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REDESIGN OF THE ATTACHED SEA WATER PUMPS FOR LSD-41/49 CLASS UTILIZING COMPOSITE COMPONENTS

Abstract

Under certain ship trim conditions, the suction supply to the attached sea water pumps became lower than the original design criteria. This condition caused a loss of the thrust balance between the sea water and jacket water pumps resulting in the over-thrusting failure of the bearing. An investigation to correct the problem included piping changes, total pump redesign and impeller redesign.

The investigation led to a redesign of the impeller utilizing composite components. The design led to a reduction of vanes and changes to vane shapes which would reduce the required suction head to be nearly half the original metallic design.

The redesigned impeller and associated casing rings were installed for a field trial onboard the USS Ashland. Test results indicated problems which required further investigation. Additional tests were run at the LSD-41 Land Base Test Facility in Philadelphia. This data was also inconsistent with design calculations.

A complete set of design performance tests were conducted in a bench test loop with the pump from the Land Base Engineering Site, the metallic impeller from this pump and the redesigned composite impellers. Test results for the metal impeller were as expected, while the composite impeller showed better than expected suction lift characteristics.

INTRODUCTION

The Attached Sea Water Pumps (APL L016021523 & L016021524) on the Coltec Main Propulsion Diesel Engines have been unable to provide a constant flow of seawater during all phases of ship operations. Failures of the mechanical seal and thrust bearing necessitated a more detailed review of the system, as well as the pump design, location, attachment and operation. This paper will address the approach taken by Warren Pumps in conjunction with the Naval Surface Warfare Center Carderock Division Ships Systems Engineering Station (NSWCCD-SSES) to correct the reported poor performance of the pumps.

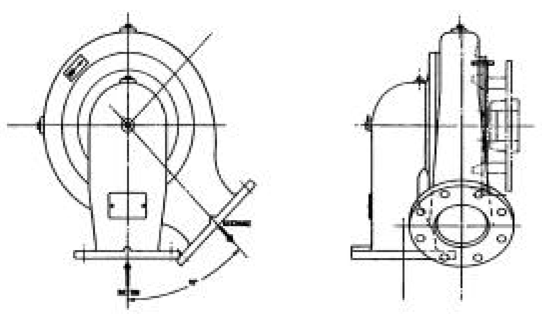


Figure 1, Warren Model 6-PSEC Outline

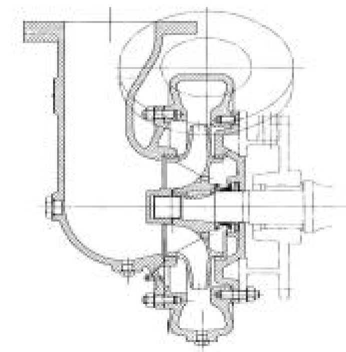


Figure 2, Sectional Assembly

BACKGROUND

Warren Pumps' involvement with the Attached Sea Water and Jacket Water Pumps goes back to 1977 when Colt Industries, Fairbanks Morse Engine Division, solicited industry for a replacement pump for the then current United Kingdom manufactured units used on the Pielstick engines. Warren Pumps was awarded a contract to manufacture a pump to duplicate the original units as closely as possible. The original units were designed to operate in either direction with a de-rated performance in the reverse rotation. Only the original order had these reversible units. All other units were to be unidirectional design (left hand or right hand rotation). These unidirectional units were to be interchangeable with the reversible units. As before, the original Pielstick supplied pumps were copied as closely as possible to ensure complete interchangeability. The conditions of service for the unidirectional pumps were to be:

Sea Water Pumps, 1200GPM, 100FT, 34FT NPSHA

Jacket Water Pumps, 1145GPM, 147FT, 34FT NPSHA

These pumps were to be mounted back-to-back, sharing a common drive shaft through a separate gear train off the engine, creating a balanced assembly.

