THE ROAD TO RELIABLE PUMPS

by

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Prior to joining Exxon, he spent 18 months in East Kalimantan, Indonesia (Borneo), with Roy M. Huffington, Incorporated, at the P. T. Badak LNG Plant as the Assistant Maintenance Manager and Logistics Manager.

Mr. Monroe has written numerous papers on turbomachinery subjects, pump installation, and grouting, and has contributed to books on the subjects of pump installation/commissioning and electric motors.

Mr. Monroe graduated from Auburn University (1966) with a B.S. degree (Mechanical Engineering) and has worked since then in turbomachinery repair techniques, optical and mechanical alignment, vibration analysis and field balancing, nondestructive testing, mechanical seals, and corrosion. Prior to graduation, he worked as a designer of rocket engine components for NASA at Redstone Arsenal in Huntsville, Alabama.

INTRODUCTION

In today's market place, the company that can manufacture a product at the lowest price and maintain or improve the quality, will be the company that survives. The goal should be "How do we make it better for the same price or slight price increase?" not, "how do we make it cheaper?" Those individuals who do maintenance work in plants have to ask, "How can we reduce the cost of our product?" It does not take a rocket scientist to arrive at the conclusion that approximately 80 percent of the maintenance budget is spent on pumps. If the pump life in plants can be improved, then every dollar saved is one dollar pure profit. Like any investment, you do not get something for nothing. In order to improve pump life, there must be up front investment in qualified manpower, properly selected equipment, and properly installed equipment. Any savings obtained by up front cost cutting is offset by the first three years of maintenance costs, which are three to five times the savings. If you doubt that, the author challenges you to make the project team responsible for the first three years of maintenance costs. Let him know if you observe a different attitude toward machinery.

Ways to improve pump life and suggestions that readers develop a Pump Reliability Checklist are presented. It is not the intent herein to cover all subjects in detail, but to make the reader aware of the areas that could cause trouble.

THE PLAN

When first asked to develop this topic, the goal was to get back to the basics. That automatically produced the following subjects that should be covered.

- Pump baseplate installation and grouting
- Mechanical shaft alignment
- Piping installation

Most of the time, maintenance gets involved when there is a pump failure, after the pump has been installed, grouted, aligned, and the piping installed. Pump problems are inherited by those who had no say-so during construction and who are asked to correct on maintenance dollars. If they are to reduce costs by improving pump life, then they need to be involved on the front end. This means assigning experienced machinery/maintenance personnel to the project to participate in the selection of pumps. If an inadequate pump is selected and installed, there will be poor performance and short life. This condition suggests that they, as maintenance people, may be missing a major step in solving pump problems. They assume that the pumps they have are the correct selection for the application and just change out parts. *That's normal pump life.*

It became apparent to the author while reviewing past pump problems, that a large number of the pump problems he had solved were caused by having the wrong pump in the right place. The solutions were slow because the wrong methods were applied, trial and error. A better method was revealed while brain storming with a colleague who is an experienced machinery engineer with outstanding computer skills. Dwight Studdard demonstrated the ease at which a pump could be checked for hydraulic and mechanical fit (including bearings and mechanical seals selection) using computer programs. These pump programs are available commercially, or some pump companies offer inhouse checking services. The third option is to develop your own computer program that calculates the hydraulic, mechanical, bearing, and mechanical seal requirements. This is what Dwight Studdard did. Some programs just look at the hydraulic requirements only, but the data generated are used to size shafts and bearings with expected running life. If the program shows a life of 99 years, any bearing lubrication method or lube oil can be used. If the expected life is six months, then special lubrication methods like oilmist or higher viscosity oil should be specified. Mr. Studdard listed the following advantages for using computer programs to review and select pumps.

- Quick analysis of pump applications with printed specifications in 10 minutes.
- Improved supplier communications. The analysis has already determined the size, configuration, and if the pump should be ANSI or API.

- Improved communication on projects. The analysis helps project engineers, operations, and the machinery engineer to determine the pump required without several iterations.

- Problem pumps can be identified early while system changes are possible.

- Standardization is improved. A 25 percent reduction in types, sizes, or material is possible.

The point is that old problem pumps should receive a computer aided analysis to verify that design parameters such as specific speed (N_s), suction specific speed (N_{ss}), net positive suction head required ($NPSH_R$), minimum flow for stability, etc., are correct for the pumping application. A good reference book to aid in developing the pump requirements for a computer review program is *Centrifugal Pumps: Design and Application* by Lobanoff and Ross. Repeated pump failures for unexplained reasons can be caused by poor hydraulic fits. The computer has reduced the laborious mathematical number crunching to a fill in the blank operation. So, the back to basics checklist should be modified to the following format and priority.

1. Review new or existing pump applications with computer aided programs for hydraulic, mechanical, bearing, and mechanical seal requirements.
2. Pump baseplate installation and grouting
3. Mechanical shaft alignment
4. Piping installation

Point 1 will not be covered here, because it will be explained in detail in a later paper.

PUMP BASEPLATE INSTALLATION AND GROUTING

Pump baseplates are designed to be grouted. The load on a baseplate is close to the center and not at the edges where the anchor bolts are located. If the top of the baseplate is not supported, any excitation force will cause it to ring like a bell. Small forces will cause large vibration levels in the pump and driver. *If a nongrouted baseplate is to be used, do a design audit.* Make sure the baseplate is rigid enough to take the loads and dampen the system vibration. Stilt mounted pumps are being used to solve poor piping designs, but the price is high because of premature bearing and mechanical seal failures. If a nongrouted baseplate has vibration levels from 0.3 ips to 0.5 ips, there will be premature failures. Stilt mounted pumps can run below 0.2 ips if the sizes are below 40 hp. Some pumps are mounted on Teflon so they can slide to adjust for piping movement, but they generally move one time and lockup. *There is no substitute for good piping design.*

The goal of this procedure is to present a proven method of installing a pump baseplate using epoxy grout with zero voids. While this method is not the only way to achieve a 100 percent void free grout job, it has been designed to shorten the pump installation and alignment time by the use of a one pour grout procedure.

The question has been asked, "Why should a $95 to $110 per cubic foot epoxy grout be used in place of a $40 per cubic foot cementitious grout?" There are three reasons to pay the additional one time cost. Epoxy grout applied to a properly prepared baseplate bonds with a 2000 psi tensile strength that transforms the baseplate into a monolith with the concrete foundation. This formation of a single block lowers the natural frequency of the pump baseplate that reduces pump shaft vibration caused by resonance.

The second reason to use epoxy grout is that it attenuates vibration 30 times better than steel and eight times better than concrete. Observation of pumps that had been installed with the new grouting procedure revealed longer mean time between failure (MTBF) over existing pumps. Older pumps had vibration levels from 0.3 to 0.5 in/sec (IPS) as compared to less than 0.15 IPS for the new pumps.

The third reason for the use of epoxy grout is that it seals the concrete foundation to prevent damage from moisture and oil. There is little bonding (500 psi) when cementitious grout is used, so there is a possibility of moisture or oil getting between the underside of the baseplate and foundation.

BASEPLATE LEVELING PROCEDURES

It is necessary to discuss the baseplate leveling procedure first in order to fully understand certain baseplate and foundation preparations. These preparations must be performed before the placement of the baseplate on the foundation.

The following assumptions are made concerning the pump foundation:

- The foundation should rest on solid or stabilized earth completely independent of other foundations, pads, walls, or operating platforms. A minimum of 3000 psi steel reinforced concrete should be used.

- The foundation should be adequately designed to support the pump. Foundation mass for centrifugal pumps should be at least three times the mass of the pump, driver and baseplate. Reciprocating pump foundation mass should be at least five times the pump system mass.

- The foundation should be designed to avoid resonant vibration conditions originating from normal excitation forces at operating speed or multiples of the rotating speed.

- The pump, gearbox (if used), and driver rest on a common foundation.

- The foundation is designed for uniform temperatures to reduce distortion and misalignment (boiler feedwater pump applications).

Do not take these assumptions for granted. Check the foundation at the design stage, not after it has been poured. There are some good computer programs available for foundation designs.

There are four popular methods used to support the pump baseplate while the grout is poured and cured. The use is illustrated in Figure 1 of single, double or parallel wedges, jack screw, and shim pack with chock to level the pump baseplate. A single wedge supports the pump baseplate with a line contact which could shift the level during the grouting process. Using parallel wedges

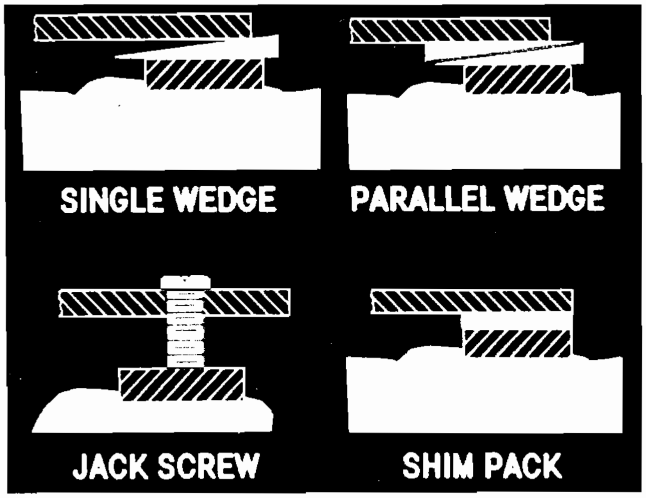


Figure 1. The Four Most Common Methods Used to Level Pump Baseplates Are a Single, Double, or Parallel Wedges, Jack Screws and Shim Pack with Chock.

provides a surface contact, which is an improvement over the single wedge, but the use of wedges, complicates the grout form design. Provisions must be made to pull the wedges and fill the voids made by the wedges. The reversed jack screw shown in Figure 1 is used by a major European manufacturer to support reciprocating compressors during grouting and remains in the grout. Method four, the shim pack with chock, is used by many U.S. manufacturers to support large, heavy rotating equipment (Figure 2).

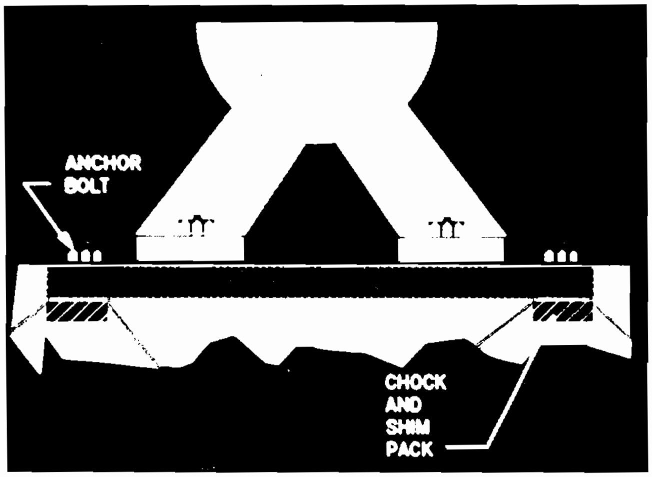


Figure 2. The Shim Pack with Chock Place is Used by Many U.S. Manufactures to Support Large, Heavy Rotating Equipment Prior to Grouting.

The major complaint about using the above mentioned methods to level/support the pump baseplate is that if left in the grout, the sharp corners of the wedges and rectangular steel plates will cause epoxy or cementitious grout to crack. Also, grout is designed to be in 100 percent contact with the underside of the pump baseplate and the concrete foundation. Think of the grout as an adaptor that matches the irregular shaped pump baseplate to the top of the irregular shaped concrete. The ideal pump baseplate installation is one that is 100 percent supported by the grout (all leveling devices removed).

This ideal pump baseplate installation can be achieved by using the method illustrated in Figure 3. Jack screws located on both sides of each anchor bolt are used to elevate the pump baseplate to the level position while the anchor bolt lightly holds the baseplate firm. In most cases, it will not be necessary to use both jack screws, but both are required if the baseplate machined surfaces are grossly out of flat. No baseplate will be within the 0.002 in coplanar machining tolerance once it is removed from the horizontal milling machine. If the mounting surfaces have ever been machined to the 0.002 in tolerance, they can be brought back to that same tolerance in the field. There are pump owners who think that if the pump is mechanically aligned at the factory, you can just mount the pump on the foundation and walk away. Please do not do that!

