GROUTING OF SMALL PUMP BASEPLATES? IS IT WORTH IT?

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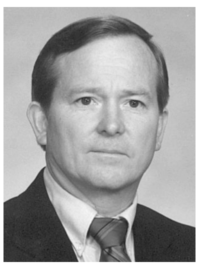

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ABSTRACT

For pump installation most experts recommend installing conventional metallic baseplates on concrete foundations and securing them to the foundation with a combination of anchor bolts and epoxy grout. Many papers have been written on the techniques required to obtain a good quality installation free of voids and properly bonded to the concrete and baseplate itself so as to give a long trouble-free installation life. There is no question that such installations provide a basis for highly reliable pumps that operate at low vibration levels. However when this installation strategy is viewed in terms of the total cost of ownership for the pump, is it really cost effective?

This paper examines the total cost of installation of *small* pumps using conventional metallic baseplates installed with epoxy grout and contrasts this installation strategy with several alternatives. Among these alternatives are polymer concrete baseplates, polymer concrete foundation systems, and pregrouted conventional metallic baseplates. Reliability and vibration data for each installation strategy are presented and the impacts of relative reliability are examined in light of total cost of ownership.

WHY ASK THE QUESTION?

Machinery alignment is critical to reliability. In the 1960s and 1970s dozens of technical papers dealt with the impact of alignment on machinery failures. At that time as many as twothirds of all pump failures were claimed to be due to poor alignment practices. The oil and chemical processing industry as a whole focused on eliminating alignment as a major cause of equipment failure. The efforts in this area fell into two categories:

- Improvement of alignment and thermal growth prediction techniques and
- Improvement of installation techniques.

Improvement of installation techniques included improved grout placement practices as well as improved pipe fitting, etc.

Until 10 or 15 years ago the majority of pump users installed conventional metallic baseplates using cementatious grouts. With these installations it was very common for voids to develop between the grout and the baseplate, often the interface rusted causing separation. As these installations deteriorated baseplate stiffness was lost and baseline pump vibration levels would climb and ultimately expensive repairs were necessary. Users began applying epoxy grouts to pump installations and these problems were perceived to disappear. By the early 90s a survey of users by the API 610 Task Force could not find a single API member company that did not specify epoxy grouts for pump installation. This resulted in the API 610 (1995) Appendix covering installation of cementatious grouts being dropped from the Eighth Edition.

If application of epoxy grouts solved all these problems, why ask if grouting pump baseplates with epoxy is cost effective? The answer is because the conversion to epoxy brought with it another set of controversies and problems. This paper discusses only a few.

It is a fact that to obtain the full bond strength the grout should be applied to clean bare metal, sandblasted to SSPC SP6 or ISO 8501 Grade Sa2. This requirement means that all the machines must be removed from the baseplate and the bottom of the baseplate sandblasted immediately before installation, leveling, and grouting. In high humidity areas like the Gulf Coast there are occasions when a rust blush would appear between sandblasting and the completion of leveling. If the baseplate was not grouted within 48 hours of sandblasting it was highly likely that a rust blush would appear. This appearance of a rust blush would initiate the next round of controversy. Is the rust blush tolerable or must the leveled baseplate be removed and the sandblast be repeated? Regardless of which side of the argument you agree with, it is a fact that the existence of the argument leads to construction delays and conflict between the machinery inspection quality assurance (QA) forces and the construction management. This equals additional project cost and gives the construction contractor a scapegoat for cost and schedule overruns. The direct result of these controversies was that the industry generally moved on to application of compatible primers to the grout contact surfaces.

The first controversy that arose with primers was compatibility. Exactly what primer is on the baseplate and will it work with grout brand A? If it is compatible with grout brand A, when was it applied and has it completely cured to where it will not bond? Did this latter issue even make sense? Is the primer clean enough? How clean must it be? All these controversies resulted in another round of conflict between QA/inspection forces and construction management. In a number of companies, instructions for installation mostly solved these problems with statements similar to the following: "Clean the bottom of the baseplate by wiping with soap and water to remove all dirt. Follow this by wiping an epoxy compatible solvent and place the grout. This will result in a satisfactory bond when combining the grout interlocking geometrically with the structural members on the underside of the baseplate."

It is rare for this advice to be accepted without still another round of costly controversy.

The grout compatibility controversy was pretty widespread. During the final review of API 610 Eighth Edition (1995) there was a major debate over the issue of allowing the purchaser to specify the epoxy primer. Pump manufacturers objected on the basis that use of other than the primers they had "certified" would violate their environmental permits. (Today it is unclear to the authors whether this was true.) A small team was chartered to investigate the primer issue and came to the conclusion that inorganic zinc silicate primer was compatible with "all" epoxy grouts. This was duly specified in the Eighth Edition (API 610, 1995) and J-hooks were required on the bottom of the baseplates to ensure a mechanical lock. Neither of these measures was enthusiastically received by the industry and both requirements have disappeared from the Ninth Edition (API 610, 2003).