In 1989, after receiving information regarding erosion of the Sea Water Pumps impellers from the Fleet, Warren was tasked to investigate alternate material which would provide a longer service life. In April 1980, after analysis, the original Gun Metal (ASTM B584 Alloy 903) impellers were manufactured of Aluminum Bronze (ASTM B148 Alloy

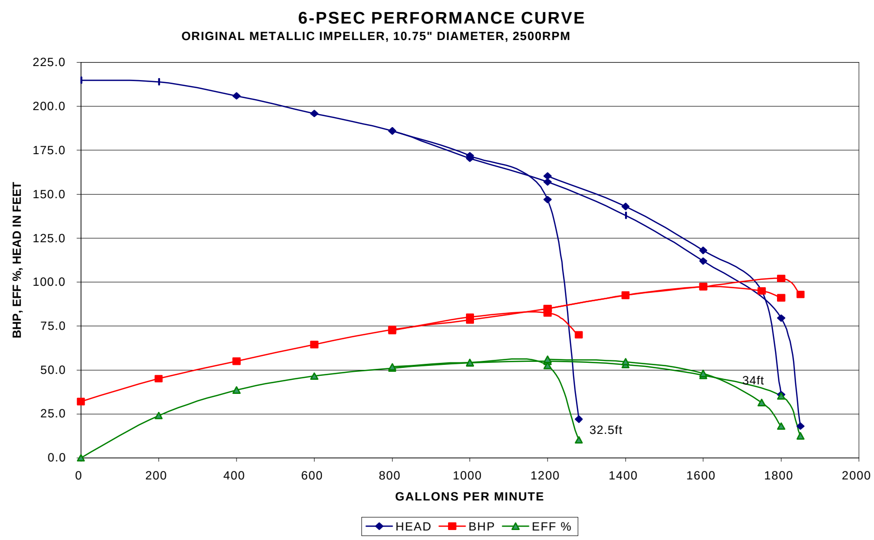
C95500). The casing rings were also upgraded to Nickel-Copper (QQ-N-288, Composition B) from Bronze (Copper Alloy 927, SAE 63). Design testing of this impeller

was conducted at Warren Pumps in August of 1990 utilizing a suction lift of 34 and 32.5FT NPSH.
The impeller's performance was to match the following conditions of service:

Sea Water Pumps, 1200GPM, 143FT, 34FT NPSHA
Jacket Water Pump, 1145GPM, 147FT, 34FT NPSHA

This performance curve is shown in Figure 3,

Figure 3
Metallic Impeller
Performance Curve
(AL-BRZ)



Due to the failure of the attached pump thrust bearing and subsequent crankcase explosions, an investigation was initiated. Several conclusions were identified for the pumps:

a) There was a potential to induce pump cavitation under ship operating conditions (system problem).
b) Crevice corrosion and the galvanic couple between the aluminum bronze impeller and stainless steel shaft were the primary cause of the pump drive shaft pitting (material problem).

Based on these conclusions the following recommendations were presented:

a) Replace the current impellers with ones designed to operate with improved NPSH characteristics.
b) New impellers should be manufactured of composite material which would perform better in a sea water environment.
c) Composite impellers would be inert thus eliminating the corrosion/ shaft pitting.
d) Conduct testing to compare baseline impeller to the new designed composite impeller performance. [1]

INITIAL INVESTIGATIONS

At the time of the investigations by NSWCCD-SSES and subsequent recommendations above, Warren Pumps was working with the Sims Pump Valve Company to qualify their composite material, Simsite® in accordance with NAVSEA Technical Publication

03Y3-101. Simsite® is a fiber-reinforced structural composite material of a phenolic laminate or epoxy laminate. The structural design of unique, continuous fibers are interwoven in a bi-directional or tri-directional weave, which gives the components both high strength and flexibility. During this test period, NAVSEA issued a comprehensive

document covering the qualification of composite materials for Fleetwide use. This document, NAVSEA Standard Drawing 803-7226047, listed specific qualification testing and subsequent approval necessary for material acceptance. In April of 1996, Warren Pumps was granted NAVSEA approval to utilize composite materials. As the impellers and casing rings from the Attached Sea Water Pumps were listed as items approved for composite conversion, the redesign effort began in earnest. Several iterations of the designs were evaluated before establishing the following final parameters:

	Original Metallic	Redesigned Composite
Vanes	8 radial vanes	5 radial vanes
Suction Specific Speed	6289 (33FT NPSHR)	9030 (20.5FT NPSHR)
Inlet vane angle	52º	20º
Exit vane angle	35º	25º
Eye diameter	6.299¨	6.097¨

Figure 4
Metallic Impeller (AL-BRZ)

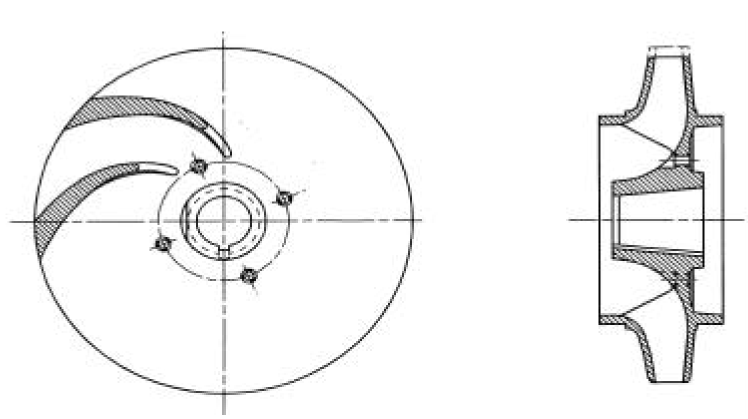
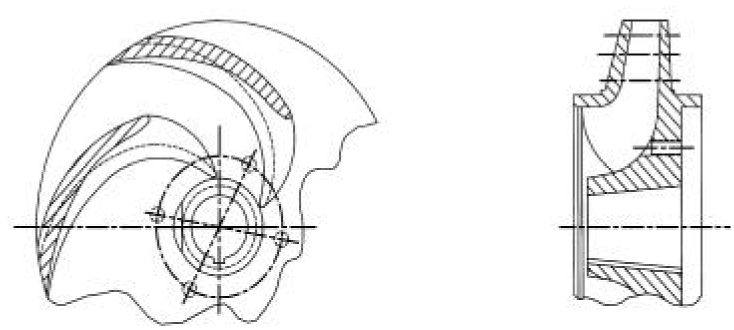


Figure 5
Redesigned Composite Impeller



The composites provide the ability to customize the impeller as it is machined from a solid block. With this machining process there is no need to manufacture a pattern or mold to manufacture the parts. It also eliminated any casting imperfections and allowed for exact vane spacing, maintaining design efficiency by allowing smooth flow passages. Additionally, the composite material is six (6) times lighter than the bronze impeller, this reduced the shaft deflection and minimized radial forces. NSWCCD-SSES funded the procurement of one right hand and one left hand impeller, along with two (2) sets of casing rings, all manufactured of composites.

INITIAL TEST PROGRAM

Once the composite parts were manufactured, a suitable test needed to be run. NSWCCD-SSES was able to acquire test time on the USS Ashland LSD-48 for September of 1996. The composite parts were installed with the desired running clearances. The test data showed that the composite impeller was developing a much lower head and flow than was desired or designed. The flows were as much as 400GPM lower than predicted. Based on this information, additional testing was required, but due to the ship's deployment schedule, this could not be accomplished. Test data is provided in table 1.