Notice that circular plates cut from 1.75 to 2.5 in diameter steel bar stock, approximately 0.250 inch thick, are used to prevent the points of the jack screw from digging into the concrete and altering the level. Grind the sharp edges of the circular steel disks to remove any stress concentration points. Use just enough tightening force on the jack screws and anchor bolts to hold the baseplate in position until the grout has been poured and cured.

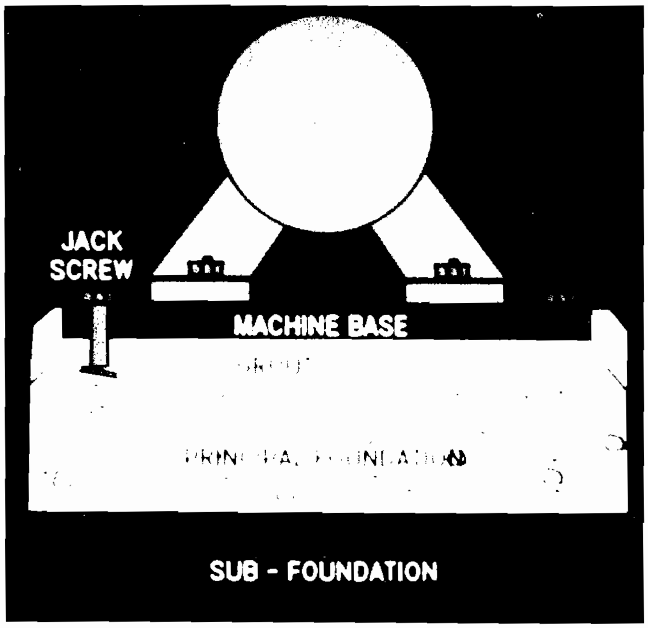


Figure 3. Jack Screws Resting on Circular Disks is the Preferred Method of Pump Baseplate Support Prior to Grouting.

Prior to the baseplate placement on the foundation, the concrete must be chipped to remove the cement rich concrete (laitance) and expose the aggregate. This provides a strong concrete/epoxy grout bond, because the strength of the concrete depends on the aggregate. The chipped surface must be blown clean with oil free air and kept dry. *Moisture and oil are the main enemies of good epoxy grout/concrete bonding.* Some epoxy grout manufacturers now have epoxy primers that can be applied to wet concrete and, after curing, still maintain the 2000 psi tensile bond strength.

Field experience has indicated that 2.0 to 3.0 in of epoxy grout are required under the pump baseplate flanges to reach the designed compressive strength. Thinner pours do not generate enough exothermic reaction heat to fully cure the epoxy. Before leveling, the baseplate should be high enough for the 2.0 to 3.0 in of grout thickness.

The use of jack screws for leveling is much faster than the more commonly used method of square steel plates and shims. Jack screws also eliminate the problem of removing the leveling shims after grout placement. As previously mentioned, the baseplate should be totally supported by the epoxy grout and not point supported at the leveling shims. Sharp cornered shims should not be left in epoxy grout, because they form stress concentrations that cause cracking. Once the epoxy grout has cured, the jack screws are removed, the holes degreased, and the holes filled with epoxy or sealant. *The jack screws are greased prior to installation to allow for their removal.*

Baseplate leveling begins with the pump and driver removed, after checking the pump suction and discharge flanges for proper location and elevation. Piping should not be attached to the pump until the baseplate has been leveled, grouted and the driver/pump aligned. *The piping comes to the pump, not the pump to the piping.* The use of a machinist's level mounted on the machined surfaces for the driver is illustrated in Figures 4 and 5. The jack screws and anchor bolts are adjusted until a level of 0.0005 in/ft is obtained in two directions 90 degrees apart. The machined surfaces for the pump receive the same treatment with a maximum elevation variation across the length of the baseplate of 0.010 in. A precision ground bar should be used across the mounting surfaces to check for coplannarity. The mounting surfaces should be coplanar within 0.002 in.

If the baseplate is long (over 15 ft), an optical level (Figure 6) might be used to speed up the leveling operation. Once the

Figure 4. A Precision Ground Square Steel Bar and a Machinist's Level is Used to Obtain a Baseplate Level of 0.0005 In/Ft in Axial Direction.

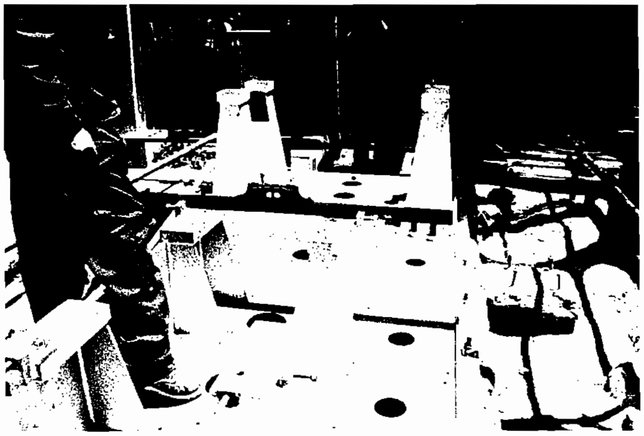


Figure 5. The Baseplate Must Be Leveled in Two Directions 90 Degrees Apart.

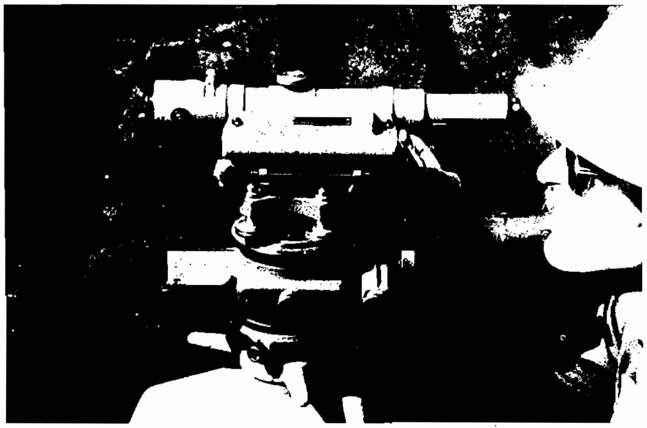


Figure 6. An Optical Level Can Be Used on Long Pump Baseplates (Over 15 Ft) to Speed up the Leveling Operation.

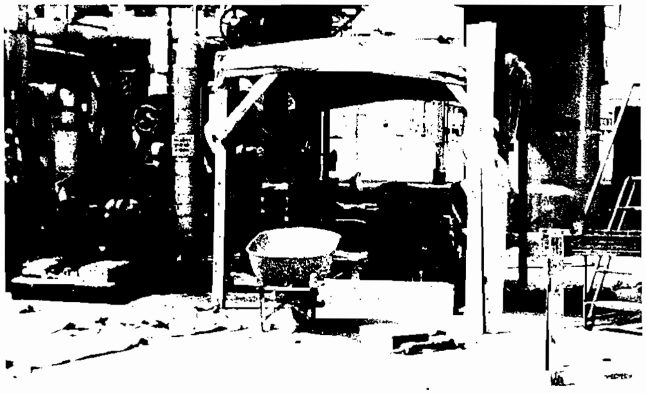


Figure 7. In Hot Weather, Shade the Baseplate/Foundation for 24 Hr Before and 48 Hr after Pouring the Grout. Also protects against rain.

baseplate is leveled, the *grouting* operations can begin. If epoxy grouting is to be done during hot weather (above 90°F), it should be started early in the morning while the baseplate is level. Check level after the baseplate temperature has stabilized overnight, and shield the baseplate from the direct sunlight for 24 hr prior to epoxy grouting and 48 hr after grouting. The use of a cover to protect the baseplate/foundation from both the sun and rain is illustrated in Figure 7. If epoxy grouting is to be done in cold weather (below 45°F), the baseplate and foundation must be shielded and heated. Consult the epoxy grout manufacturer for details.

BASEPLATE PREPARATION

Now that the baseplate leveling procedure has been discussed, the baseplate requirements listed below should be better understood. These requirements should be spelled out in the purchaser's pump specifications/purchase order. Pump manufacturers are providing these requirements now, but negotiate prior to placing the order.

- All welding on the baseplate shall be completed and stress relieved (if required) prior to machining the pump and driver mounting surfaces.
- All machined mounting surfaces shall be coplanar to 0.002 in.
- All baseplate welds shall be continuous (no skip welding) and free of cracks.
- Underside of baseplate shall be sandblasted to white metal and coated with 0.008 in wet thickness of epoxy coating (not epoxy paint) as specified by purchaser.
- All cross bracing on the underside of the baseplate shall have a 2.0 in × 6.0 in wide opening to allow for grout flow.
- Vent holes (0.5 in diameter) shall be provided for each bulkhead compartment at all corners, high points, and perimeter edges of bulkhead. Perimeter vent holes in baseplate shall be on 18 in centers minimum. Any angle iron or C channels added for stiffeners will require vent holes on both sides.
- Radius all sharp corners on baseplate flanges, minimum 0.5 in radius.
- Provide 1/8 in minimum shim adjustment under driver feet for mechanical alignment.
- Provide eight alignment positioning screws for the driver.
- Machined mounting surfaces shall extend 1.0 in beyond pump and driver mounting feet on all sides.
- Drill and tap two holes on the baseplate flanges, one on each side of the anchor bolt holes, for one-half in diameter (minimum) jack/leveling screws.

If the mounting surfaces are machined to 0.002 in coplanar after the welding has been completed, the same tolerance can be repeated in the field. This helps to eliminate soft feet and to speed up alignment. The common practice of machining steel plate mounting surfaces and welding them to the baseplate causes skewed surfaces that cannot be leveled in the field.

A void free grout job is ensured by providing vent holes at the baseplate periphery and in each compartment. Some pump purchasers never look under the baseplate to see how cross bracing makes a good grout job impossible. Notice in Figure 8 that the center compartment is blocked by cross braces and would not receive grout though only in from two grout holes. (A top view would lead to the belief that all is well.) In this case, an additional 4.0 in grout pour hole was cut into the center of the compartment along with additional vent holes. On occasions, the author has cut openings through braces to provide a path for grout.

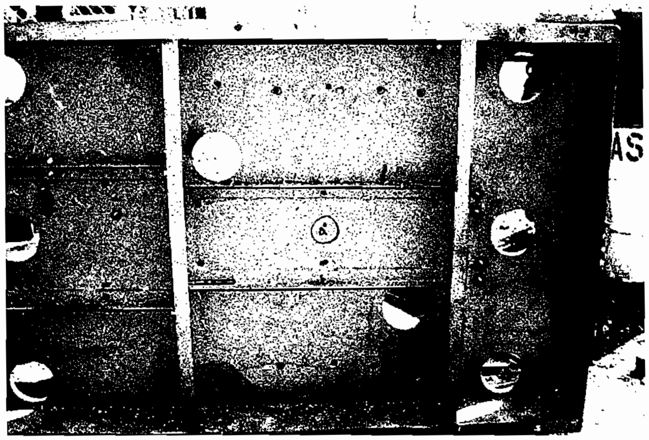


Figure 8. Always Check the Underside of the Baseplate. Notice the center compartment is blocked by cross braces and would receive no grout.

The request for a 1.0 in wider mounting surface on each side of the equipment feet can be a life saver, if baseplate leveling is required with pump and driver in place. The additional cost of a few more inches of steel plate is peanuts compared to the flexibility of baseplate leveling with mounted equipment in emergency conditions. A machinist's level can be placed on the additional border around the pump and driver, allowing the baseplate to be leveled. This is not the preferred method of leveling, but it will work.

NEW CONCRETE PREPARATION

Freshly poured concrete must be allowed to cure before epoxy grout is applied. As mentioned earlier, moisture will ruin the epoxy grout/concrete bond on unprimed concrete, even the small amount of moisture from green concrete. It is a good practice to run an ASTM-157-80 Concrete Shrinkage Test to determine when the shrinkage drops to a minimum. This will indicate the end of the chemical reaction of the cement and water, which causes the concrete to cure. If no shrinkage test is run, the following rules of thumb for cure time should be used:

- Standard concrete (five bag mix)—28 days
- Hi-early concrete (six to seven bag mix)—7 days

An additional test for moisture can be made by taping a one foot square piece of plastic garbage bag over the new concrete and allowing it to set overnight. If there is moisture on the underside of the plastic bag the next day, the concrete is not ready for the placement of epoxy grout. Repeat the test until there is no moisture. Unprotected cured concrete will absorb moisture from rain, so give it the moisture test also.