In spite of the requirement in API 610 and many user specifications that the grout holes be located such that grout can be placed and properly vented without the removal of the equipment, the fact is, this is neglected in baseplate design or in many cases impractical for small machines. The result is that it is widely perceived to be necessary to remove the machines from the baseplate to place the grout. (It is noted that API/PIP 686 (1996), paragraph 3.12.5, requires equipment to be removed unless otherwise specified.) This allows the mounting surfaces to be exposed to the elements and the formation of the rust blush and now they must be cleaned and how clean is clean enough and construction management is involved in a controversy resulting in more construction delays and more finger pointing.

Perhaps the most amazing grout controversy is the brand selection. For whatever reason most plants tend to apply/standardize on a particular brand of grout. When a large project arrives invariably there is an argument unless the project plans to use the location's preferred grout. The authors of this paper have significant amounts of experience with many brands of grout. They have found that applied properly per the manufacturer's instructions they are all good products that yield good results (noted controversies not withstanding). In spite of this there are an amazing number of customers who are absolutely positive that the only grouts that are acceptable are the ones they have chosen.

In spite of all these controversies, the authors and their colleagues continued to support the use of epoxy grouts for installation of pumps. This support was finally shaken in 1999. On two projects, one in Canada and one in Houston, baseplates were found to be distorted such that they failed to meet the API 686 (1996) requirement to be level within 0.002 inch/ft for API pumps and 0.005 inch/ft for ASME pumps. These two projects involved about 250 pumps about half of which were ASME pumps supplied with a Process Industries Practices (PIP) type baseplate. Only a fraction of the API pump baseplates were distorted but nearly all the ASME bases were. Without sufficient investigation—that is, with a grotesquely inaccurate, low estimate of cost to field machine—the pump manufacturer gave instructions to field machine the distorted baseplates as a matter of warranty. Approximately a quarter of a million dollars later a root cause analysis team was formed. Ultimately approximately 150 baseplates were field machined at a cost of more than $300,000.

BASEPLATE DISTORTION

The baseplate distortion varied in amount but invariably followed the same pattern. The center of the baseplate "sank" causing all the mounting surfaces to be out of level with the mounting surface edge closest to the nearest side of the baseplate to be high. This pattern is represented in Figures 1 and 2. Field machining was felt to be necessary because typical values of level after cure for the ASME pumps were .010 to 0.012 inch/ft both axially and transversely. This condition is essentially impossible to shim out because the shims must taper in two directions to correct the condition. The baseplate distortion issue was further complicated by National Electrical Manufacturers Association (NEMA) frame motors failing soft foot tests.

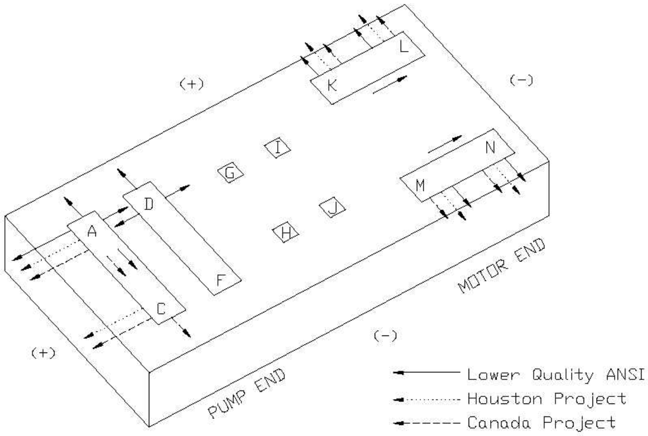

Figure 1. Pattern of Level Measurements. (Arrows point to high side.)

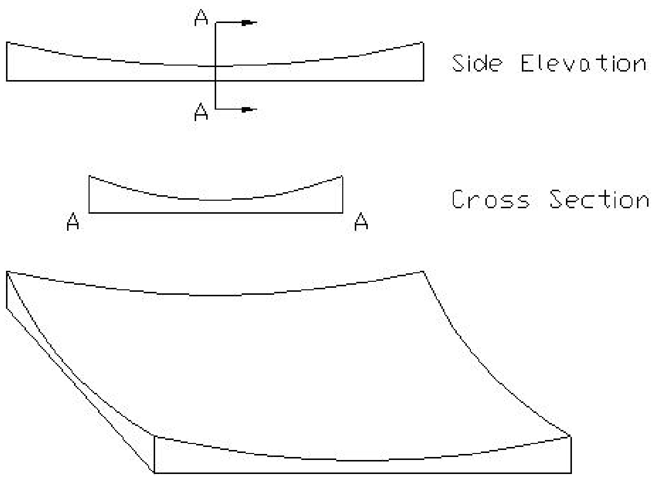

Figure 2. Typical Pattern of Baseplate Distortion.