USS ASHLAND ATTACHED SEA WATER PUMP TESTING 9/10/96

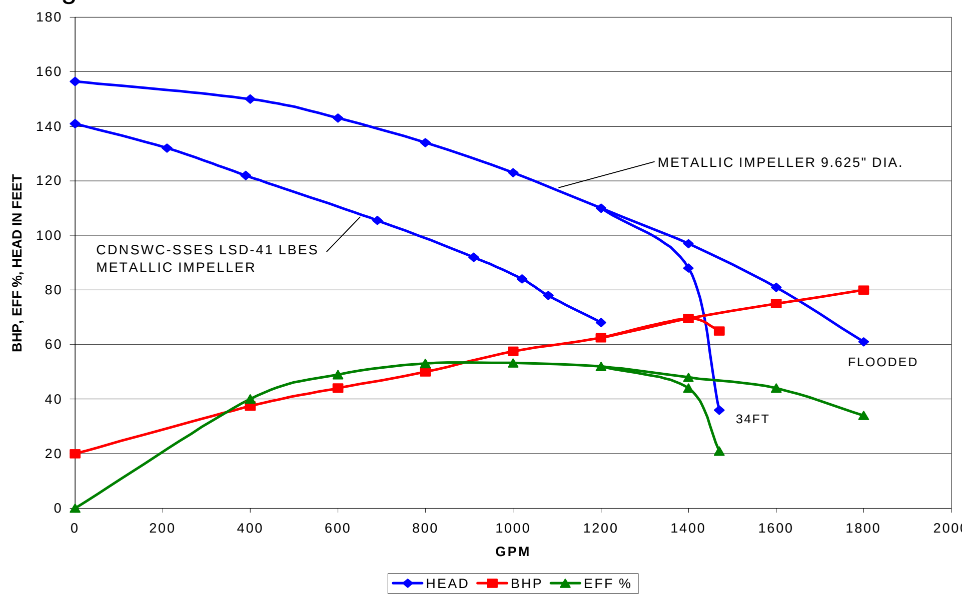
METALLIC IMPELLER TESTING

CONDITION	ENGINE SPEED	PUMP SPEED	FLOW	SUCTION PRESSURE	DISCHARGE PRESSURE	TOTAL HEAD (PSI)	TOTAL HEAD (FT)	FLOW @ 2500RPM	TDH @ 2500RPM
0% Open	195	936	544	2.7	12.5	9.8	22	1,453	157
	305	1,464	751	2.2	19.5	17.3	39	1,282	113
	408	1,958	1,023	1.6	31.3	29.7	67	1,306	109
	504	2,419	1,267	0.8	48.3	47.5	107	1,309	114
	530	2,544	1,310	0.6	49.5	48.9	110	1,287	106
100% Open	210	1,008	487	3.1	12.8	9.7	22	1,208	134
	305	1,464	688	3.1	22.3	19.2	43	1,175	126
	409	1,963	903	3.1	36.5	33.4	75	1,150	121
	502	2,410	1,101	3.2	54.6	51.4	115	1,142	124
	523	2,510	1,227	3.1	57.8	54.7	123	1,122	122
COMPOSITE IMPELLER TESTING									
0% Open	230	1,104	326	1.5	15.0	13.5	30	738	155
	220	1,056	277	2.0	14.5	12.5	28	656	157
	215	1,032	155	2.7	19.3	16.6	37	375	218
	220	1,056	3	3.2	20.1	16.9	38	7	212
	402	1,930	602	-1.0	39.2	40.2	90	780	151
	400	1,920	491	0.4	45.3	44.9	101	639	171
	402	1,930	74	3.0	60.3	57.3	129	96	216
100% Open	402	1,930	817	2.9	37.8	34.9	78	1,059	131
	397	1,906	621	2.9	44.2	41.3	93	815	159
	403	1,934	433	2.7	49.9	47.2	106	560	177
	401	1,925	2	2.8	60.0	57.2	128	3	216
	530	2,544	1,044	3.1	60.9	57.8	130	1,026	125
	524	2,515	923	2.4	68.7	66.3	149	917	147
	530	2,544	60	2.8	98.8	96.0	215	59	208

Table 1, USS ASHLAND Test Data

Due to ship schedules no additional testing could be completed in 1997 and early 1998 showed no promise of an availability. It was decided to utilize the LSD-41 Class Land Based Engineering Site (LBES) in Philadelphia to establish a baseline for the metal impeller and then the composite. The metal impeller test on the Sea Water Pump was run at LBES in February 1998. Data was taken over a range of operational points limited by the system. Once the data was plotted, we observed major differences from those we would have expected. The metallic impeller in Philadelphia had been turned down (reduced outside diameter) at some point in time as the Land Based Site had a suction pressure of 15-18PSI. This additional suction pressure improved the performance of the pump to an extent that a full diameter impeller provided excessive flow and head. Based on all of the data that was available, it appeared that the metal impeller had been turned down to 9.625". Once this information was made available, the test data was plotted against the test curve developed at Warren Pumps for the same impeller diameter a few years before. Again a large discrepancy was noted. The LBES test data plotted against the original curve is found in figure 6.