During the placement of concrete for the pump foundation, samples of the concrete should be taken to make slump and compressive strength tests. During a routine compressive strength test for a 600 hp pump, a 3000 psi concrete mix, which passed the slump test, cracked at 1400 psi. The foundation was chipped out and the job started over at the expense of the concrete supplier. The concrete mix had been in the truck too long and additional water was added to pass the slump test. This retempering of the concrete made it much weaker.

Surface preparation of the new concrete can begin after curing by chipping away the laitance with a light duty pneumatic hammer and a sharp pointed chisel. *Do not use a jack hammer, because that may crack the foundation.* Chip away at least the top 0.50 in of concrete until all laitance is removed and the aggregate is exposed (Figure 9). Chamfer all the foundation edges at least 2.0 to 4.0 in at a 45 degree angle in order to remove stress concentration (Figure 10). Remove all dust, dirt, chips, oil, water, and any other contaminants, and cover the foundation.

Figure 9. All Laitance Must Be Chipped Off the Surface of the Foundation to Expose the Aggregate.

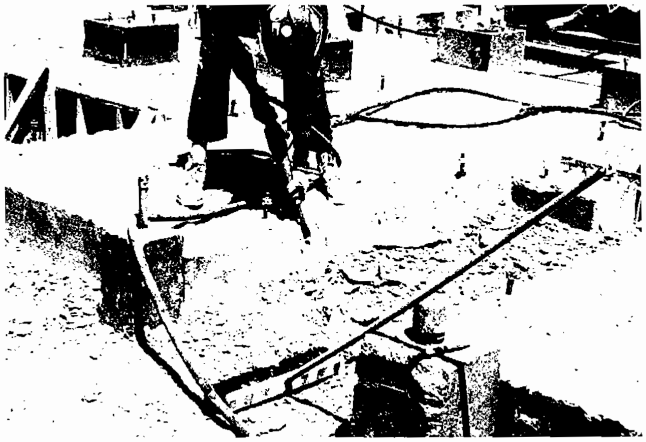


Figure 10. Chamfer All the Foundation Edges at a 45 Degree Angle to Remove Stress Concentrations.

It is a good practice to coat the clean, dry, chipped concrete with a coating of epoxy. This protective coating is a layer of unfilled (without aggregate) epoxy grout, applied with a brush or broom (Figure 11). Once the coating has cured, the concrete is sealed from moisture and oil. If there is a delay in grouting, the surface can be easily cleaned with a spray of degreaser from an air gun.

Figure 11. Coat the Clean, Dry, Chipped Concrete with a Coating of Unfilled (Without Aggregate) Epoxy Grout.

OLD CONCRETE PREPARATION

Old concrete has already cured and does not present the problem of determining moisture content as with new concrete, unless it rains. A visual check for foundation cracks must be made after chipping the surface to expose the aggregate. All oil soaked concrete must be chipped away and all cracks repaired. The edges of the old foundation are chamfered as with the new concrete for 2.0 to 4.0 in at a 45 degree angle. It is a good practice to trepan a test core of the old concrete and run a compressive strength test. If the compressive strength is under 3000 psi, the foundation should be replaced. Coat the chipped concrete surface with a protective coating of unfilled epoxy grout.

ANCHOR BOLTS

Anchor bolts should have 10 to 15 times the bolt diameter of free bolt length for proper stretch to develop the designed holding force. If epoxy grout is allowed to grip the anchor bolt, the bolt will break at the grout surface even when tightened to the design torque. This requirement must be met at the foundation design stage and might require the use of bolt sleeves in the concrete. If sleeves are used, they must be filled with a nonbinding material such as sand, flexible foam, or wax to prevent the epoxy grout from filling the sleeves and bonding to the anchor bolt. If sand is used, the top of the sleeve must be sealed with wax, or duxseal or the epoxy grout will flow into the sand. The exposed length of anchor bolt from the top of the concrete to the bottom of the baseplate should be wrapped with duxseal or one layer of weather stripping and one layer of duct tape. The method most used by the author is a 0.25 in thick layer of duxseal applied around the anchor bolt and sealed to the concrete and baseplate (Figure 12). This method may also be used on the jack screws, so they can be removed when the grout has cured.

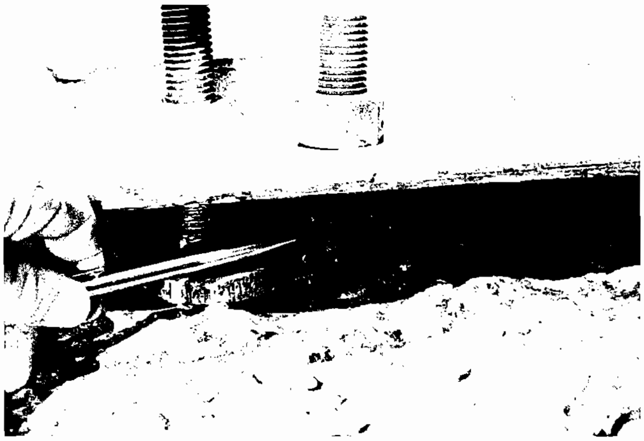


Figure 12. Use Duct Sealing Tape to Protect the Free Length of the Anchor Bolt from the Epoxy Grout. Bolt breakage is common if not protected.

GROUT FORMS

Forms to contain epoxy grout must be of a heavy duty design because epoxy grout is approximately 0.84 times as heavy as concrete. Forming material should be a minimum of 0.75 in thick grade one plywood with 2.0 in × 4.0 in bracing. *If in doubt, make it stout.* All surfaces coming in contact with the epoxy grout must receive three coats of heavy duty paste wax to prevent bonding to the wood. Allow time for the wax to penetrate into the wood and dry before applying the next coat (Figure 13).

Figure 13. Three Coats of Paste Wax Must be Applied to all Grout Form Surfaces Coming in Contact with the Grout.

Forms are to have 0.75 to 1.0 in by 45 degrees chamfer strips at all vertical corners and at the horizontal surface of the grout. A liquid tight form is made by using RTV sealant at all joints and at the mating surfaces of the foundation.

Up until this point, all the requirements for the grout forms have been those used for many years. Most API designed baseplates required two grout pours, one to fill the void between the concrete and the baseplate flanges, and the second to fill the void between the baseplate flange to the top of the baseplate (Figure 14). If the free surface of the grout at the baseplate flanges is confined, the 6.0 in to 7.0 in higher grout level at the top of the baseplate can be filled in one pour (Figure 15). A wooden top form, shown in Figure 16, is attached to the sides of the grout forms and the top of the baseplate flanges. Vent holes (0.38 to 0.5 in diameter) are drilled in the top form on 18 in to 24 in centers to allow air to escape as the grout flows from the center of the baseplate to the edges. When the grout begins to run out of the vent holes, duct tape is used to cover the holes and the filling operation continues (Figure 17). The use of this method allows a one pour grout job that should be completed in 45 minutes and forms removed 24 hr later. If the temperature at the time of the pour is above 80°F, the pump and driver can be mounted when the forms are removed. A two pour grout job doubles the labor cost for grouting and lengthens the completion time of the installation.

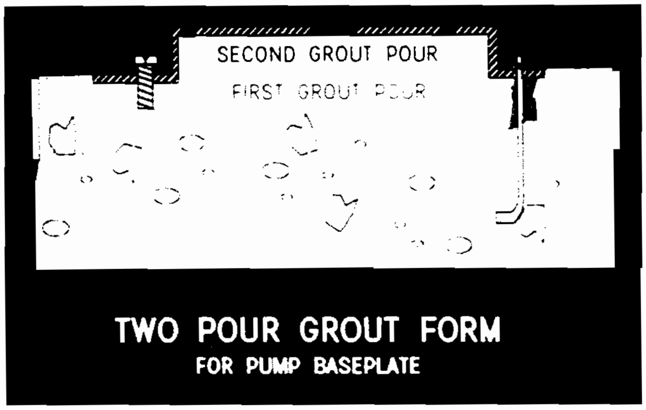


Figure 14. A Two Pour Grout Job is Required with Standard Type Grout Forms.

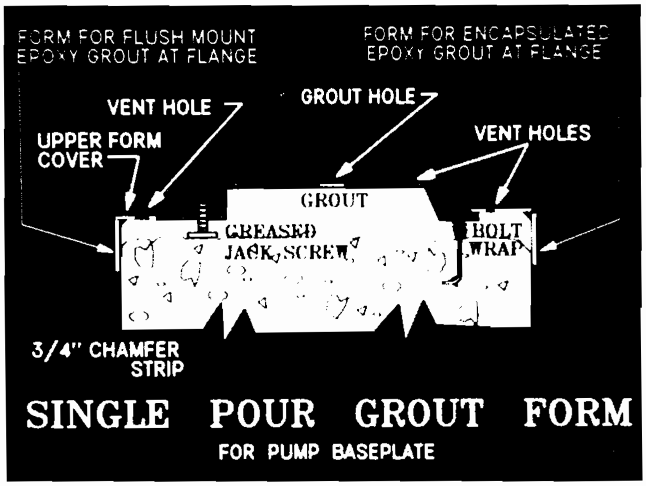


Figure 15. A Single Pour Grout Job is Possible when the Grout Free Surface at the Baseplate Flanges Are Sealed with a Vented Top Form.

EPOXY GROUT PLACEMENT

The pump baseplate is ready for grouting after the following last minute checks are made:

- Baseplate under surface is free of oil, scale, dirt, or moisture, and is sealed with a coating of unfilled epoxy grout.

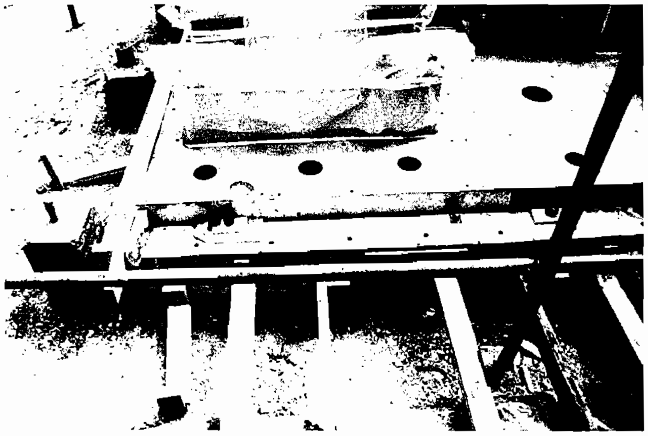


Figure 16. An API Pump Baseplate Formed up for a Single Pour Grout Job. Notice the vented top form attached to the side forms and baseplate flanges.

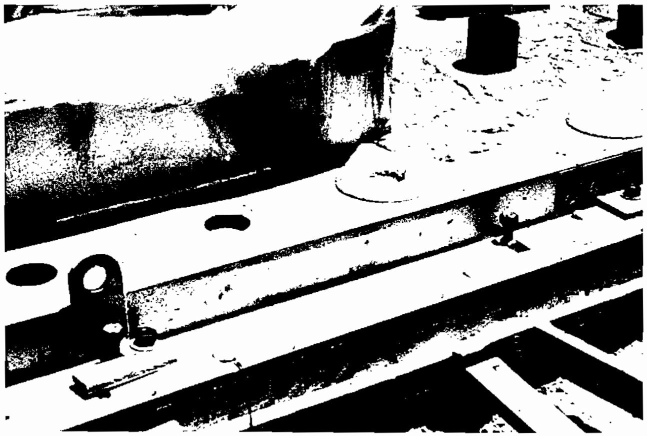


Figure 17. Duct Tape was Used to Stop the Flow of Grout Out Vent Holes as the Baseplate Grouting Continued.

- Concrete surface is clean, free of oil, dirt and moisture. It is sealed with a coating of unfilled epoxy grout.
- Anchor bolt sleeves are filled with nonbonding material.
- Exposed surfaces of anchor bolts are covered with duct sealing tape.
- Jack screws are lubricated for easy removal.
- Circular steel plates are under each jack screw point.
- Vent holes are in correct locations and unobstructed.
- Forms in contact with grout are properly waxed (three coats).
- Grouting materials are in unopened containers, dry and stored at 70°F to 80°F for 24 hr prior to placement.
- Sufficient quantities of grout materials are on hand at the site to complete the pour. (Add 25 percent to calculated grout requirement.)

