DRIVING PUMP RELIABILITY FORWARD WITH ADVANCED COMPOSITE WEAR RINGS

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ABSTRACT

In 2003, a refinery began a program to apply advanced composite wear rings, line shaft bearings, and related components. By September 2006, the program had expanded to 61 pumps, at which point plant personnel quantified results. The reliability impact of the program was evaluated using pump repair history, vibration records, and mechanical seal emissions data.

Results indicate that the program has been successful. Failures thin the subject population decreased by 45 percent, overall vibration levels fell by an average of 25 percent, and mechanical seal emissions failures (for pumps subject to testing) dropped by 70 percent. These results suggest that the proper application of composite materials can lead to improved reliability, and should be one of the options considered by plants seeking to increase their pump life.

INTRODUCTION

In 2003, the Sunoco, Eagle Point refinery began using composite wear materials to improve the reliability of pumps in challenging services. Common problems for the subject pumps included inadequate suction conditions, potential run-dry exposure due to process upsets, and inadequate rotor stability in light hydrocarbon service. The refinery was seeking a material that could survive these adverse process conditions, be chemically compatible with refinery process chemicals, have an adequate temperature range to allow broad application, and have good machining and installation properties for the site repair facility. Success in the initial problem pumps led to a program approach, resulting in a total of 61 pumps being converted to composite wear components as of the summer of 2006.

The material used in this program (hereafter referred to as "composite") is a compression molded composite of a fluoropolymer resin reinforced by long carbon fibers oriented in a directional matrix. The directional matrix creates an anisotropic material that has different properties in the x-y plane as compared to the z-axis. For the purpose of pump components, the x-y plane represents properties perpendicular to the rotating element, and the z-axis represents properties in the direction along the axis of the pump shaft. Material properties and selected test data are shown in Table 1.

Table 1. Composite Properties and Test Data.

Property	English Units	Test Method
Thermal Expansion Coefficient (x-y plane)	1.8 X 10^{-6} in./in./ºF	ASTM D-696
Thermal Expansion Coefficient (z-direction) to 300ºF	180 X 10^{-6} in./in./ºF	ASTM D-696
Dynamic Coefficient of Friction (@ 25 ft./min.)	0.20	--
Limiting PV	>155,000 ft./min.-psi	--
Hardness	75-80 Shore D	ASTM D-2240
Ultimate Compressive Strength (x-y plane)	11.7 ksi	ASTM D-695
Compressive Modulus (x-y plane)	383 ksi	ASTM D-695
Ultimate Compressive Strength (z-direction)	43.8 ksi	ASTM D-695
Compressive Modulus (z-direction)	318 ksi	ASTM D-695
Water Absorption	<1%	ASTM D-5229

Stationary pump wear rings, throat bushings, interstage bushings, pressure reducing bushings, and vertical pump line shaft bearings and bowl bushings were converted from metal to the composite. Figure 1 shows the location of composite components in a typical horizontal pump. Figure 2 shows the location of composite components in a typical vertical pump.

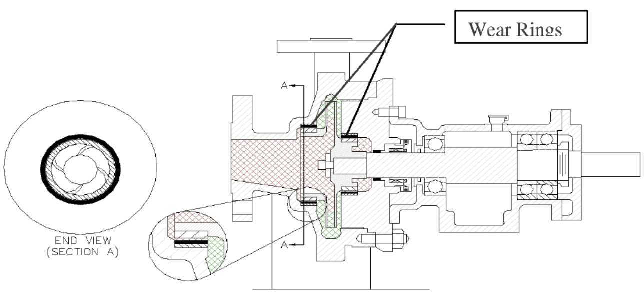

Figure 1. Composite Components in a Horizontal Pump. (Courtesy, http://www2.dupont.com/Vespel/en_US/Literature/crfam.pdf)

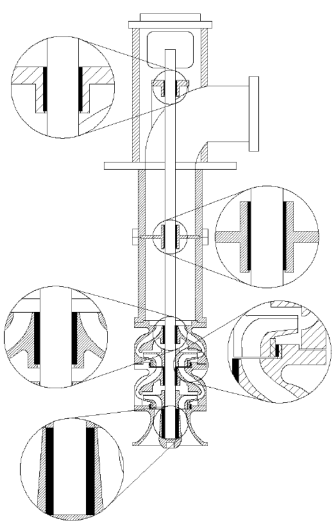

Figure 2: Composite Components in a Vertical Pump.

Most pump repairs were completed by the onsite refinery maintenance facility using the following procedures. Composite components were machined and installed with an interference fit. Some applications used the composite as a solid component (Figure 3), other applications used the composite as an insert into the existing metal wear ring, which was machined and used as a holder (Figure 4). In either case, additional anti-rotation devices such as pins or screws were not used—the interference fit providing the sole anti-rotation mechanism. This method has proved effective. Existing metal rotating components were run against the composite stationary components with no special machining or hardness requirements.

