently that a large percentage of the installed base of rotating machinery is operating in a less-than-optimal alignment condition. This percentage could be as high as 70% of all operating machinery. Mis-alignment causes excessive vibration, increased power consumption, reduced output, and wear and tear on components. But the major cause of mis-alignment - ***grout failure*** - is very rarely diagnosed. During the last 35 years or so our group of companies has regrouted and repaired the foundations for thousands of rotating machines in all types of industrial plant. Invariably, alignment is a found to be miles out, and the grout severely degraded. Using the techniques developed and refined in various Alphatec operations around the world, we are able to restore a machine to a condition which is close to original, or even better in cases where "original" was actually sub-standard.

Our work is based on a series of premises:

- The concrete foundation is the main vibration absorbing element of the installation,

provided that it is of sufficient mass; that it is one integral whole; and that it is properly connected to the machine.

- Sufficient mass can be calculated from the traditional rule-of-thumb (6 times the weight of the machinery in the case of reciprocating equipment, or 3 times for general rotating machinery), or using a power based criterion. Our records suggest that 100 kg of concrete per kW of power input (in the case of a driver) or output is normally adequate to damp the vibrations of a reciprocating machine, and that 30 kg/kW will do the job for most other machines.
- The primary cause of a foundation's inability to attenuate vibrations is the cold joint. These occur when the concrete is poured in several lifts, and cannot be avoided by chipping the surface, water-blasting, or any of the usually mandated construction techniques. Use of an epoxy bonding agent is the only way to obtain full adhesion between pours, and its use is rare. Most foundations therefore have this inherent problem.
- The best way to ensure that the foundation is correctly connected to the machine is to use epoxy grout, and good anchoring techniques.
- The anchor bolts are designed to hold the machine down, and the grout is designed to hold it up. The grout must therefore have sufficient resistance to the anchor bolt's fastening force, which is inevitably much greater than the deadweight load of the machine itself.
- The shaft alignment must be as close to "zero-zero" as possible when the machine is operating in its normal condition, not when it is stopped for repairs, adjustment, etc. The question of offsets, both thermal and mechanical, must therefore be addressed before pouring the grout.
- In order to ensure the best possible connection between machine and foundation, full-contact grouting is always advised. The base of the machine should be encapsulated in the grout, to ensure good contact on the underside, as well as a measure of lateral and longitudinal restraint. Many clients prefer soleplate grouting, which is a second-best approach, and stems mainly from the many small failures which are built into a majority of installations, and the necessity to make subsequent modifications and adjustments. If the job is professionally done, these adjustments become unnecessary.

Below specific case histories may help to illustrate the above points.

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# WORK REPORT
# FOUNDATION REPAIR COMPRESSOR & MOTOR REGROUT

*Project: J-602-A gas compressor foundation repair, compressor regrout, and electric motor grout baseplate regrout.*

## 1. ORIGINAL CONDITIONS

The machine in question is a Worthington Type BDC 1-1, gas compressor in Process Unit 6, powered by a direct coupled Siemens electric motor of 410 kW at 422 rpm.
An inspection of the compressor was carried out on 14 June 2007 by Alphatec and customer engineers, to evaluate the existing problems, and discuss outline repair methods.

The compressor was manufactured and installed in 1967, and was grouted in place with a cementitious grout material. The machine had been shut down because of high vibrations, so it was not possible to see how the degree of movement of the crankcase within the grout. The grout was seen to be thoroughly oilsoaked,and several cracks and separations were visible. The grout must be replaced by a modern epoxybased grout product, correctly mixed and installed by a competent and experienced contractor.
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The motor baseplates were very poorly supported by the surrounding grout, with evidence of voids over large areas. The possibility of corrosion of the baseplate was also considered, which can often be caused by induced currents within the concrete and the cement-based grout material. For these reasons, a regrout using epoxy grout was recommended.

The secondary supports, under the intermediate bearing, the crossheads, and the cylinder heads, were all seen to be in bad condition due to oil contamination, and a regrout was recommended.

Many of the piping supports were also in bad condition, and a regrout of those closest to the compressor was recommended.

From the foundation drawings, it was calculated that the above-ground plinths had a combined volume of around 22m3, giving an estimated mass of 54 tonnes. Based on the foundation-mass-to-power rule of 100 kg/kW, this should be enough to damp out the vibrations. However, another rule suggests 6 times the weight of the compressor train, and it is unlikely that this requirement is met. Injection through the foundation and into the underlying mat was therefore recommended, with an exploratory core hole drilled before the main drilling to establish the depth of this mat.