Epoxy grouts have a narrow temperature range for mixing and placement. This range is from 50°F to 90°F for best pot life, flow ability and curing. Can epoxy grout be poured at temperatures below or above these limits? The answer is yes, but special procedures must be followed and the grout manufacturer should be consulted. Low temperature accelerators can be added for cold weather pours with the foundation and baseplate covered and heated. In the Gulf Coast area, the problem is with temperatures above 95°F. The author has occasionally stored epoxy grout and aggregate in air-conditioned offices for 48 hr to increase the pot life on hot days. In hot weather, construct temporary shelters over the baseplate to provide shade 24 hr before and 48 hr after the grout placement.

It is a good practice to rope off a work area in congested construction sites to set up the grouting operation. Move all of the grouting material and tools inside the roped off area just before the job starts. *Do not have epoxy grout stored out in the hot sun for days before the grout pour.* Keep all personnel who are not part of the grout team out of the area. Have all the grout team take their smoke, water, or pit stop breaks before the epoxy grout mixing begins. Once started, there is no stopping until the job is complete and the tools cleaned. If executed properly, the time lapse from mixing to cleaning is 45 minutes.

With temperature conditioned grout at the pump site and all the checklist items completed, it is time to mix the grout. Two ways to mix the grout are:

- In a wheelbarrow with a mortar mixing hoe.
- In a motorized mortar mixer.

Both methods work well, but for a large grout job (10 units or more) the motorized mixer should be used. If the hand mixing method is used, have two wheelbarrows and stagger their mixing sequence to provide a continuous supply of grout to the men making the pour. The author prefers the motorized mortar mixer method, because it reduces the number of men required for mixing (relief mixers not required), but cautions about overmixing the grout. When using a motorized mixer, limit the mixer blade speed to a maximum of 30 rpm. A mortar hoe used to mix grout is shown in Figure 18, while a typical motorized mortar mixer is shown in Figure 19.

Most grout manufacturers furnish epoxy resin containers large enough to hold both the "A" part (resin) and the "B" part (hardener), so use this container for mixing. Add the hardener to the resin and mix by hand with a paddle for three to five minutes (Figure 20). Mix slowly to prevent air entrainment, because this causes the grout to foam and have air bubbles. A jiffy mixer (Figure 21) can be used with a variable speed drill, because it is designed to mix without entraining air. A stop watch should be used to time the epoxy resin mixing and to record the total time required for grout placement. If the grout container is not large enough to hold the total epoxy mixture, use a clean five gallon can. Be sure to remove all of the hardener from its storage can and place it in the epoxy resin. No partial units of epoxy resin and hardener are to be used. If the mixture of Part A and B is poured into the empty Part B hardener can, the Part B residue can be catalyzed. This procedure

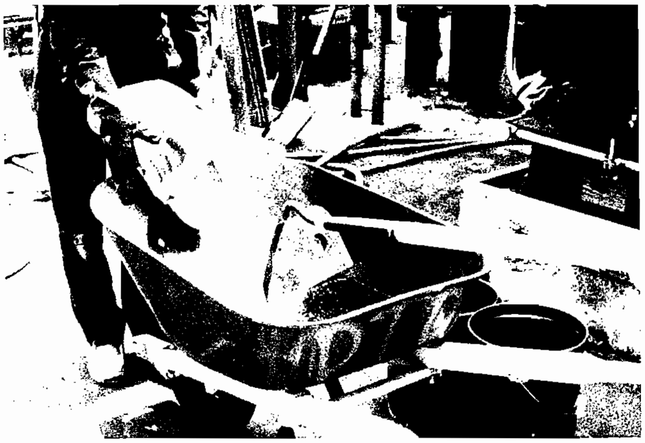


Figure 18. One Method of Epoxy Grout Mixing is by Hand Using a Wheelbarrow and Mortar Hoe. Aggregate is slowly added to the liquid epoxy.

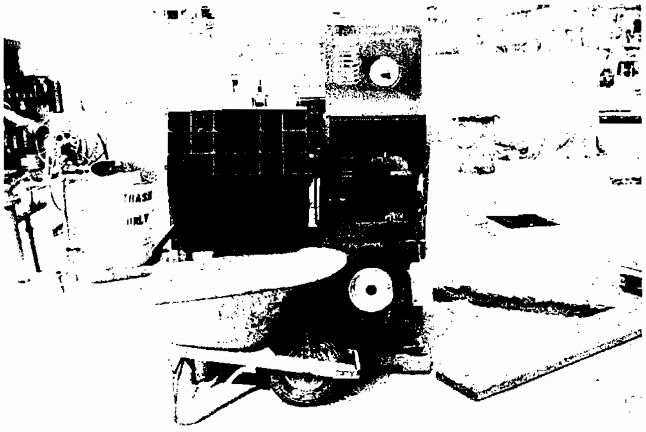


Figure 19. A Second Method of Epoxy Grout Mixing is with a Motorized Mortar Mixer with a Mixer Blade Speed of 15 to 30 RPMs.

Figure 20. The Epoxy Resin and Hardener can be Mixed by Hand in the Resin Container. Mixing time should be three to five minutes.

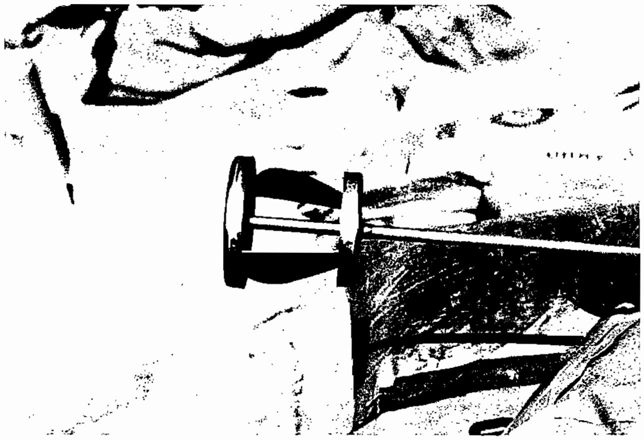


Figure 21. A Second Method of Mixing the Epoxy Resin and Hardener Is with a Jiffy Mixer Driven by a Variable Speed Motor.

will eliminate an EPA disposal problem for unreacted organic residue in the cans.

When the epoxy has been mixed, place it into a wheelbarrow or motorized mixer and remove all the epoxy from the can. Use a putty knife to remove the last drop. Slowly pour the aggregate into the epoxy to allow the air trapped in the aggregate to escape. Approximately one gallon of air is entrained in each bag of aggregate, which causes air bubbles in the cured grout. Fold the aggregate into the epoxy until the aggregate is completely wet. Add all the bags of aggregate and mix until completely wet. Use the containers that the epoxy resin was mixed in for the placement of grout. Slowly pour the grout into the baseplate grout holes to allow air to escape. Pour from the center of the baseplate and allow the grout to flow to the outside edges, displacing the air through the vent holes (Figure 22). *Do not use vibrators or rods to place epoxy grout.* Continue to fill the baseplate until the grout runs out the vent holes on the wooden top form at the baseplate flanges (Figure 17). Cover the vent holes with duct tape and continue to fill the baseplate until grout escapes from the vent holes at the top of the baseplate. A large funnel located two or three feet above the baseplate can be used to provide the force necessary to push the grout out of the vent holes as shown in Figures 23 and 24. Another method used to compress the grout is a homemade positive displacement pump made by a Baytown, Texas manufacturer. The grout pump cylinder in Figure 25 is being used as a funnel to fill the baseplate. The grout pump piston is shown in Figure 26 being placed in the pump cylinder prior to being pushed down to force the grout out the vent holes. All the air being displaced under the baseplate by grout is shown in Figure 27. Today's epoxy grouts flow much better than grouts of three to five years ago. Because of this, wooden pour boxes can be used around the grout holes to dump the grout into and provide a hydraulic head to improve flow. A grout level is maintained in the pour box until the grout starts to set up. This hydraulic head helps to sweep air bubbles to the vent holes, thus providing a void free grout job. The grout mushrooms formed at the vent holes should be removed and added to the pour box for the first 30 minutes of the pour. After that, leave the mushrooms as they become small grout reservoirs until the grout starts to cure. Remove the pour box and mushrooms when the grout takes a set and before it hardens. Mold a grout dome over each pourhole to prevent the forming of a water trap and cut the mushrooms flush with the baseplate.

Random grout samples should be taken during the grout pour and placed in waxed 4.0 in wooden cubes, or 6 in sonic tubes, for compression strength testing at 24 hr, three-day and seven-day intervals. Record the times, date, ambient temperature, and location of the grout pour on the samples. Allow the grout sample to cure at the job site to duplicate the ambient temperature cure conditions. Ambient cured samples will not be the same strength as the manufacturer's published data due to ASTM procedure of post-curing the samples. This is good information to put in the pump maintenance history file for future reference.

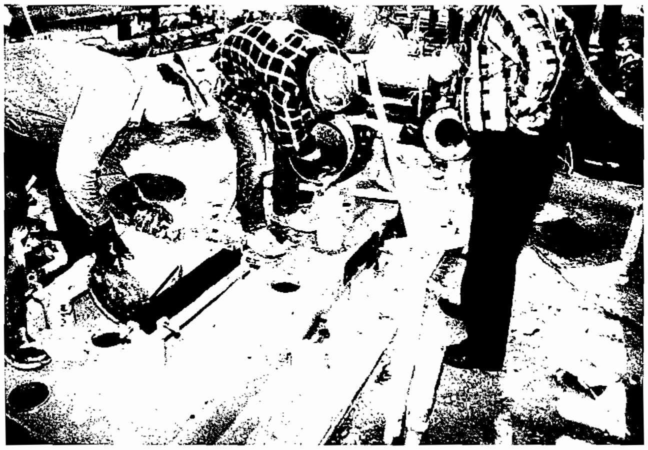


Figure 22. The Resin Containers Are Used to Place Grout in the Center Baseplate Grout Holes.

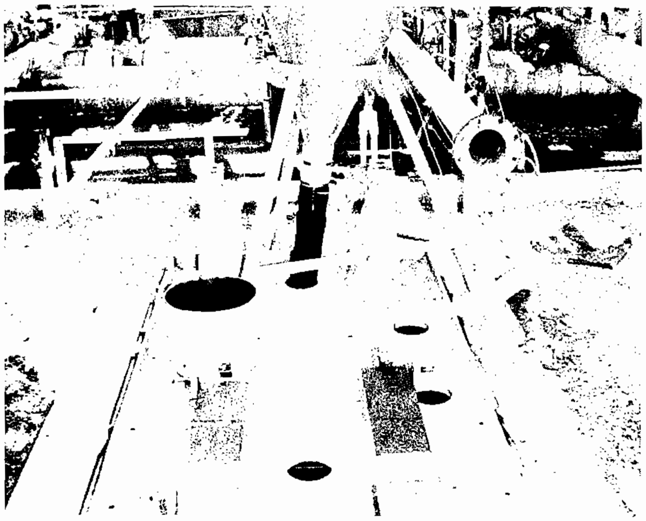


Figure 23. An Elevated Funnel was Used on this Grout Job to Provide the Head Necessary to Push Grout Out the Baseplate Vent Holes.

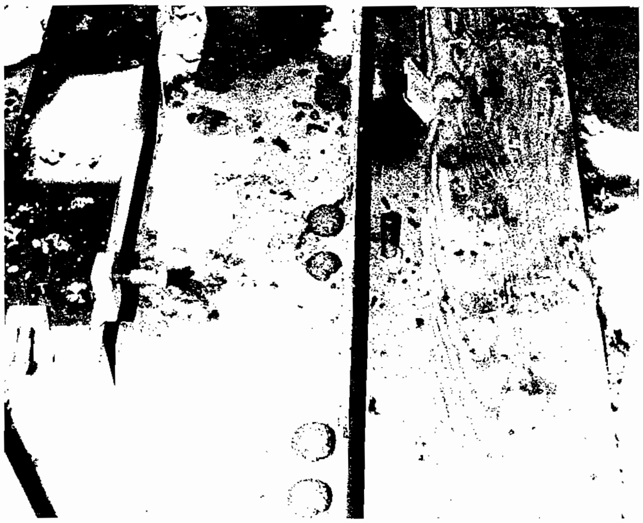


Figure 24. Notice the Air and Grout Flowing from the Baseplate Vent Holes. A vent hold was drilled on each side of the cross braces.

Immediately after the completion of the grout pour, clean all tools and mixing equipment. Water can be used to remove the wet grout as illustrated in Figure 28 by the use of a fire water monitor. After grouting, clean up operations are made easier if the machined surfaces of the baseplate has been greased or covered with plastic, and sand has been sprinkled on the slab in the path from the mixer prior to the pour. There will be grout spills in the process of grouting, and they are easy to shovel up when mixed with sand.