SIDE ISSUES, NEMA FRAME MOTOR FEET AND SOFT FOOT CRITERIA

On the Houston and Canada projects approximately 3 percent of NEMA frame motors failed soft foot tests. It was discovered that the bottom of motor feet were typically out of flatness. This issue was investigated with the manufacturer and was found to likely be related to the manufacturing process. The motor feet are machined first and then used for a reference point for the bore of the motor body. After this machining is completed the stator is pressed in with an interference fit. This "stretches" the material between the motor feet resulting in the outside edges of the motor feet being high. That is, a motor set on a flat surface would rest on the inner edges of the feet. Depending on the stator being on the high side and the bore being on the low side, some number of these motors then fail the 0.002 inch API 686 (1996) soft foot test. Experiments were conducted with the motor manufacturer simulating out of flatness up to 1/32 of an inch with no change in motor vibration or bearing temperature. Based on this further motor machining was avoided. It should be noted that since this project this phenomenon has been observed on NEMA frame motors from three manufacturers. It is not unique to the original supplier.

It is noted that the 0.002 inch is a soft foot tolerance that has been accepted industry wide for more than 20 years and has been in the authors' company installation specifications for more than 25 years. NEMA on the other hand has no stated tolerance for foot planeness. IEEE 841 (2001), which upgrades NEMA requirements to produce a premium motor, establishes a limit of .005 inch. Unfortunately IEEE 841 (2001) does not have any figures showing what the .005 inch applies to. There are at least three cases of angular out of planeness that are unclear in the specification. However all four of the cases, including parallel out of plane, can result in a motor meeting the IEEE 841 (2001) specification and failing the .002 inch soft foot test. Of the four "foot out of plane" cases only the parallel out of plane case can be effectively shimmed out. Shimming takes about an hour and typically two craftsmen are involved.

It typically costs about $400 plus staff/craft time to remove/replace the motor, place an order to machine, and remachine the motor feet. This gets into the neighborhood of $1000 per event. The aggravation factor is unacceptable. The manufacturer footed the bill to remachine these motors but they pointed out that the motors were in specification.

Another side issue is that the origin of the .002 inch criterion is unclear. It is crystal clear that in the years that this criterion has been applied the author's company and the industry have enjoyed huge increases in the reliability of the equipment installed. This results in a dilemma. There are two conflicting specifications, (i.e., NEMA and 686 soft foot) both of which probably exist for a reason. The authors however do not know the reasons. In the absence of data they have not changed their requirements, however they recommend a change to API/PIP 686 (1996) or at least a justification of the criterion. It is likely that the industry should adopt soft foot test acceptance criterion dependent on machinery type.

GROUT BRANDS AND PLACEMENT

As soon as the baseplate distortion issue occurred the construction and quality assurance/quality control (QA/QC) teams began looking for answers. Why is this happening? Why have we not detected it before? Is it something we are not doing right?

The first measure was to bring the grout manufacturer in to supervise grout placement. The baseplates still distorted. Grout brands were changed and grout was placed under supervision of the new brand's service representative. We experimented with multiple pours. A lot of time and effort were spent but the distortion of these baseplates continued.

The machinery QA/QC engineer from a previous, successful project was consulted. That project had used still another grout but had grouted the equipment with the pumps and motors on the baseplate. Level readings were attempted to see if the postgrouting distortion had simply been overlooked. These readings were inconclusive according to the Houston projects' QA/QC engineers because there was not a great deal of room to place the level on the edges of the machined pads. The baseplates appeared to be level but it is possible that the readings were not completely accurate (in some cases only a fraction of the length or width of the level could be placed on a machined surface). This particular project did not field machine any baseplates, had a very happy project manager, and since start up has enjoyed a very favorable mean time between maintenance (MTBM) relative to both other units at the site and to all of the authors' company's U.S. facilities.

BASEPLATES

The ASME baseplates in question comply with PIP RESP002. The most numerous of the pumps used the design shown in Figure 3. This baseplate had been on the market with no changes in design for seven years. The manufacturer had very few complaints and had no plans to improve it. The two projects the authors have referred to were the first to report significant numbers of problems with the baseplate. Subsequently several other major projects detected the same distortion.