Figure 3. Solid Composite Wear Ring.

Figure 4. Composite Insert Wear Ring.

Subject Pump Population

The subject population provides a good cross section of typical refinery services. A total of 61 pumps were retrofitted to include composite wear components, in both horizontal and vertical pumps, with exposure to nearly all of the most common refinery-service products and chemicals.

- Temperatures from 65°F (18°C) to 475°F (246°C)
- Services included ethane, propane, gasoline, boiler feed water, furnace oil, kerosene, diethanolamine (DEA), cumene, sulfuric acid, caustic, naphtha, and sour water
- Thirty-six vertical pumps and 25 horizontal pumps, with power ranges from 25 horsepower to 750 horsepower
- API pump types single-stage overhung (OH2), vertical inline (OH4), between bearings double-suction (BBI) as shown in Figure 5, between bearings horizontally split multistage (BB3), and multistage vertical (VS6)

Figure 5. Between Bearings Pump with Composite Wear Rings Installed.

- Sixteen pumps in intermittent services, such as tank farm and loading pumps, and 45 pumps inside continuous process units
- Twenty-one pumps in volatile organic compound ([VOC]—hydrocarbons with vapor pressure greater than 14.7 psia at ambient temperature—68°F) service, 12 of which use single seals and are subject to the site leak detection and repair (LDAR) program
- Specific speeds from 600 to 8500, and rotational speeds from 1200 rpm to 3600 rpm

The Potential Benefits of Composites in Pumps

Composites in pumps offer two types of benefits. The first is the potential for the pump to survive run-dry or off-design conditions that could cause metal components to seize. The first benefit leads to the second benefit—a material that is not prone to seizure can be installed with reduced clearances compared to the API standard.

Looking at the first benefit, a very small fraction of pumps failures are blamed on wear ring seizure or run-dry conditions. Reliability studies where failure causes have been identified suggest these failure modes to account for 2 to 4 percent of pump failures (Bloch, 1988). However, pump seizure has the potential to be a high-energy failure mode leading to serious consequences, such as excessive pump repair costs or potential environmental or safety incidents. Avoiding these failures, therefore, offers a significant benefit for many pumping applications.

Reducing wear ring clearance creates a number of opportunities for improved pump reliability and performance. Reducing clearance increases rotor damping forces due to the Lomakin effect (Lobanoff and Ross, 1992), which would suggest pumps should achieve lower vibration levels. Lobanoff and Ross (1992) also note that reduced wear ring clearance reduces the net positive suction head required (NPSHR), which has the potential to mitigate cavitation in marginal situations. (Unfortunately, field instrumentation did not allow for measurement of NPSHR and these data could not be included in this study.) Lower vibration and reduced cavitation should logically result in improved pump reliability. Individual case studies have been published to support this assertion, with small groups of pumps showing substantial reliability improvement (Komin, 1990; Pledger, 2001).

RESULTS OF STUDY

Pump Reliability

While pump design texts and individual case studies would suggest pump reliability should improve, key questions remain: Does pump reliability for a population improve, or is the improvement limited to the 2 to 4 percent of the population with adverse process conditions that could lead to seizure? Is the improvement sustainable over long periods of time, or is vibration reduced at the initial installation only to increase six months later? The results from this program suggest that composite wear components with reduced running clearance produce a significant and lasting improvement in pump reliability.

Data were collected for 61 pumps with time in service ranging from 86 days to 1240 days, with an average time in service of 407 days. The population of 61 pumps generated a cumulative run-time of 68 years (refer to APPENDIX A on methodology for details). Total failures during the equivalent run-time before and after were counted and used to calculate mean time between repair (MTBR), using total time in service divided by number of failures.

For the entire population, there were 22 failures during the 68 years of run-time before conversion, and 12 failures during the 68 years of run-time after conversion. MTBR increased from 37 months to 68 months.

A legitimate question would be whether or not this reliability improvement is sustainable over several years. To evaluate the longer term reliability improvement, the same calculation was completed for pumps in service for more than one year, and for pumps in service for more than two years. Table 2 shows the results. At a minimum, these data suggest that the reliability improvement is not a short-lived phenomenon.

Table 2. Reliability Improvement Based on Time in Service.

	> 1 Year Service	> 2 Years Service
Number of Pumps	29	5
Total Run Time	46.5 Years	12.8 Years
Failures Before	20	7
Failures After	9	1
MTBR Before	27 Months	22 Months
MTBR After	62 Months	154 Months

The improvement has obviously been the most dramatic for the initial pumps converted to composites. This should not be a surprise, as these pumps were “bad actors” with repeat failures prior to conversion to composite components.