There was some discussion about the connection between the compressor anchor bolts and the concrete foundation, and a secondary injection to deal with this problem was planned.
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## 2. REPAIR WORK CARRIED OUT

Because of the poor state of the foundation, a decision was made to carry out the recommended work immediately, and the Alphatec team mobilized in record time. Materials and equipment were delivered to site on Monday 18 June, and work started the same afternoon.

There are 4 main components of the repair work effected: injection repair of the foundation; grout removal and support of the machine; alignment of all components; and forming and regrouting of all machine bases.

## 2.1 Injection Repair:

A preliminary core was drilled from ground level to determine the depth of the underground mat. Including the final floor thickness, there was 900 mm of concrete to be added to the foundation's mass.
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Several deep holes were drilled from the foundation top through the main block, and into the pile cap. These holes were drilled with a diamond core drill, with a 60 mm ø bit, and with a rotation-percussion rock drill.
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Once the holes had been flushed clean, high-strength reinforcing steel bars (DYWIDAG rods) were inserted into these holes with copper tubing attached. The top of the hole was then sealed for pressure resistance of up to 300 bar. ALPHATEC® 300 injection grout was pumped into the holes until flow out was observed from the vent tube. The vent was crimped shut, and pressure applied to the hole to push the resin into all separations, cold joints, fissures, stress cracks, shrinkage cracks, honeycombs, and any other void or imperfection intersected by the hole. Evidence of coverage was seen at various places around the foundation, and the pressure was maintained on each hole until the site supervisor was satisfied that optimal coverage had been achieved. The injected resin cured in approximately 24 hours, and the protruding tubes were cut off. The repaired foundation will show much greater resistance to movement, and its ability to damp out vibrations will be greatly enhanced by this repair.
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Additional injection work was done on the crankcase and frame extension anchor bolts, after the main chipping work was complete. No evidence of loose bolts was found.
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Two of the suspect pipe support plinths were repaired by pressure injection, since the baseplates appeared to be relatively well grouted. The plinths, however, were not properly fastened to the underlying concrete mat, and the injection work has solved this problem.
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## 2.2 Grout Removal:

The existing grout and underlying damaged concrete was removed by pneumatic chippers to a depth of approximately 150 mm beneath the motor baseplates. Work on the compressor was delayed due to problems removing piping and wiring.

As this picture shows, the method of installing the baseplates left a lot to be desired, with multiple shims, and gaps between baseplate and grout.
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The grout was removed in sections, with at least 50% of the original grout being left in place while the initial supports were put in place. The baseplate was supported by the ALPHAPAD® system, consisting of specially designed hydraulic jacks, with a ball joint incorporated to ensure parallel support on the underside of the machine flange.
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These jacks were placed on epoxy grout pads to ensure proper stress distribution into the concrete. Corrosion of the baseplate was found to be negligible.

The remaining grout was then chipped out.
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The bearing pedestal grout was then chipped out, and the sleeves around the anchor bolts cut away.
Note the steel packers driven into the sleeves to push the anchor bolts into the correct position. This became something of a pattern, since all anchor bolts on this machine appear to have been "persuaded" into their final positions.  Photo 13  Work on the crankcase and frame extensions eventually started on 21 June, and progressed rapidly. Approximately 200 mm of grout and oil-soaked concrete was removed under the crankcase and frame extensions, as can be seen in the picture below.
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Grout removal around the pipe supports resulted in the complete demolition of the plinth in

some cases, since there was no bond at all to the floor level concrete.
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## 2.3 Alignment:

After the grout had been completely removed the crankcase was aligned. This work was carried out together with the mechanical contractor, and a reasonably good alignment was achieved, considering the age of the machine.
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Crankcase and frame extension grout was poured after alignment. The bearing pedestal was next aligned to the compressor and grouted, and finally the motor was adjusted using the ALPHAPAD and OPTALIGN systems to realise a good driveshaft alignment.

## 2.4 Grout Replacement:

Formwork was prepared and set in place to contain the grout pour. ALPHATEC 800 epoxy grout was mixed and poured to properly encapsulate the machine bases. Forms were removed the following day, and anchor bolts finally tightened after transferring the load from ALPHAPAD to grout by cutting off the protruding steel tubes.
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Additional epoxy grout was poured in the areas between the machine base supports to provide an oil impervious surface.
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Anchor bolts were tightened according to the following schedule:

- M42 bolts (motor baseplates) 1600 Nm
- M30 bolts (crankcase & frame extensions 630 Nm
- M24 bolts (crosshead supports, etc) 320 Nm
- M18 bolts (bearing pedestal, etc) 130 Nm

These figures are based on the assumption that the bolt material has a tensile yield strength of 300 N/mm2, and that the bolt tension should be approximately 50% of this figure. The motor bolts should be tightened to 1740 Nm according to this calculation, but 1600 Nm was the maximum achievable with the equipment to hand, and is considered to be satisfactory.

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