Working with one grout manufacturer, the authors initiated testing to find out what was going on. It was found that the "nonshrink" grout was in fact shrinking. There is apparently no ASTM test for volumetric shrinkage of epoxy grouts. The test cited by grout manufacturers (ASTM C531, 2000) is a linear shrinkage test and does not seem to adequately predict the behavior of the

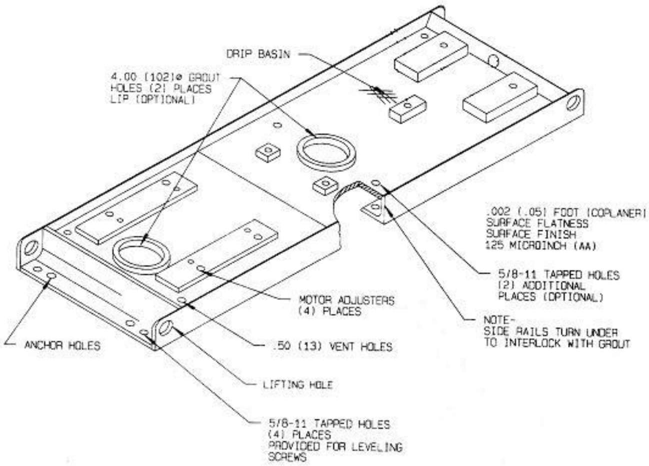

Figure 3. PIP Type Baseplate.

grout under this type of baseplate. The ASTM data given by grout manufacturers investigated was factual and correct. Figure 2 was developed from the actual tests completed.

The tests conducted to investigate shrinkage showed that the center of the baseplate sank straight down. This caused the machined surfaces, which were stiffer, to slope upward toward the edges of the baseplate. This pattern of distortion suggested that placing a stiffening member across the baseplate under the motor pads where the majority of the deflection was found and an additional member under the pump might solve the problem. Twelve modified baseplates were manufactured in time to be used on the Houston project. Ten of the 12 stayed with tolerance and two were marginally out of tolerance after the grout cured. Clearly there are very large forces at work here. Also note that these baseplates were primed with inorganic zinc silicate. Prior to grouting, the baseplate was wiped down with solvent until there was no visible contamination. If the authors ever had any concern about bond strength with a properly applied primer, they thought they had it no longer.

In a subsequent project the authors had no significant deflection issues but found that they had large voids. To investigate they took core samples and found that the grout had pulled a layer of the primer away from the baseplate. The baseplate remained coated with primer. The problem was that the primer is not as strong as either the steel or the epoxy grout and separated. It was found that the primer was applied to the baseplate in too thick a layer.

On the Canada project the authors initially focused on grouting API pumps thinking that the stiffer baseplates were more likely to stay within specification and that this would give them some time to find a solution for the ASME baseplates. In grouting the first 30 API baseplates, five baseplates from two manufacturers failed to stay in tolerance. One of the failing baseplates was impressively stiff in appearance. This confirmed that they really did not know what was going on and that this was not solely a baseplate design issue but also a grout performance issue.

ALTERNATIVE PUMP SELECTION AND INSTALLATION STRATEGIES

Vertical Pumps

The authors' company has routinely applied vertical pumps for about 50 years. Internationally that company's favorite pump has been the close coupled vertical inline. This pump has been abandoned by most user companies in North America and is noted to not be completely API compliant. In North America we prefer to apply OH3 type (bearing bracket) vertical inlines. Unfortunately, the hydraulic coverage available from preferred vendors has been rather limited until the last year or so and usually net positive suction head required (NPSHR) is slightly higher than for a comparable horizontal pump. Additionally there are significant numbers of rotating equipment staff who believe that vertical inlines are less reliable than horizontal pumps.

In order to consider wider application of vertical pumps (including close coupled units) the authors investigated relative reliability within their chemical plant sites. The authors were completely appalled to find that they had (in violation of their selection guidelines) purchased significant numbers of OH4 and OH5 pumps. OH4 pumps are rigidly coupled vertical inlines and OH5 pumps are close coupled vertical inlines. The reliability of all single-stage overhung pumps installed in chemical facilities from 1991 to 2001 is shown in Figure 4.

In Figure 4, the length of the bar is reflective of the 95 percent confidence limits given the size of the sample. OH1 through OH6 are the API pump types identified in API 610 (1995) (ISO 13709). The longer bars indicate smaller sample sizes. The results of this analysis were initially somewhat surprising to the authors. However, discussion of their surprise is outside the scope of this paper. Suffice to say, their data say that single-stage overhung vertical inline pumps are at least as reliable as SSOH horizontal pumps.

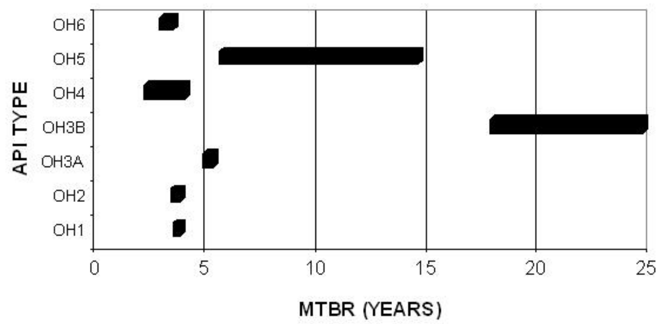

Figure 4. Single-Stage Overhung Pump Reliability in U.S. Chemical Plants.