As mentioned previously, when the epoxy grout begins to harden, form a dome of grout over the baseplate grout holes to

Figure 25. The Cylinder of a Homemade Grout Pump Was Used as a Funnel to Fill the Baseplate.

Figure 26. Once the Grout Cylinder was Filled, the Grout Pump Piston Was installed and Pressed Down.

Figure 27. Notice the "Grout Worms" Pressured Out of the Vent Holes Around the Anchor Bolts by the Grout Pump.

prevent a low spot that might hold water (Figure 29). The grout extrusions at the baseplate vent holes can be removed at this time or broken off flush with the baseplate when they have cured. Wait 24 hr before removing the grout forms, and three days before removing the jack screws. Clean the thread lubricant from the jack screw holes with a degreaser and fill the holes with epoxy, RTV, or liquid rubber to seal out moisture and oil. A small but important point that has not been covered is the greasing and insertion of the coupling guard bolts into the baseplate. Epoxy grout will use those tapped holes as air vent holes if not plugged. It is very hard to drill and tap the holes after being filled with grout.

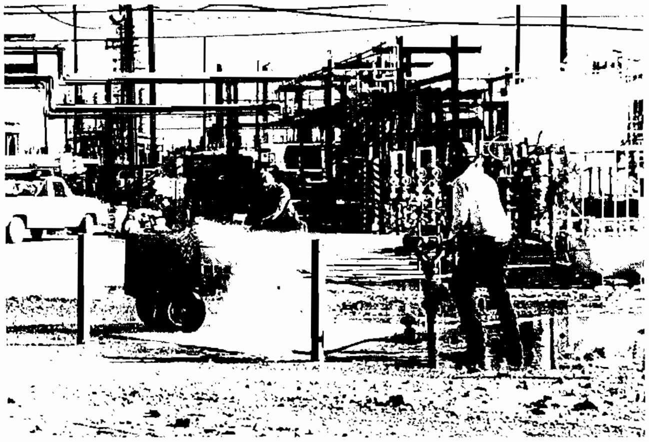


Figure 28. The Motorized Mixers and Tools Can Be Cleaned of Epoxy Grout with High Pressure Water, if Done Immediately After Grout Placement.

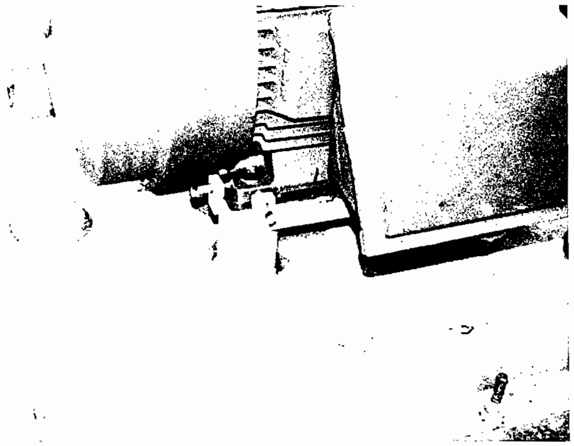


Figure 29. When the Epoxy Grout Begins to Stiffen, Mold a Dome Over the Grout Hole to Prevent Forming a Pool of Water.

After the jack screws have been removed, torque all the anchor bolts to their designed load. This should be the first and last time the anchor bolts are tightened. Check the grout job for voids by ringing the baseplate with a hammer (Figure 30). A good grout job will sound like hitting a lead plate and voids will ring like a bell. If this procedure has been followed to the letter, there will be no voids in the grout, but there is a repair procedure for filling voids in old baseplates.

BASEPLATE GROUT VOID REPAIR

Ring the baseplate with a hammer as mentioned and draw the outline of the void on the baseplate with a magic marker. After the void has been defined, drill multiple 0.250 in holes into the periphery of the void. Tap one hole and insert a grease fitting. The other holes should be used as vents to prevent the lifting of the baseplate as unfilled epoxy grout is pumped into the void with a grease gun (Figures 31 and 32). It would be a good idea to put a dial indicator at the center of the void, held by a magnetic base, mounted on the void free section of the baseplate. If there is a 0.003

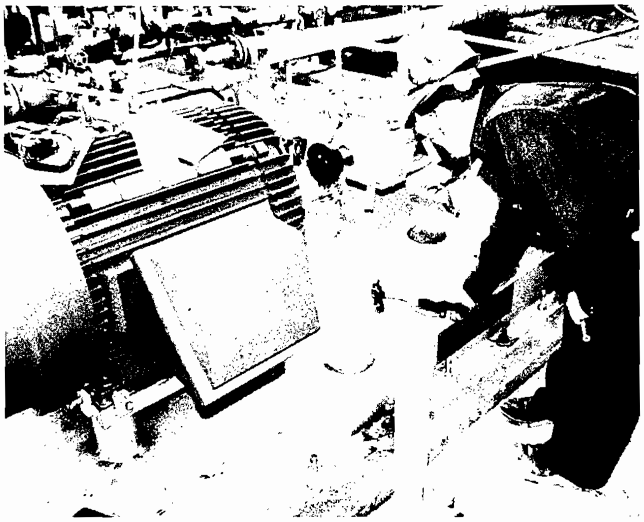


Figure 30. A Hammer Was Used to Test the Baseplate Grout Job for Voids.

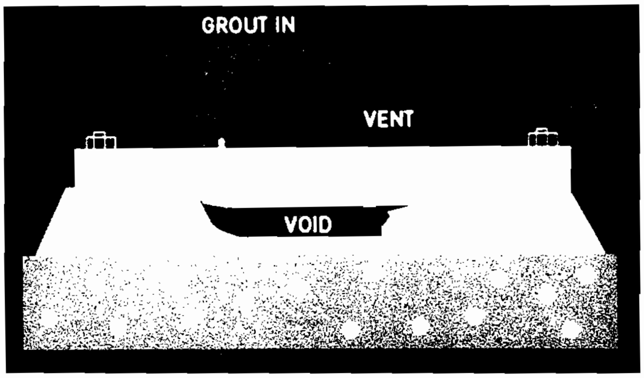


Figure 31. Voids in a Poor Grout Job Can Be Filled by Pumping Unfilled Epoxy Grout Through a Hole in the Baseplate. Notice the vent hole at the opposite side of the void.

Figure 32. This Machinist Used a Clean Grease Gun to Fill a Void Under the Baseplate with Unfilled Epoxy Grout.

in rise in the dial indicator, stop pumping the epoxy until the indicator goes to zero. Pump the unfilled epoxy grout into the void until the void is filled and grout runs out the vent hole. Remove the grease fitting, allow the grout to cure, and grind both holes smooth. This procedure should be considered a patch job and in no way a permanent fix. An alternate method would be to suck the unfilled epoxy grout into the void by using a vacuum source on one side and a small reservoir of unfilled epoxy grout on the opposite side. There would be no danger of lifting the baseplate if this method was used.

At this point, the baseplate installation and grouting is complete and the pump and driver are ready to be installed and mechanically aligned. The method of using jack screws for leveling baseplates and the reasons for using epoxy grout have been presented. Some of the subtleties for baseplate, foundation and grout form preparations have been covered and the procedure for the mixing/placement of epoxy grout presented. A procedure for a one pour grout placement of pump baseplates has been outlined, so the next step is the application of this procedure. A void free grout job is obtainable, but attention to details is required.

MECHANICAL SHAFT ALIGNMENT

Mechanical shaft alignment begins when the pump foundation is poured and continues until the piping is installed. Anything which can disturb the shaft to shaft relationship of the pump and driver must be eliminated. The details of installing the pump baseplate have been covered and piping will be covered later. Look at what is required to place the shafts in a straight line or within acceptable limits.

Preparation for Alignment

The first thing to be done is to check and clean the machined mounting surfaces. Remove all burrs, paint, rust, and hone the surfaces with a fine honing stone. Once this is done, the surfaces can be checked for level with a machinist's level. The hashmarks on the vial are calibrated at 0.005 in per foot, but can be used to obtain a leveling tolerance of 0.0005 in per foot. If the baseplate was properly installed, the mounting surfaces will be flat and coplanar. Any warped or skewed surfaces must be field machined or alignment will be very difficult. Each time the adjustable piece of equipment is moved, there is a different solution for the correction shim thickness. Predictable shim changes then become trial and error and that is not how you want to do alignment. The feet on both the pump and driver must be cleaned and checked for flatness. Do not be surprised to find that electric motor feet are not flat. This can cause a severe soft foot condition, making predictable shim changes next to impossible. If precut shim stock is not used, now is the time to cut and deburr a variety of thicknesses of stainless steel shims. The precut shims is the cheaper way to go in the long run, even though there is a upfront cost of approximately \$300 to \$400. Once the shims are ready, dimensional information of the distances from the dial indicators to the inboard and outboard movable feet must be recorded. Draw a picture indicating the dimensions and directions. This should become part of the permanent equipment history file.

Alignment of Rotating Equipment

Before alignment can begin, the operators must pick which piece of rotating equipment is the *fixed* and which is the *movable.* The fixed equipment should be the one that has the biggest piping problem, like a pump or steam turbine. Motors are generally picked as the movable equipment and in the case of a steam turbine driver, the pump is the movable. Once the steam turbine piping is correct, do not mess with it. There are cases where a gearbox is the fixed equipment, and the driver/driven pieces of equipment are the movable. The fixed equipment is leveled and doweled in place to provide a fixed target for the movable equipment. In the process of leveling the fixed piece of equipment, it too must be checked for a soft foot. *What is soft foot*? The two types of soft foot illustrated in Figure 33 are the parallel and the skewed or angular. Parallel soft foot is caused by one or more of the mounting feet of the rotating equipment being noncoplanar, but parallel to the baseplate mounting surfaces. This type of soft foot is the easiest to correct, because shims added to fill the gap make a 100 percent contact to both mounting surfaces. As you would expect, the easiest to correct is seldom experienced. The angular soft foot is caused by stress relief in casting as green casting ages and distorts. Angular soft foot is hard to correct because to do it properly would require a tapered shim. How many tapered shims have you seen lately? To check for soft foot, tighten all holddown bolts using a torque wrench and place a dial indicator near the bolt. Loosen one bolt at a time being careful not to bump the indicator, record the amount and location of each soft foot. Retighten each bolt to the original torque value to see if the indicator goes to zero. If it does not return to zero, check to see what went wrong and correct the problem. *Soft foot readings less than 0.002 in require no correction.* Once all the readings have been taken, add shims to the largest soft foot and correct all soft feet. The way to correct diagonal soft feet is illustrated in Figure 34, and it really works. Once the soft feet are corrected, the movable piece of equipment can be aligned. How this is accomplished is covered later, but alignment tolerances should be discussed. A good rule-of-thumb tolerance for the face and RIM method of alignment is 0.002 in TIR at a 10.0 in diameter. *For the reverse indicator* method, the alignment tolerance is 0.0005 in/in of indicator separation. Both alignment methods will be explained later.

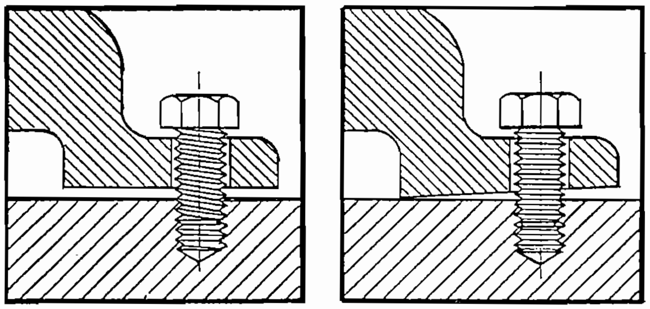


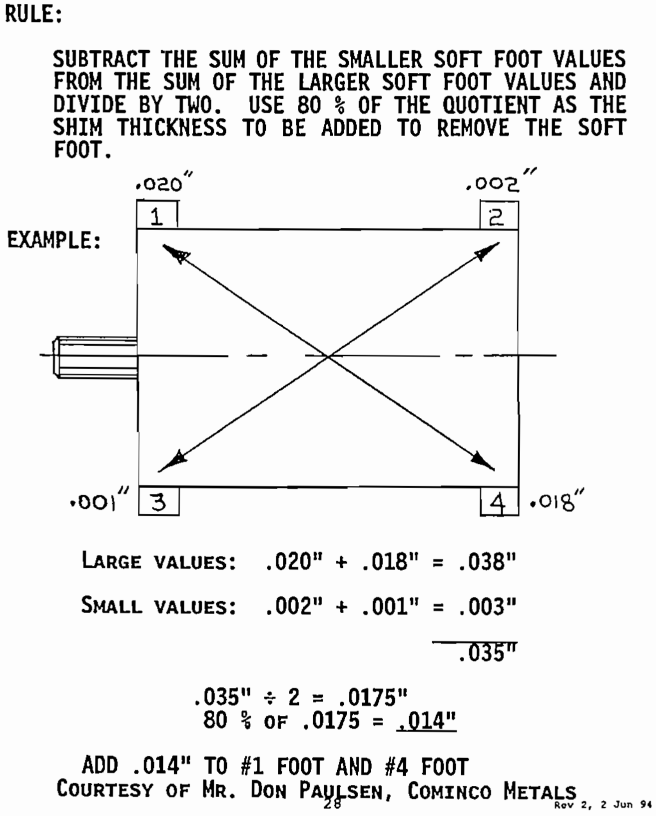
Figure 33. Types of Soft Foot.