Figure 6,
LBES Test Versus
Warren Pumps Test
Data



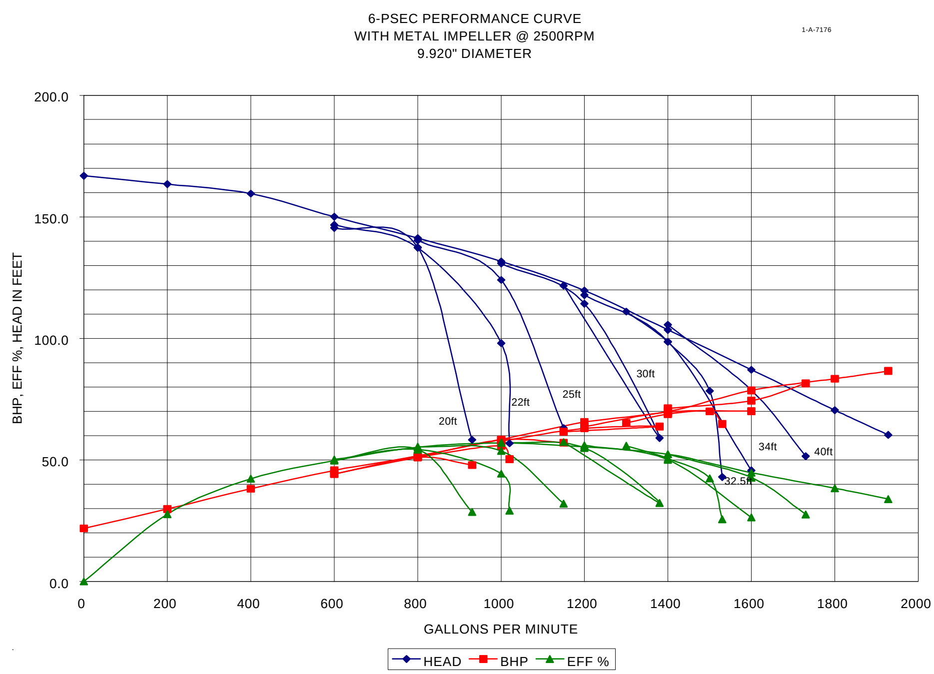
After reviewing this test data, there again seemed to be a discrepancy in the test data taken versus the original test stand data. After further discussions with CDNSWC-SSES, it was decided that a controlled test needed to be run at Warren's facility. The required pump parts could be removed from the LBES engine and mounted on the original test powerframe. Warren Pumps agreed to performance test the metallic and composite parts at no cost, as the test would be covered by their Internal Research & Development (IRAD) funds.

TEST STAND PERFORMANCE

The following parts were removed from the LBES engine and sent to Warren Pumps: impeller, backhead, backhead case ring, suction head, mechanical seal, impeller nut and impeller lockwasher. Upon inspection of the impeller it was found to have an outside diameter of 9.920" in lieu of the 9.625" diameter expected after the initial LBES tests. This further supported running a complete test at Warren Pumps facility under controlled conditions. Additionally, the suction head piece was received without it's corresponding case ring. A metallic ring was manufactured and installed in the suction head. The ring

was machined to achieve the desired 0.022” - 0.025” impeller to case ring clearance required on the outline drawing.
Testing of the metallic impeller was conducted at 2500RPM, 1800RPM and 1032RPM and at various NPSH conditions. Head, flow and break horsepower readings were recorded. The performance map of the 2500RPM test is shown in figure 7.