The authors will not investigate relative installation costs of vertical and horizontal pumps in this paper. They will postulate that vertical pumps are less expensive to install and let it go at that. They will however use some vertical/horizontal comparative data to further question the need to grout small pumps to concrete foundations.

It is a normal "rule of thumb" that the foundation should have a mass three times that of the equipment. What is the mass of the equipment? Does it include the mass of the seal auxiliaries? Does one need a larger foundation if one installs the seal pot and/or exchanger on the baseplate as opposed to off? How do vertical pumps fit into this puzzle?

Data show that vertical pump reliability competes well with horizontal pump reliability. Horizontal pumps have massive foundations. Examine this: the authors took two services that could be handled by ASME pumps. They then selected a horizontal (OH1) and a vertical (OH3) pump to handle the head and flow. They then examined the weight of the pumps and their rotors. Tables 1 and 2 show comparisons of total rotating weight to total equipment weight with no auxiliaries.

Table 1. Pump Rotating and Total Assembly Weight.

ASME Pump Weights								
Pump Type	Max Motor Size	Pump Rotor Weight	Bare Pump Weight	Baseplate Weight	Motor Rotor Weight	Bare Motor Weight	Total Rotor Weight	Total Weight
OH3A	284TS (25HP)	17	166	0	75	336	92	502
OH1	286TS (30HP)	17	124	212	85	410	102	746
OH3A	365TS (75HP)	26	307	0	157	875	183	1182
OH1	365TS (75HP)	30	225	328	157	875	187	1428

Their data say that vertical and horizontal pump reliability is at least comparable, yet heavier horizontal pump assemblies require an additional foundation of 3× total mass/weight epoxy grouted

Table 2. Ratios of Rotor to Total Weight.

Rotor/Total Weight Ratios and Forces					
Pump Type	Max Motor Size	Ratio of Rotor to Total Weight	Allowable Unbalance (Oz-in)	Unbalance Force	Unbalance Force @ 10X Limit (lb)
OH-3A	284TS (25HP)	0.1833	0.3843	8.83	88.35
OH1	286TS (30HP)	0.1367	0.4261	9.80	97.96
OH3A	365TS (75HP)	0.1548	0.7644	17.57	175.73
OH1	365TS (75HP)	0.1310	0.7811	17.96	179.57

to the earth's soul? And why is this? The answer is of course related to nozzle loads and the ability to maintain alignment.

At the time that the authors began gathering and analyzing the data for this paper the lack of the hydraulic coverage issue prevented them from wholesale application of vertical pumps. Instead they investigated several other alternatives.

Polymer Concrete

Polymer concrete baseplates eliminate equipment removal, primer, grout distortion, and void concerns. In addition, the polymer concrete baseplates are corrosion resistant and have a lower installation cost than traditionally grouted baseplates (Figure 5).

Figure 5. Polymer Concrete Baseplate During Installation.

Installation cost is lower because the baseplate itself is less expensive than a comparable metal baseplate, less grout is required (only a seal pour between the baseplate and the foundation), and the leveling and installation process is faster. Refer to estimates later in this paper.

Unfortunately, this type of baseplate is only available for ASME pumps. Also, extra care must be taken with training craftspeople how to install these baseplates, as they can be easily broken if handled improperly. The authors' experience is that every project breaks one of the first 10 installed and then has no further problems.

Polymer Concrete Foundation

Polymer concrete foundation systems combine a baseplate with a foundation in a hollow shell configuration. These systems are installed by placing the shell over a rebar cage and filling the shell with concrete or cementatious grout (Figure 6).

These baseplates have been available for quite a long time but have been marketed for their corrosion resistance. However in addition to having all the benefits described above for a polymer concrete baseplate, the installation costs of a polymer concrete foundation system are lowered even further by eliminating the time and cost of constructing a separate concrete foundation.

Once again, the standard product lines of this type of baseplate can only be used with ASME pumps. They are only available for

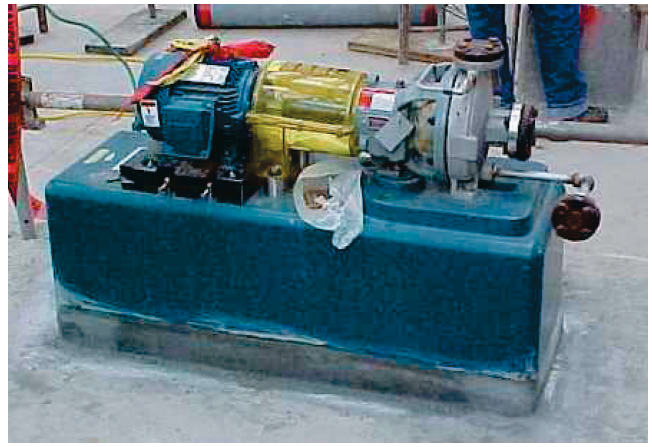

Figure 6. Polymer Concrete Foundation During Installation.