Types of Misalignment

There are three types of shaft misalignment, *parallel*, *angular*, and *parallel-angular*. Parallel misalignment occurs when the shaft centerlines extend to infinity without intersecting (Figure 35). Angular misalignment is shown in Figure 36 and is defined by the intersection of the movable centerline at the center of the fixed coupling hub face. It is rare to find parallel or angular misalignment on rotating equipment, but parallel-angular misalignment is very common. Parallel-angular misalignment occurs when the extension of the movable centerline intersects the fixed centerline at any location other than the fixed coupling hub (Figure 37).

Shaft alignment can be accomplished in several ways and there are reasons for using each method. Some of these methods are:

- Straight edge and feeler gage.
- Dial indicator face and rim.
- Dial indicator on the rim and inside mikes on the face.
- Reverse dial indicator.
- Laser alignment.



RULE:

SUBTRACT THE SUM OF THE SMALLER SOFT FOOT VALUES FROM THE SUM OF THE LARGER SOFT FOOT VALUES AND DIVIDE BY TWO. USE 80 % OF THE QUOTIENT AS THE SHIM THICKNESS TO BE ADDED TO REMOVE THE SOFT FOOT.

EXAMPLE:

LARGE VALUES: .020" + .018" = .038"

SMALL VALUES: .002" + .001" = .003"

.035"

.035" ÷ 2 = .0175"

80 % OF .0175 = .014"

ADD .014" TO #1 FOOT AND #4 FOOT

COURTESY OF MR. DON PAULSEN, COMINCO METALS

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Figure 34. Soft Foot Shim Correction Formula.

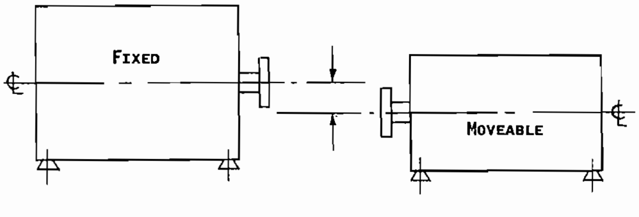


Figure 35. Parallel Misalignment.

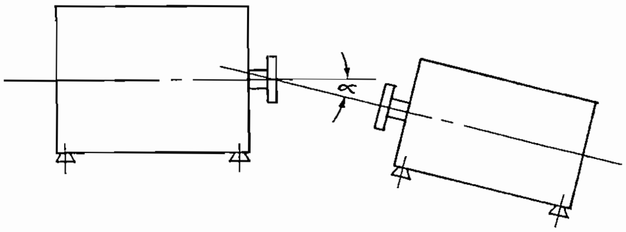


Figure 36. Angular Misalignment.

When pumps were sealed with packing, the straight edge and feeler gage were the prime tools for shaft alignment. The straight edge was used to correct parallel misalignment and the feeler gage corrected angular misalignment. A careful millwright would have aligned a pump within 0.015 in to 0.020 in with this method, which

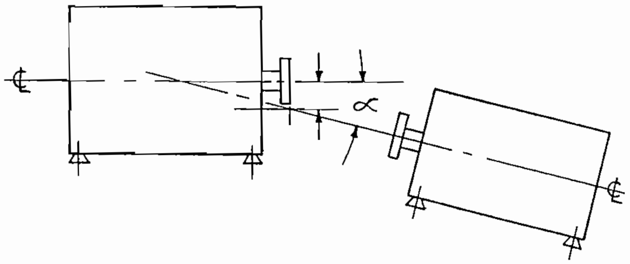


Figure 37. Parallel and Angular Misalignment.

was acceptable for packed pumps. Today, most pumps are sealed with mechanical seals requiring shaft alignment tolerances below 0.002 in. The question is asked, "Should we still use the straight edge and feeler gage method?" The answer is yes, it should be used to rough align shafts to bring the misalignment below the range of the dial indicator. A good dial indicator has a total range of approximately 0.200 in, and is mounted on the shafts at the center of the travel. The straight edge method should be used to rough align the shafts to within 1/16 in (0.063 in), which is under the indicator's range.

The face and rim dial indicator method is a very popular way of aligning shafts and has been used for many years. One indicator is mounted on the rim (OD) of the coupling hub to read parallel misalignment and one indicator is mounted on the coupling hub face to read angular misalignment. *When making shim correction calculation, always divide the OD (Rim) readings by two. Rim readings are total indicated reading (tir) and are twice the actual centerline displacement. Face readings are used at their full value for shim correction calculations. The face and rim method of shaft alignment should not be used on applications where axial float cannot be referenced against thrust bearings (i.e., sleeve bearings in electric motors).* If this method is to be used on sleeve bearing applications, two face dial indicators must be used. That means the alignment brackets will have to support three indicators, which increases indicator "sag." Sag will be explained later.

A third method of alignment uses a dial indicator on the rim for parallel offsets and inside mikes on the face for angular misalignment. This method can be used on sleeve bearing applications because OD readings are not affected by axial movement. The shafts are rotated together to obtain parallel offsets and the inside mikes are used while the shafts are stationary, to obtain angular offsets.

The reverse dial indicator method has become more popular in the last 10 years for aligning rotating machinery because of its accuracy. This method uses two indicators mounted on the OD of each coupling hub, so it can be used on sleeve bearing applications. The indicators describe two points in space, that when joined by a straight line, define the parallel and angular misalignment of the movable shaft centerline to the fixed shaft centerline. Since all reverse indicator reading are OD readings, they must be divided by two when making correction calculations. *The reverse indicator method of shaft alignment should not be used on applications where the distance between the two indicators is less than the diameter the indicators sweep (less than the coupling hub diameter).* The reverse indicator method should be the first choice when shaft alignment is required.

The term "sag" was mentioned earlier, but now it needs to be defined. Sag is an error in the dial indicator reading caused by the force of gravity pulling down on the indicator. When the indicator is zeroed at the top of the coupling hub, the gravitational error is subtracted out. As the indicator is rotated to the bottom, the indicator goes through the neutral position and sags below the neutral position the same amount as at the top. Sag can be checked by mounting the alignment brackets and indicators on a rigid piece of pipe in the same arrangement as on the rotating equipment shafts. With the indicators at the top position, zero the indicators and rotate the pipe 180 degrees. The readings on the OD indicators are the amount of sag you must correct for. *Notice the full indicator reading is used as the sag value.* On a reverse indicator setup, check both indicators. Most of the time they read the same, but it is possible for them to differ. Read only the OD indicator on a face and rim setup to obtain sag. Sag can be compensated for by setting the indicator at a positive value equal to the sag rearing, when the indicator is at the top position. If the indicator is at the bottom position, which is the case with some alignment brackets, set the indicator at a negative value equal to the sag reading. This brings up the question, "What is a positive or negative reading on an indicator?" *A positive reading occurs on a dial indicator when the indicator stem is pushed in. A negative reading occurs when the indicator stem goes out (extends).*

The last alignment method listed is the laser. It is the latest method and is very popular. More companies are springing for the laser, in spite of the $14,000 to $20,000 price tag, in hopes of improving plant wide alignment. The purchase of a laser system does not reduce the need for alignment training. Maintenance personnel need to understand the basics of shaft alignment prior to using the laser. It may sound like the author is against laser systems and that is not true. Use them for the right reasons. There is no sag in a laser system, so it can be used over long distances and will also perform the soft foot checks without the use of indicators. In most cases, shims are ready to be changed within 15 minutes of arrival at the misaligned equipment. Horizontal alignment adjustments are made much easier with the laser, without dial indicators. One caution though, it is very important that the operator positions the laser computer in the correct orientation or he will make the alignment moves in the wrong direction. Also, the laser transmitter is mounted on the fixed shaft and the mirror on the movable shaft.

METHODS FOR CALCULATING SHIM CHANGES

There are three methods to calculate the amount of shims required at the inboard (IB) and outboard (OB) feet of the movable pieces of equipment. *Inboard is defined as the position closest to the shaft coupling hub, and outboard as the position farthest from the coupling hub.* All alignment calculations are based on height-to-base relationship of a *scalene triangle,* as illustrated in Figure 38. The point of the triangle represents the location of the dial indicator on the fixed coupling hub for a reverse indicator setup. The distance, HT, is the location of the indicator on the movable coupling hub and the vertical distance, BS, defines the slope of the triangle's sides. HHT and HHHT are the locations for the inboard and outboard shims, respectively. Shim changes can be deter-

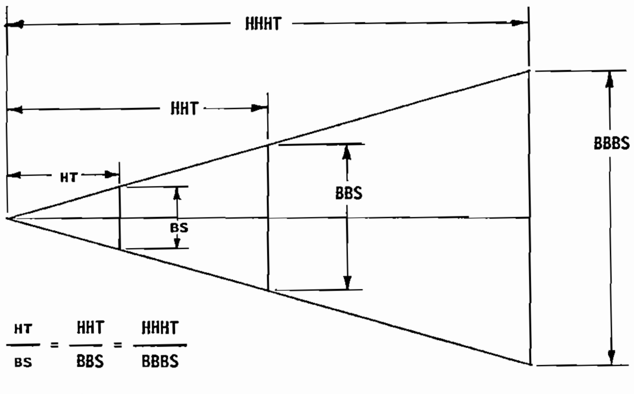


Figure 38. Base-to-Height Relationship in Scalene Triangle.

mined by (1) hand calculations using formulas, (2) graphically using a plotting board or graph paper, or (3) by using computers. The face and rim alignment method shim correction formulas are shown in Figure 39, and an example using the formulas is depicted in Figure 40. If the reverse indicator method is used, hand calculations can be obtained per the equations in Figure 41. Notice these equations allow the driven piece of equipment to be fixed or movable. Data sheets are provided in Figures 42 and 43 to record alignment readings developed for use with an alignment plotting board. For a reverse indicator alignment, example using the formulas see Figures 44, 45, and 46.

A plotting board is a good tool to use when doing alignment because it draws a picture of where the movable shaft centerline is. It transforms eight numbers around two circles into a drawing of the shafts, illustrating the parallel and angular offsets showing if

INBOARD FOOT SHIM =
C/A (FACE READING) ± (O.D. READING)/2

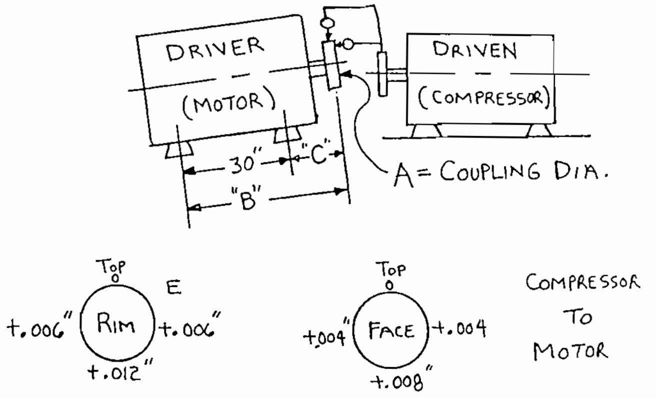
OUTBOARD FOOT SHIM =
B/A (FACE READING) ± (O.D. READING)/2

A = THE DIAMETER THE FACE READINGS WERE TAKEN ON THE COUPLING HUB OF THE DRIVER SHAFT (COUPLING O.D.)