Vibration

As discussed, reduced wear ring clearance should result in greater rotor stability due to the Lomakin effect. One would think that greater rotor stability would lead to lower overall vibration levels; however, no field study known to the authors has been undertaken to establish the degree to which vibration is reduced when wear ring clearances are reduced.

Essentially the same methodology was used to evaluate the impact on vibration—using overall vibration readings from before and after the conversion date. Three points before conversion and after conversion were used. The three “before composite” data points were from readings one year, six months, and one month before conversion. The three “after composite” data points were from readings one month, six months, and one year after conversion. (In practice, due to the pumps being converted to composites at different times, being on different data collection routes, and running only during some of the vibration collection intervals, these “dates” for the data points can best be described as “approximate timeframes.”)

It is difficult to compare before and after vibration data due to the mass of data—multiple data collection points on each pump, different pump types, and vibration occurring at multiple

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frequencies. Therefore, the data needed to be simplified. First, vibration frequency was ignored and only overall velocity readings were used for each data point. Next, the average of the individual overall readings for a pump was used as the vibration magnitude for any point in time—an overall of overalls. (Example: if an overhung horizontal pump had three data collection points, with horizontal, vertical, and axial overall vibration readings of 0.12, 0.18, and 0.20 inches per second (ips), the "overall" reading at that point in time would be the average of these three overalls, or 0.17.) Vibration readings were only used for horizontal pumps, due to data collection points being directly on the pump rotor (refer to *Note on Vertical Pumps* below). Sufficient data were available for a total of 24 pumps, with results shown in Figure 6.

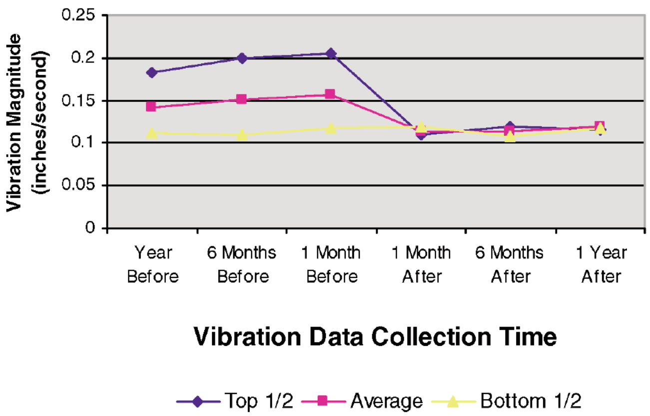

Figure 6. Vibration Magnitude Before and After Composite Installation.

The results show an average reduction of 25 percent in overall vibration levels for the subject population from 0.15 to 0.11 ips. The impact of composites was evaluated by dividing the data set into two groups, the "Top ½" of pumps showing the largest improvement and the "Bottom ½" of pumps showing little or no vibration reduction. We find that the top half of pumps were previously running with higher vibration amplitudes (>0.15 ips), and experienced an average vibration reduction of 42 percent. For the bottom half of pumps, which were already running at very low vibration (close to 0.1 ips), reducing the clearance with composites had no impact on vibration.

Note on Vertical Pumps

Vibration data for vertical pumps were not used in this study. This was a function of methodology, not whether or not there is a rotor stability benefit for vertical pumps. Horizontal pump vibration measurement occurs on the bearing housings for the pump rotor. Vertical pump vibration measurement typically occurs at the motor, which may provide a better indication of motor health than pump rotor stability. To avoid this debate, vertical pumps were omitted from this study.

This is not to say that vertical pumps have stable rotors. Rotor instability problems are actually more common in vertical pumps than in horizontal pumps (Corbo and Malanoski, 1998). Long shaft vertical pumps can experience serious problems such as whirl at the line shaft bearings (Corbo, et al., 2002). Reducing clearance at the line shaft bearings may help to address some of these problems with vertical pumps.

Emissions

Pump failures are most frequently attributed to mechanical seals (Bloch, 1988). In practice, vibration, shaft deflection, cavitation, or multiple other causes can result in a pump failure that is identified in maintenance records as "mechanical seal failure." Similar to the vibration data, it would seem self-evident that improved rotor stability would also improve mechanical seal reliability.

An area of particular importance is the reliability of mechanical seals in VOC service, due to increasingly restrictive national and local emissions regulations. Furthermore, this section of pumps lends itself to study. At the time of this study, the site recorded emissions failures of pumps in VOC service in an LDAR database, providing a record of how many times each pump exceeded the local standard for VOC emissions.

Within the population studied, 21 pumps were in services that fell under the definition of VOC. Most of these pumps were in gasoline, butane, or propane service. Twelve of these pumps use single seals and therefore have a recorded emissions failure history within the site LDAR program.