API pumps on a special order basis with negative impact on their cost effectiveness. Extra care must again be taken with training craftspeople in proper installation techniques.

Pregrouted Baseplates

The pregrouted baseplate has been gaining popularity in recent years. This type of baseplate system is produced by turning a conventional metallic baseplate upside down and filling the cavity with epoxy grout while still at the manufacturer (Figure 7). This strategy saves cost in the fabrication of the baseplate because grout placement holes, vent holes, and other features are not required.

Figure 7. Pregrouted Baseplate Bottom.

Pregrouting uses more or less conventional API and PIP type baseplates without grout holes, so the pump manufacturer is not required to deviate significantly from their standard baseplate construction practices.

Pregrouting eliminates the need for primer. Pregrouted baseplates can be sandblasted and grout applied within eight hours. If this is done, a primer is not necessary.

Pregrouting eliminates the need to remove equipment from the baseplate prior to installation in the field. This however has not stopped certain projects from doing it anyway.

Pregrouting eliminates grout distortion concerns. When a traditionally grouted baseplate is curing, the force exerted on the metal by the grout as it shrinks can be great enough to pull the pump machined surfaces out of level. With pregrouting, the grout is allowed to cure first, and then the equipment mounting surfaces can be finish machined.

Pregrouting can be used with both ANSI and API pumps.

Pregrouting was believed to prevent voids from forming at the time of grouting since the baseplate is upside-down at grouting.

The authors are currently involved with investigating large voids that have magically formed on pregrouted baseplates. These are believed to be due to improper grout placement (i.e., the baseplates were hot from sitting in the sun prior to grouting).

Due to the additional labor and grout costs, pregrouting leads to higher initial baseplate costs. The grout can also add hundreds or even thousands of pounds to a pump unit's weight, so shipping costs can increase. However, all costs are still believed to be less than for a conventionally grouted baseplate.

PERFORMANCE OF ALTERNATIVES

TIC Models

In examining the issue of whether it is worth the investment to epoxy grout pump baseplates, it is necessary to examine total installed cost (TIC) and total cost of ownership (TCoO) for pumps. In the models the authors will examine they will make a number of assumptions and they will ignore energy costs and lost production costs. Energy costs are ignored because they are more or less fixed once the service is defined and the pump is selected. Lost production costs are ignored because the machines they are discussing are nearly always spared. They will examine two "average pumps." The two pumps in question are a 15 horsepower ASME and a 40 horsepower API.

The assumptions made in this analysis are:

- The average repair cost for an ASME pump is $5200.
- The average repair cost for an API pump is $8900.
- Both pumps are spared and production losses do not occur.
- The mean time between maintenance for ASME pumps is two years.
- The mean time between maintenance for API pumps is four years.
- The interest rate used in calculating present value is 3 percent.

With these assumptions the TCoO appears in Table 3. The authors note that TIC varies somewhat with installation strategy. However, the variation is relatively small compared with TIC so this variation will be ignored. Note also that as MTBM declines the lifetime maintenance costs go up very quickly. Note that the Lang factor times the bare equipment costs results in the total installed cost, TIC.

Table 3. Total Cost of Ownership of ASME and API Pumps.

Total Cost of Ownership for Pumps		
	ASME	API
Bare Cost:	$12,500	$40,000
Lang Factor:	6.50	3.25
Total Installed Cost:	$81,250	$130,000
Life Time Maintenance Costs:	$21,254	$37,090
Spares Inventory Costs:	$4,243	$14,120
Total Cost of Ownership:	$106,747	$181,210

Next examine the relative costs of various installation strategies. Estimates are based on the detailed steps required to install the various baseplate options. These steps are shown in Table 4 for a conventional metallic ANSI pump baseplate. Similar tables were created for various sizes of baseplates and for each installation strategy. Table 5 shows that the costs are not much different between various sizes of ASME baseplates. Likewise there is not a great deal of difference between API and ASME baseplates so only ASME pumps are shown.

After completing estimates throughout the ANSI size range for all options, the authors chose a representative size and used this for the comparison shown in Table 6.

Table 4. Baseplate Installation Steps.

Conventional Metallic Base Labor	Labor Cost $40 Work-hour		
ANSI Pump Installation Steps	Crafts Persons	Hours to Complete	Total Work-hours
Roughen paving to remove laitance to pour foundation	2	3	6
Dowel paving and install rebar support system	2	2	4
Pour pump foundation on top of paving	4	2	8
Roughen foundation top surface to remove laitance	2	3	6
Clean out anchor bolt sleeves and seal	2	2	4
Inspection and prepare the pump base	2	2	4
Set base to center line and elevation	2	3	6
Level with jack bolts using pump and drive mounting pads	2	2	4
Check equipment alignment and coupling spacing	2	4	8
Form base for grouting	2	2	4
Pour first lift (grout or concrete)	4	4	16
Grout Clean Up from First Lift	2	1	2
Pour second lift to top baseplate	4	4	16
Grout Clean Up from Second Lift	2	1	2
Check for voids	1	1	1
Check for levelness after grout cures	2	2	4
Remove forms	2	1	2
Remove jack bolts and fill the holes	2	1	2
Fix voids in base	2	2	4
Total Work Hours per Option			103
Labor Cost			$4,120

Table 5. Cost Comparison for Various Sizes of Baseplates.