B = THE DISTANCE FROM THE OUTBOARD FOOT TO WHERE THE READINGS WERE TAKEN ON THE DRIVER COUPLING HUB

C = THE DISTANCE FROM THE INBOARD FOOT TO WHERE THE READINGS WERE TAKEN ON THE DRIVER COUPLING HUB

Figure 39. Face and Rim Alignment Method—Shim Correction Formula.



A= 4″ , B= 39′ , C = 9″

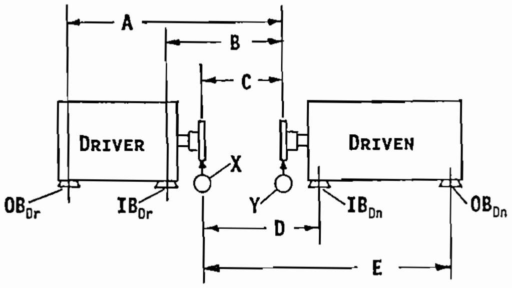
$$\text{"C" SHIM} = \frac{C}{A}\left(\text{FACE READING}\right) \pm \frac{\text{O.D. READING}}{2}$$

$$\text{"B" SHIM} = \frac{B}{A}\left(\text{FACE READING}\right) \pm \frac{\text{O.D. READING}}{2}$$

$$\text{"C" SHIM} = \frac{9}{4}(.008'') + \frac{.012''}{2} = .018'' + .006 = \underline{\underline{.024''}}$$

$$\text{"B" SHIM} = \frac{39}{4}(.008'') + \frac{.012''}{2} = .078'' + .006 = \underline{\underline{.084''}}$$

Figure 40. Face and Rim Example.



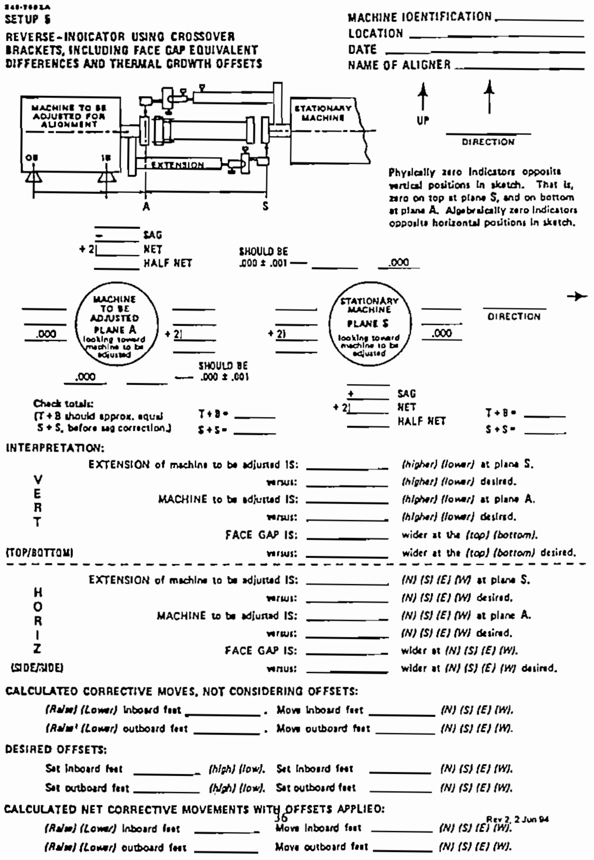
USE THESE FORMULAS WHEN DRIVER IS "MOVABLE"	USE THESE FORMULAS WHEN DRIVEN IS "MOVABLE"
$IB_{dr} = \frac{B[(X)+(Y)]}{C} - (Y)$	$IB_{dn} = \frac{D[(Y)+(X)]}{C} - (X)$
$OB_{dr} = \frac{A[(X)+(Y)]}{C} - (Y)$	$OB_{dn} = \frac{E[(Y)+(X)]}{C} - (X)$

NOTE:
POSITIVE (+) VALUES FOR SHIM CALCULATIONS INDICATE UNIT IS TO BE RAISED OR MOVED TO THE LEFT.

NEGATIVE (-) VALUES FOR SHIM CALCULATIONS INDICATE UNIT IS TO BE LOWERED OR MOVED TO THE RIGHT.

X & Y = ½ T.I.R. (AFTER SAG CORRECTION).

Figure 41. Reverse Indicator Shim Calculation Formulas



840-7602A
SETUP 5
REVERSE-INDICATOR USING CROSSOVER BRACKETS, INCLUDING FACE GAP EQUIVALENT DIFFERENCES AND THERMAL GROWTH OFFSETS

MACHINE IDENTIFICATION ____________
LOCATION ____________
DATE ____________
NAME OF ALIGNER ____________

MACHINE TO BE ADJUSTED FOR ALIGNMENT
OB
IB
EXTENSION
STATIONARY MACHINE
A
S
UP
DIRECTION

Physically zero indicators opposite vertical positions in sketch. That is, zero on top at plane S, and on bottom at plane A. Algebraically zero indicators opposite horizontal positions in sketch.

\- ______ SAG
\+ 2) ______ NET
______ HALF NET

SHOULD BE .000 ± .001 — ______ .000

MACHINE TO BE ADJUSTED PLANE A looking toward machine to be adjusted
.000
\+ 2) ______

\+ 2) ______
STATIONARY MACHINE PLANE S looking toward machine to be adjusted
.000

DIRECTION

.000 ______ — SHOULD BE .000 ± .001

Check totals:
(T + B should approx. equal S + S, before sag correction.)
T + B = ______
S + S = ______

\+ ______ SAG
\+ 2) ______ NET
______ HALF NET
T + B = ______
S + S = ______

INTERPRETATION:

VERT (TOP/BOTTOM)
EXTENSION of machine to be adjusted IS: ______ *(higher) (lower)* at plane S.
versus: ______ *(higher) (lower)* desired.
MACHINE to be adjusted IS: ______ *(higher) (lower)* at plane A.
versus: ______ *(higher) (lower)* desired.
FACE GAP IS: ______ wider at the *(top) (bottom)*.
versus: ______ wider at the *(top) (bottom)* desired.

HORIZ (SIDE/SIDE)
EXTENSION of machine to be adjusted IS: ______ *(N) (S) (E) (W)* at plane S.
versus: ______ *(N) (S) (E) (W)* desired.
MACHINE to be adjusted IS: ______ *(N) (S) (E) (W)* at plane A.
versus: ______ *(N) (S) (E) (W)* desired.
FACE GAP IS: ______ wider at *(N) (S) (E) (W)*.
versus: ______ wider at *(N) (S) (E) (W)* desired.

CALCULATED CORRECTIVE MOVES, NOT CONSIDERING OFFSETS:
(Raise) (Lower) inboard feet ______. Move inboard feet ______ *(N) (S) (E) (W)*.
(Raise' (Lower) outboard feet ______. Move outboard feet ______ *(N) (S) (E) (W)*.

DESIRED OFFSETS:
Set inboard feet ______ *(high) (low)*. Set inboard feet ______ *(N) (S) (E) (W)*.
Set outboard feet ______ *(high) (low)*. Set outboard feet ______ *(N) (S) (E) (W)*.

CALCULATED NET CORRECTIVE MOVEMENTS WITH OFFSETS APPLIED:
(Raise) (Lower) inboard feet ______ Move inboard feet ______ *(N) (S) (E) (W)*.
(Raise) (Lower) outboard feet ______ Move outboard feet ______ *(N) (S) (E) (W)*.

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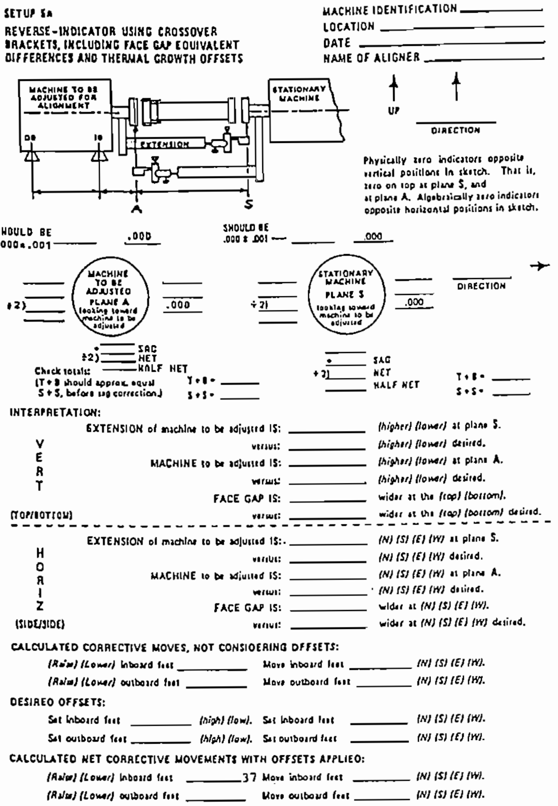
Figure 42. Reverse Indicator Using Crossover Brackets, Including Face Gap Equivalent Differences and Thermal Growth Offsets.



SETUP 5A

REVERSE-INDICATOR USING CROSSOVER BRACKETS, INCLUDING FACE GAP EQUIVALENT DIFFERENCES AND THERMAL GROWTH OFFSETS

MACHINE IDENTIFICATION ______
LOCATION ______
DATE ______
NAME OF ALIGNER ______

Physically zero indicators opposite vertical positions in sketch. That is, zero on top at plane S, and at plane A. Algebraically zero indicators opposite horizontal positions in sketch.

SHOULD BE .000±.001 ______ .000
SHOULD BE .000 ± .001 — ______ .000

MACHINE TO BE ADJUSTED PLANE A looking toward machine to be adjusted
÷2) ______ .000

STATIONARY MACHINE PLANE S looking toward machine to be adjusted
÷2) ______ .000
DIRECTION

+ ______ SAG
÷2) ______ NET
______ HALF NET

Check totals: (T + B should approx. equal S + S, before sag correction.)
T+B= ______
S+S= ______

+ ______ SAG
÷2) ______ NET
______ HALF NET
T+B= ______
S+S= ______

INTERPRETATION:

VERT (TOP/BOTTOM)
EXTENSION of machine to be adjusted IS: ______ (higher) (lower) at plane S.
versus: ______ (higher) (lower) desired.
MACHINE to be adjusted IS: ______ (higher) (lower) at plane A.
versus: ______ (higher) (lower) desired.
FACE GAP IS: ______ wider at the (top) (bottom).
versus: ______ wider at the (top) (bottom) desired.

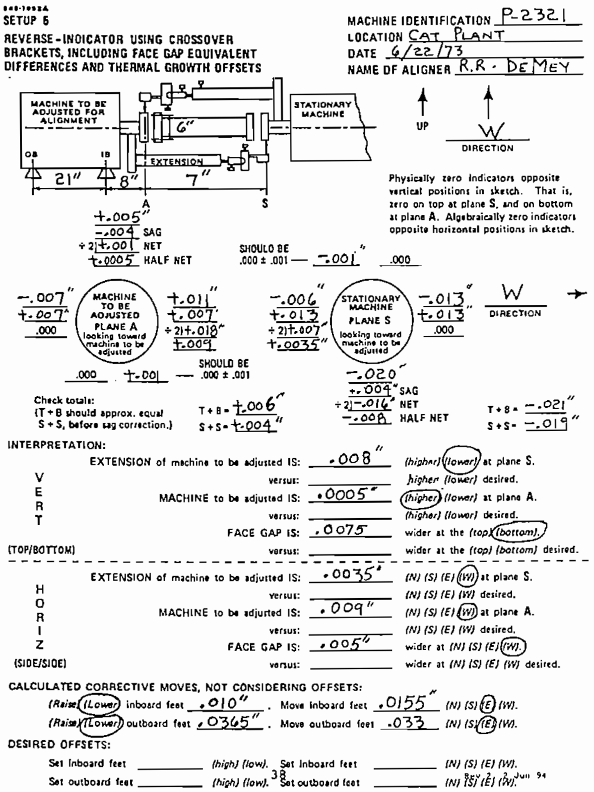
HORIZ (SIDE/SIDE)
EXTENSION of machine to be adjusted IS: ______ (N) (S) (E) (W) at plane S.
versus: ______ (N) (S) (E) (W) desired.
MACHINE to be adjusted IS: ______ (N) (S) (E) (W) at plane A.
versus: ______ (N) (S) (E) (W) desired.
FACE GAP IS: ______ wider at (N) (S) (E) (W).
versus: ______ wider at (N) (S) (E) (W) desired.