The impact of composites was evaluated by counting emissions failures during the equivalent run-time before and after conversion to composite wear rings. For the 12 pumps with single seals, there was a total of 14.2 years of run-time with composites. Figure 7 shows the number of emissions failures before and after the composite program. During the period prior to composite installation, there were seven emissions failures; after composites, there were two emissions failures—a 70 percent reduction in emissions failure rate.

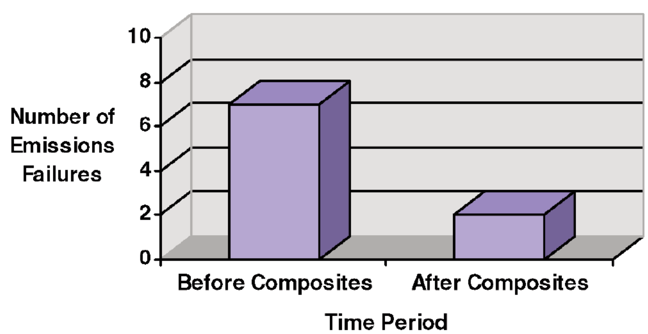

Figure 7. Emissions Failures Before and After Composite Installation.

Efficiency

Efficiency improvements from reduced wear ring clearance have been well documented both in pump design texts (Bloch and Geitner, 1985) and case histories (Pledger, 2001). Unfortunately, typical field instrumentation does not allow for extremely accurate measurement of pump efficiency, and for that reason efficiency data have not been included in this study.

Combined with previous work demonstrating improved efficiency, the improved pump reliability demonstrated by these results should be of significant interest to business managers. In the past, reliability managers would suggest that a 2 percent increase in pump efficiency was interesting, but the real goal of the organization was to improve reliability. Looking at the gains in reliability demonstrated by this study, it appears as though plants can both increase efficiency and reliability simultaneously.

CONCLUSIONS

This work has highlighted several key benefits of using composite wear components in pumps: reduced vibration, reduced seal VOC failures, and improved reliability. While it would not be responsible to assume the degree of success in this program is typical or entirely due to the conversion to composites, the authors can make some conclusions:

- The 61 pumps converted to composites demonstrated an improvement in reliability. The total number of failures for all pumps converted to composites fell by 45 percent during the test period.

- The pumps that were converted to composite wear rings with reduced clearance demonstrated lower vibration, particularly for pumps that previously operated with higher vibration levels. The average vibration reduction was 25 percent.
- Single seals in VOC services showed significantly improved reliability after conversion to composite wear rings with reduced clearance. After conversion, pump failures due to mechanical seal emissions in services subject to the site LDAR program were reduced by 70 percent.
- Pumps that may experience run-dry conditions or process upsets showed the largest increase in reliability. The initial group of pumps that were targeted due to process-related issues experienced an 85 percent reduction in failures.

This study of 61 pumps, incorporating over 68 years of running time demonstrates that composite wear materials can contribute toward improved pump reliability. The reliability impact was demonstrated across the entire data set. This would suggest that a significant opportunity exists for plants to improve pump reliability and efficiency simultaneously.

APPENDIX A— METHODOLOGY

To quantify the reliability impact of the program, the study compiled pump repair, vibration, and mechanical seal emissions failure data from before and after the composite conversion. The site maintenance management system provided pump repair history, the site vibration monitoring program provided vibration data, and emissions failure history was obtained from the site LDAR program.

One of the difficulties in establishing the impact of any change in pump repair practice is that the change occurs at the time of repair. Therefore, each pump has a different "conversion date" from which to evaluate results. Therefore, simply using the conversion date of the first pump as the starting date for all 61 pumps would obscure the results.

To address this issue, the conversion date for each pump was identified from maintenance records so that the actual time in service for each pump was used as the evaluation period. Subtracting the conversion date from the data collection date for each pump generated the run-time for each pump. Adding the run-times for all 61 pumps resulted in the "cumulative run-time" of 68 years.

A related problem arises in determining how much prior repair history to use in determining baseline performance. Perhaps a pump failed twice in the five years before conversion, but the composite has only been in service for 18 months with no failures. Is it accurate to say that the prior MTBR was 30 months and the current MTBR is infinite?

To avoid this misrepresentation, equal time periods before and after conversion were used for data collection. In other words, if the conversion date was three years ago, then three years of prior conversion data were evaluated. If the conversion date was six months ago, then only six months of prior conversion data were evaluated. The end result is an "equivalent" run-time before conversion, and again a cumulative run-time of 68 years prior to the composite conversion.

Finally, this study draws conclusions based on simple criteria: pump failures are bad, low vibration is better than high vibration, and emissions failures are unwanted. In other words, no attempt was made to evaluate the root cause of failures, the cause of vibration, or the cause of mechanical seal leakage before and after the composite installation.

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