Pump Group	Baseplate No.	Base Cost	Foundation Concrete Cost	First Pour Epoxy Grout Cost	Second Pour Epoxy Grout Cost	Installation Labor Cost	TIC
GP 1	139	$1,310	$201	$50	$124	$4,120	$5,805
	148	$1,472	$290	$72	$212	$4,120	$6,166
GP 2	245	$1,498	$229	$57	$143	$4,120	$6,047
	252	$1,384	$313	$77	$231	$4,120	$6,125
	258	$1,523	$396	$98	$304	$4,120	$6,441
GP 3	368	$1,752	$594	$147	$511	$4,120	$7,124

Table 6. Cost Comparison of Various Options.

Base Cost	Foundation Concrete Cost	First Pour Epoxy Grout Cost	Second Pour Epoxy Grout Cost	Installation Labor Cost	TIC
Conventional Metallic Base					
$1,523	$396	$98	$304	$4,120	$6,441
Polymer Concrete Base					
$1,028	$396	$98	xxx	$2,120	$3,643
Polymer Concrete Foundation					
$2,150	$0	xx	xxx	$1,760	$3,910
Pre-Grouted Metallic Base					
$2,727	$0	$98	xxx	$2,760	$5,585

From these data the low cost option is shown to be the polymer concrete baseplate on a conventional concrete foundation. The options are ranked from least costly to most costly in Table 7.

Table 7. Cost Ranking and Deltas.

Option	TIC	Cost Premium
Polymer Concrete Baseplate	$3643	Zero, Low Cost Option
Polymer Concrete Baseplate/Foundation System	$3910	$267
Pre-Grouted Metallic Baseplate	$5585	$1942
Conventional Metallic Baseplate with Epoxy Grout	$6441	$2798

Note that these cost estimates do not include any cost for problems encountered during the installation of conventional baseplates such as pumping voids and field machining. Further if the deltas are compared to the TCoO of an ASME pump in Table 3, one can see that the choice of installation strategy can add 0.25 to 2.6 percent to the TCoO. Given this the authors have a glimmer of understanding as to how some companies have decided to "stilt mount" such pumps.

The obvious next question is what about reliability? Does the conventional metallic baseplate installed with epoxy grout buy enough reliability to reduce maintenance costs by a sufficient amount to make it a good investment. This is not an easy question to answer because there are so many things that affect reliability. The authors frankly feel the answer is no, but will turn the question around and ask, "How much reliability does the installation strategy have to buy to be a good investment?"

Figure 8 shows the present value of pump maintenance costs for an ASME and an API pump. If one assumes that one has a one year MTBM and increase it to two years, the MTBM changes by a present value of $46,000. If one allows present value to be the investment criterion, this is the investment justified to obtain this improvement. On the other hand if the investment must compete for capital with the kind of criteria most companies use today it is more likely one must be in the neighborhood of a three year simple payout. Both techniques have been used to generate Figure 9.

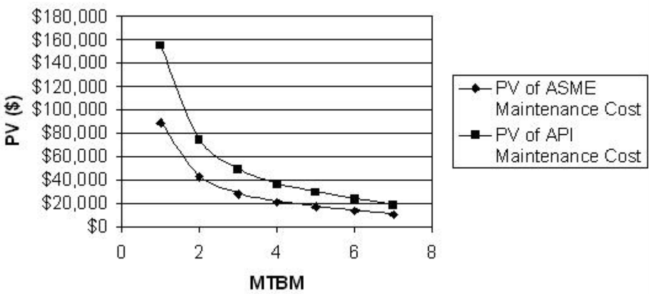

Figure 8 Present Values of Pump Maintenance Costs.

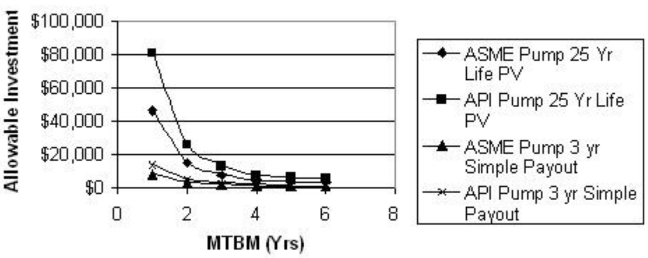

Figure 9. Investment Justified to Obtain One Year Improvement in MTBM.