CALCULATED CORRECTIVE MOVES, NOT CONSIDERING OFFSETS:
(Raise) (Lower) inboard feet ______ Move inboard feet ______ (N) (S) (E) (W).
(Raise) (Lower) outboard feet ______ Move outboard feet ______ (N) (S) (E) (W).

DESIRED OFFSETS:
Set inboard feet ______ (high) (low). Set inboard feet ______ (N) (S) (E) (W).
Set outboard feet ______ (high) (low). Set outboard feet ______ (N) (S) (E) (W).

CALCULATED NET CORRECTIVE MOVEMENTS WITH OFFSETS APPLIED:
(Raise) (Lower) inboard feet ______ 37 Move inboard feet ______ (N) (S) (E) (W).
(Raise) (Lower) outboard feet ______ Move outboard feet ______ (N) (S) (E) (W).

Figure 43. Reverse Indicator Using Crossover Brackets, Including Face Gap Equivalent Differences and Thermal Growth Offsets.



SETUP 6

REVERSE-INDICATOR USING CROSSOVER BRACKETS, INCLUDING FACE GAP EQUIVALENT DIFFERENCES AND THERMAL GROWTH OFFSETS

MACHINE IDENTIFICATION P-2321
LOCATION CAT PLANT
DATE 6/22/73
NAME OF ALIGNER R.R. DEMEY

Physically zero indicators opposite vertical positions in sketch. That is, zero on top at plane S, and on bottom at plane A. Algebraically zero indicators opposite horizontal positions in sketch.

+.005"
-.004 SAG
÷2) +.001 NET
+.0005 HALF NET

SHOULD BE .000 ± .001 — -.001" .000

MACHINE TO BE ADJUSTED PLANE A looking toward machine to be adjusted
-.007"
+.007"
.000
+.011"
+.007
÷2) +.018"
+.009

.000 +.001 — SHOULD BE .000 ± .001

STATIONARY MACHINE PLANE S looking toward machine to be adjusted
-.006"
+.013
÷2) +.007"
+.0035"
-.013"
+.013"
.000

W DIRECTION

-.020"
+.004" SAG
÷2) -.016" NET
-.008 HALF NET

Check totals: (T + B should approx. equal S + S, before sag correction.)
T+B= +.006"
S+S= +.004"
T+B= -.021"
S+S= -.019"

INTERPRETATION:

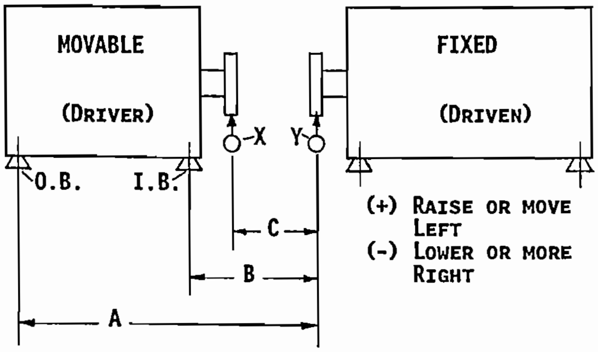
VERT (TOP/BOTTOM)
EXTENSION of machine to be adjusted IS: .008" (higher) [✓ (lower)] at plane S.
versus: ______ higher (lower) desired.
MACHINE to be adjusted IS: .0005" [✓ (higher)] (lower) at plane A.
versus: ______ (higher) (lower) desired.
FACE GAP IS: .0075 wider at the (top) [✓ (bottom)].
versus: ______ wider at the (top) (bottom) desired.

HORIZ (SIDE/SIDE)
EXTENSION of machine to be adjusted IS: .0035" (N) (S) (E) [✓ (W)] at plane S.
versus: ______ (N) (S) (E) (W) desired.
MACHINE to be adjusted IS: .009" (N) (S) (E) [✓ (W)] at plane A.
versus: ______ (N) (S) (E) (W) desired.
FACE GAP IS: .005" wider at (N) (S) (E) [✓ (W)].
versus: ______ wider at (N) (S) (E) (W) desired.

CALCULATED CORRECTIVE MOVES, NOT CONSIDERING OFFSETS:
(Raise) [✓ (Lower)] inboard feet .010". Move inboard feet .0155" (N) (S) [✓ (E)] (W).
(Raise) [✓ (Lower)] outboard feet .0365". Move outboard feet .033 (N) (S) [✓ (E)] (W).

DESIRED OFFSETS:
Set inboard feet ______ (high) (low). Set inboard feet ______ (N) (S) (E) (W).
Set outboard feet ______ (high) (low). 38 Set outboard feet ______ (N) (S) (E) (W). Rev 2, 2 Jun 94

Figure 44. Reverse Indicator Using Crossover Brackets, Including Face Gap Equivalent Differences and Thermal Growth Offsets.



$$I.B._{shim} = \frac{\underline{B\ [(X) + (Y)]}}{C} - (Y)$$

$$O.B._{shim} = \frac{\underline{A\ [(X) + (Y)]}}{C} - (Y)$$

NOTE:

VALUES FOR "X" AND "Y" ARE ½T.I.R. READINGS (AFTER SAG CORRECTIONS).

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Figure 45. Reverse Indicator Shim Calculation Formulas—Example.

A = 36", B = 15", C = 7"

X = -0.0005", Y = - 0.008"

VERTICAL:

$$I.B._{shim} = \frac{\underline{15\ [(-0.0005") + (-0.008")]}}{7} - (-0.008")$$

$$I.B._{shim} = -0.0182" + 0.008" = \underline{-\ 0.010"}\ \text{(LOWER)}$$

$$O.B._{shim} = \frac{\underline{36\ [(-0.0005") + (-0.008")]}}{7} - (-0.008")$$

$$O.B._{shim} = -0.0437 + 0.008" = \underline{-\ 0.036"}\ \text{(LOWER)}$$

Figure 46. Reverse Indicator Shim Calculation Formulas—Example.

shims need to be added or removed. On top of that, it requires no batteries. If the reader does not have one of these plotting boards, get one. A plotting board was used in Figure 47 to solve for the shim changes required in the example shown in Figures 45 and 46. All the examples shown solve for the vertical shim corrections, but the horizontal solutions use the same formulas and techniques except rotated by 90 degrees. As a general practice, the author does not make a shim correction for values less than 0.005 in. On pump applications above 50 hp, moves of 0.005 in will not be detected at the dial indicators.

The following is a comparison of the shim changes using the equations, the plotting board, and a computer program.

- *Equations*
  - IB = -0.010 in (lower)

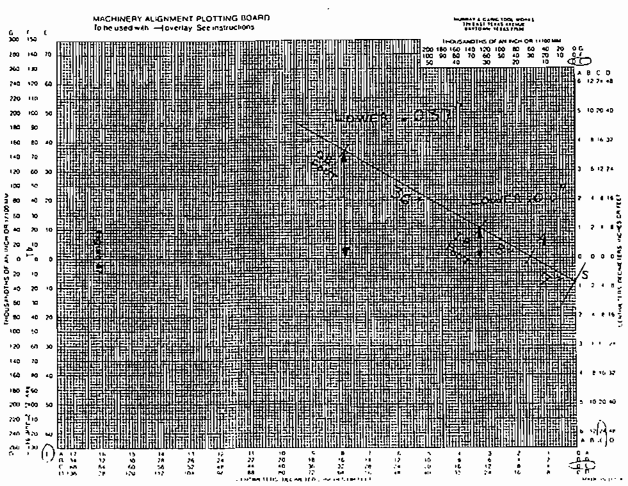


Figure 47. Machinery Alignment Plotting Board.

  - OB = -0.036 in (lower)
- *Plotting Board*
  - IB = 0.010 in (lower)
  - OB = 0.037 in (lower)
- *Computer*
  - IB = -0.0102 in (lower)
  - OB = -0.0357 in (lower)

Notice how close the solutions are, a maximum difference of 0.0013 in. The pocket computer with alignment and balancing programs cost $1000 as compared to $35 for the plotting board. Plotting boards help prevent the millwrights from making mistakes in adding or subtracting shims because it reduces math errors.

Once the alignment process is in progress, the operator must know when to stop. If the operator continues to make shim changes to obtain perfect alignment, he is wasting time and money. In most cases, perfect alignment is not desired. Journal bearings and gear coupling require a small amount of eccentricity for proper lubrication. A graph for acceptable alignment tolerances based on speed and shaft distances is shown in Figure 48. Notice that the rule of thumb alignment of 0.0005 in per inch of shaft separation gives acceptable alignment up to 14,000 rpm. Most of the rotating equipment that we align is below 5000 rpm.

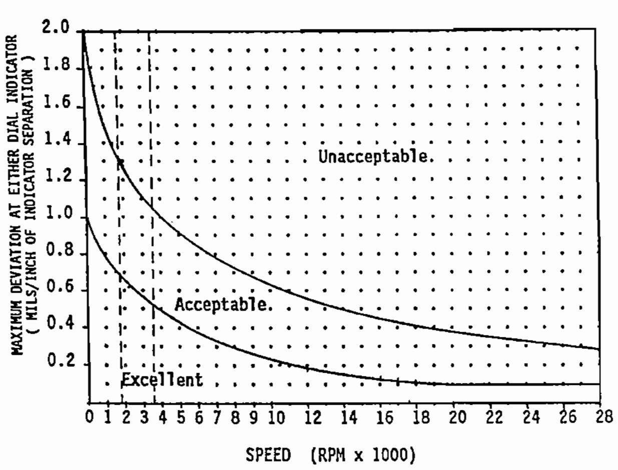


Figure 48. Guideline for Alignment Tolerances.

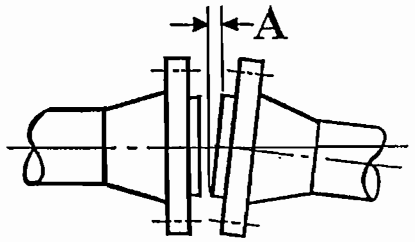
PIPING

If the previous procedures had been followed to the letter, the pump could be doomed to an early failure because of piping. It seems that most pipe stress analysts believe that pumps and compressors are designed as anchors for piping. In large new construction projects, 90 percent of the piping is installed before the pumps are in place. As soon as the pipe racks are up, the piping goes in. The following rules-of-thumb should be adhered to when piping is attached to the pump to prevent shaft misalignment.

- Concentricity of the flanges should be such that the bolts can be inserted into the flange holes with finger pressure only. No spud wrenches or come-a-longs are to be used to align the flange holes.

- Parallelism of the flange gasket surfaces are to be limited to 0.002 in/in of nominal pipe size, with a maximum of 0.030 in (4 in pipe: 4 × 0.002 in = 0.008 in max). A 16 in pipe would have a maximum flange out-of-parallelism of 0.030 in (Figure 49).

Pipe sizes under 3.0 in are flexible enough to allow a 0.008 in maximum out-of-parallelism on the gasket mounting surfaces. Vertical inline pump flanges under 3.0 in can have a maximum out-of-parallelism of 0.020 in without causing shaft alignment problems.



A = 0.002"(Nominal Pipe Dia.)

For 4" pipe:
A = 0.002"(4) = 0.008"

For 16" pipe:
A = 0.002"(16) = 0.032"
Limit to max of 0.030"

Figure 49. Rule-of-Thumb Tolerances for the Installation of Piping to the Pump.

- The flange gap at the gasket surfaces is 0.063 in, plus the gasket thickness.

There are steps that can be taken to minimize the effects of piping on pumps.

- The last 20 ft of piping to the pump suction and discharge flanges should be installed after the pump is grouted and aligned. Both suction and discharge piping flanges, with gaskets, should be four-bolted to the pump flanges and the piping field fitted back to the pipe headers.

- Dial indicators should be installed from the driver to the pump to monitor movement when the piping is bolted up. The maximum acceptable movement is 0.002 in.

- Modify existing flange tightening procedures to the following. Tighten the flange bolts to $^1/_3$ the design torque using a crisscross pattern. This reduces the possibility of cocking the flanges and causing shaft movement. Make a second pass on the bolts tightening them to $^2/_3$ their design torque in a crisscross pattern. The bolts are then tightened to the designed torque level in a crisscross pattern. A final bolt torque is made in a circular pattern.

If these steps are followed, the pump flange loads will be at a minimum and pump life at a maximum.

CONCLUSION

In order to improve pump life, there must be written procedures and these procedures adhered to. Once there is agreement between the engineering/construction team and the owner, an enforcer must be assigned to see that it gets done. You only get what you inspect. We know how to improve pump reliability, we just cannot agree who will pay for it or do it!