Figure 7, Metallic Impeller Performance @ 9.920” Diameter

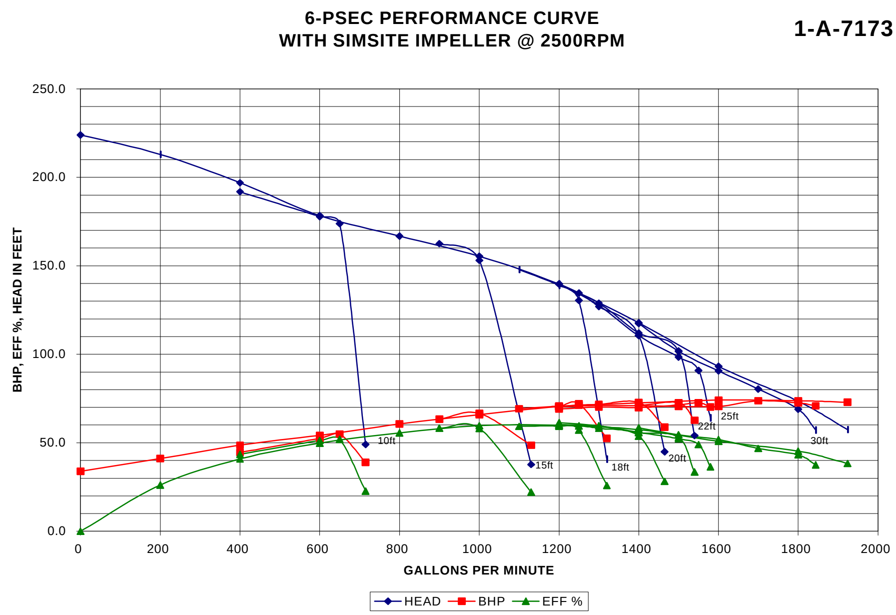


After a review of the actual metallic performance curve with a diameter of 9.920” (figure 7) versus that of a previous test at a diameter of 9.625” (figure 6), we finally had consistent data. A further review of the two (2) tests utilizing the affinity laws, confirmed the performance and validated the data. Once the data was correlated, an explanation as to the lower than expected reading at the LBES Facility was assumed. Receipt of the suction head without the case ring indicated that this may have been the installed condition on the engine. Without the case ring in place, the sealing clearance at the inlet of the pump was excessive due to internal recirculation, producing lower head and capacity. [2]

After all of the metallic impeller tests were run and determined to be acceptable, the composite impeller was installed. It was decided that the metallic casing ring would be left in for the test with the composite impeller to prove out the ability of the composites to run successfully against metallic components. We also had a greater than recommended running clearances of 0.041” on the suction side, with a clearance of 0.046” on the backhead side. The recommended clearance for the composite impeller against a metallic ring is 0.019” – 0.029”. By running with the larger clearance we would ensure that if the condition points were met, when the pump was operated with the proper clearance, even better performance would be recorded.

The same test conditions that were run with the metallic impeller were repeated with the composite. The performance at 2500RPM is graphed in figure 8.