It appears that if a plant has less than about a three year MTBM and if all of the one year improvement can be attributed to the traditional approach to pump installation and if the investment criterion is present value for a 25 year life maybe one can justify applying conventional baseplates grouted in with epoxy. If one uses an investment criterion of a simple three year payout, then the least expensive method will be used that the authors think will work.

RELATIVE RELIABIILTY

Vibration Levels for Different Installation Methods

Cost effectiveness has been discussed but what about pump performance. One of the perceived benefits of epoxy grouting pump baseplates is a stiffer pump installation, which leads to better alignment (resistance to pipe strain) and lower baseline vibration levels. The authors reviewed a number of installations installed per several of the methods previously mentioned and compared their baseline vibration levels to the rest of the plant's baseline vibration level for that class of equipment. The data presented in Tables 8 and 9 would indicate that method of baseplate installation has little to do with pump baseline vibration levels. The authors would contend that since the industry has focused on the complete installation (i.e., baseplate level, equipment alignment, equipment soft foot, pipe strain, etc.) on both new and existing pump installations that better alignment and pipe stain practices are what has lead to the lower vibration level.

Table 8. ASME Pump (OH1) Overall Vibration Levels.

1800-rpm data				
	Method 1	Method 2	Method 3	Plant Avg.
Sample size	26	24	0	~ 300
Overall	0.05 ips – pk	0.05 ips – pk		0.05 ips – pk
3600-rpm data				
	Method 1	Method 2	Method 3	Plant Avg.
Sample size	52	48	10	~ 700
Overall	0.09 ips – pk	0.08 ips – pk	0.05 ips – pk	0.09 ips – pk

Table 9. API Pump (OH2) Overall Vibration Levels.

1800-rpm data			
	Method 1	Method 2	Plant Avg.
Sample size	12	19	~ 40
Overall	0.08 ips – pk	0.04 ips – pk	0.06 ips – pk
3600-rpm data			
	Method 1	Method 2	Plant Avg.
Sample size	12	24	~ 60
Overall	0.09 ips – pk	0.08 ips – pk	0.08 ips – pk

Notes:
1. Installation method:
   Method 1 – Cementatious Grout
   Method 2 – Epoxy Grout
   Method 3 – Polymer Concrete Foundation (Pre-cast)
2. All readings are taken in the horizontal direction
3. At time of data collection there weren't any 1800-rpm pumps installed to Method 3 in operation.

Relative Reliability

On a recent project in Louisiana several of the installation methods discussed in this paper were employed. The reliability of those installations was compared to similar process units at the same location. Using the same location would mean that the equipment would be operated and maintained in the same manner, which would lead to better statistical accuracy.

For this paper MTBM is:

$$MTBM\left(years\right) = \frac{Equipment\ Count}{Average\ Maintenance\ Occurrences\ Per\ Year} \quad (1)$$

A maintenance occurrence is defined as a task that includes any of the following:

- Replace failed, failing, worn, or questionable parts.
- Replace seals, including those that exceed fugitive emissions regulations.
- Replace parts (except case gasket) when disassembling to remove deposits, debris, or plugging.
- Replace parts to correct faults/incipient failures identified by surveillance, preventive maintenance, or condition monitoring activities.
- Component upgrades performed during repairs not funded by improvement projects
- Replacement of all or a portion of coupling

Looking at the data in Tables 10, 11, and 12, the authors conclude that relative to equipment reliability it is irrelevant what method of baseplate installation is employed.

Table 10. Number of Units by Pump Type and Installation Method.

Equipment Counts					
	BB1	BB2	OH1	OH2	Overall
Cementatious	16	6	393	56	471
Epoxy	16	4	93	37	150
Various	7	6	62	43	118
Total	39	16	548	136	739

Table 11. Number of Maintenance Occurrences by Pump Type and Installation Method.

Maintenance Occurrence Counts					
	BB1	BB2	OH1	OH2	Overall
Cementatious	15	12	586	139	752
Epoxy	21	5	145	133	304
Various	0	3	14	27	44
Total	36	20	745	299	1100
Note: The cementatious and epoxy grout maintenance occurrence counts are from Jan 99 – Jun 03. The various category is from Jun 02 – Jun 03.					

Table 12. MTBM by Pump Type and Installation Method.

MTBM (years)					
	BB1	BB2	OH1	OH2	Overall
Cementatious	4.80	2.25	3.02	1.81	2.82
Epoxy	3.43	3.60	2.89	1.25	2.22
Various		2.00	4.43	1.59	2.68
Total	4.88	2.36	3.11	1.56	2.65

CONCLUSIONS

There are many components to optimum machinery reliability and to optimization of total cost of ownership. The driving factors vary by machine type and depend upon whether a particular machine is spared. For small spared process pumps it is completely unclear that conventional industry endorsed methods of installation are cost effective. Specifically the authors see little or no justification for epoxy grouting conventional metallic baseplates.

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