Figure 8, Composite Impeller @ 10.75" @ 2500RPM



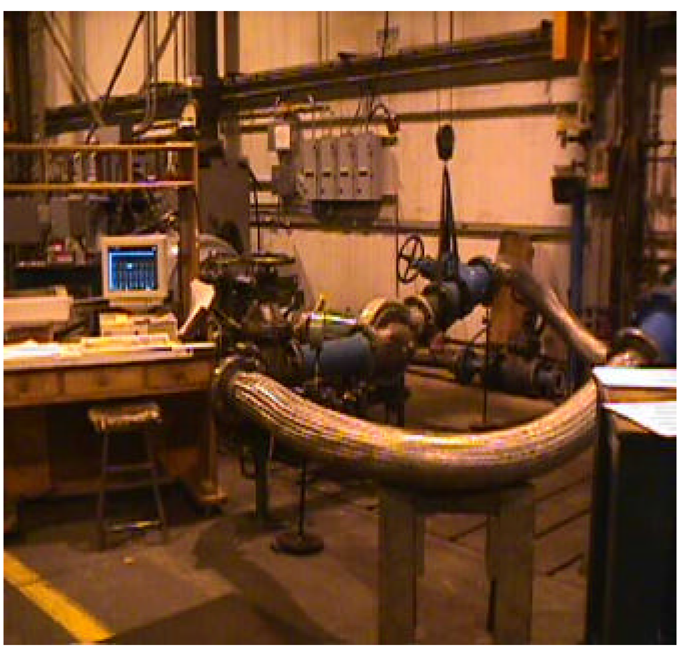


Figure 9, Test Stand Setup

Figure 10, Pump Assembly

TEST SUMMARY AND RECOMMENDATIONS

In analyzing the composite impeller performance, the data shows the actual tested NPSHR for the impeller is 18FT. This is slightly better than the original design prediction of 20.5FT and reduced the overall pump requirement from 32.5FT NPSHR. With the reduction of the NPSHR the pumps are capable of operating with a significant reduction in the supplied suction pressure. As shipboard conditions change during various mission profiles, the pump must continuously operate to insure adequate engine cooling. Poor pump performance during ballast operations were reported. The reduction of the NPSHR should help during this operational condition. In addition to the change of the impeller and case ring to composites, several other recommendations were made as a result of this test program:

a) Redesign the impeller nut with a smoother inlet profile to further improve performance by reducing turbulence at the eye of the impeller.
b) Modify the impeller puller holes from the current metric design (M10 X 1.5) to 3/8-16 in order to aid pump maintenance and eliminate the need for special metric tools.

It is believed that the above changes will result in longer pump life, however the issues of shaft pitting and corrosion still need to be addressed. The current shaft design utilizes a 304 stainless steel shaft (supplied by diesel engine manufacturer). The current impeller is made of aluminum-bronze, the impeller nut is bronze, impeller nut washer is stainless steel and the mechanical seal parts are monel. This material combination has created pitting and crevice corrosion of the shaft around the impeller, impeller nut and mechanical seal, as the less noble shaft material becomes the anode in the galvanic reaction.

Utilizing composite components for the impeller and case rings will solve much of this problem as the composite is inert. However, the nut and mechanical seal parts will still attack the shaft. [2]

In a review of the original purchase specifications for the mechanical seal, the diesel manufacturer allowed the use of nickel-copper alloy (monel) or highly alloyed corrosion resistant steel. The material choice of corrosion resistant steel should be considered for not only the mechanical seal, but for the impeller nut as well.

CONCLUSION

The test results have shown the adaptability of the composite components to solving design and service issues. No additional design modifications were required to meet the intended performance criteria, and better than design results were recorded. This type of redesign could be applied to other systems where changes to the original ship design criteria have occurred (double hull) or where increased/decreased pump performance is desired without initiating a total pump redesign or replacement.

Since the submittal of the test results to NAVSEA, message R 191147Z AUG 98 has been issued indicating that composite impeller replacement is approved when current replacement is required. Additionally, new National Stock Numbers (NSNs) have been established as follows:

Impeller Right Hand (Clockwise) 4320-01-436-9233, APL L016021524
Impeller Left Hand (Counter Clockwise) 4320-01-436-8457, APL L016021523
Wear Ring, 4320-01-436-3222, APL L016021523 & L016021524
Wear Ring, Undersize, 4320-01-443-7216, APL L016021523 & L016021524

Both APL L016021523 & L016261524 have been updated by NAVICP to include these NSN changes.

Current “at sea” reports are considered promising but preliminary at this time. Current information from the first ship to have the composites installed mentioned “improved” operation of the pump. We are awaiting additional reports as several other ships have also installed the composites and are adding in service hours.

References

[1] Stehr, Thomas E., “LSD-41 Class Main Propulsion Diesel Engine Attached Sea Water Pump Failure Investigation”, September 1995

[2] Clough, Philip A., “Simsite Impeller Performance Test Report, 10.75” Diameter & Original Metal Impeller Performance Report 9.920” “, May 1998

Author’s Biography

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Employed by Warren Pumps Incorporated for over 20 years, holding the current position of Product Manager, Navy and Marine Composites for the last three (3) years.
Previous positions included Manager of Contract Administration, Research and Development Supervisor and Field Service Engineer.
Attended the Massachusetts Maritime Academy and received a Bachelor of Science degree in Marine Engineering in 1978.
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