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SPACE STATION WATER PROCESSOR PROCESS PUMP

Final Report

for

Ion Electronics

Contract # NAS8-38250-12

prepared by

United Technologies Corporation

Hamilton Standard Space

Systems International Inc.

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Prepared By: David Parker — Date: July 14, 1995

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Approved By: Kathy Ferner — Date: 7/15/95

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2. Abstract

This report presents the results of the development program conducted under contract NAS8-38250-12 related to the International Space Station (ISS) Water Processor (WP) Process Pump . The results of the Process Pumps evaluation conducted on this program indicates that further development is required in order to achieve the performance and life requirements for the ISSWP.

3. Summary

During the first and second quarter of 1992, Hamilton Standard Space Systems International (SSI) evaluated prototype Process Pump model number (M/N) 2992 for performance capabilities in meeting the Space Station Freedom (SSF) requirements. These two identical gear pump assemblies were procured from Howden Fluid Systems (HFS), formally Pneu Devices Inc. (PDI). A photo of the pump and motor controller is shown in **FIGURE 3-1**. The initial evaluation concluded that the corrosion resistance of the gear and cartridge materials needed to be improved to meet the life requirements. This program was conducted to improve the operational life of the ISSWP Process Pump by making material changes to the existing gear pump configuration. All of the material improvements selected for the cartridge assembly proved acceptable for pump operation. On the other hand, the materials selected for the gears, while they have proven acceptable for corrosion resistance, have not met the requirements for gear loading and life.

4. Introduction

The Process Pump , Item WP4596, is an integral component in the Waste Water Orbital Replacement Unit (WWORU). A schematic of the WWORU is shown in **FIGURE 4-1**. This WP ORU is used for receiving, degassing, storage and pressurization of the ISS waste water. The Process Pump provides the pressurization and system flow which are normally 70 psig and 15 pph, respectively.

The Process Pump, along with all of the other WWORU components, must be capable of surviving the harsh environment imposed by the waste waters. This fluid, which is corrosive as well as non-lubricating, has proven to be a considerable challenge for this gear pump application.

This program, which has been conducted from March 94 through July 95, was to continue the Process Pump development initially started on the SSF Program. The SSF Program initially procured the two pumps (M/N 2992, serial numbers 0001 & 0002) in February 92 which were modified on this program. The pump configuration includes a canned water cooled 120 vdc motor contained within a pump housing, (refer to **FIGURE 4-2** for an cross section of the motor assembly), a variable speed motor controller and a integral pump cartridge, refer to **FIGURE 4-3** for a gear cartridge exploded view. Initially, these pumps were procured with nitrited 17-4 PH stainless steel gears. After conducting two months of life testing with real waste waters at SSI on S/N 0001, from March through May of 92, a pump lock up occurred. Although the subsequent teardown evaluation indicated that the pump lock up was a result of foreign contamination, it also revealed that the cartridge materials required additional corrosion resistance. Several areas of the cartridge required improvements. These included the gears, cartridge end plates and center spacer as well as areas around the carbon graphite bearings. During this program several modifications were made to the cartridge and gear materials for improved corrosion performance. This report describes the modifications, test results, conclusions and recommendations for future action as a result of the data obtained on this program.

The main area of development on this pump has been to find a gear material that provides excellent corrosion resistance in combination with the mechanical properties required for a long life gear pump in a non lubricating fluid.

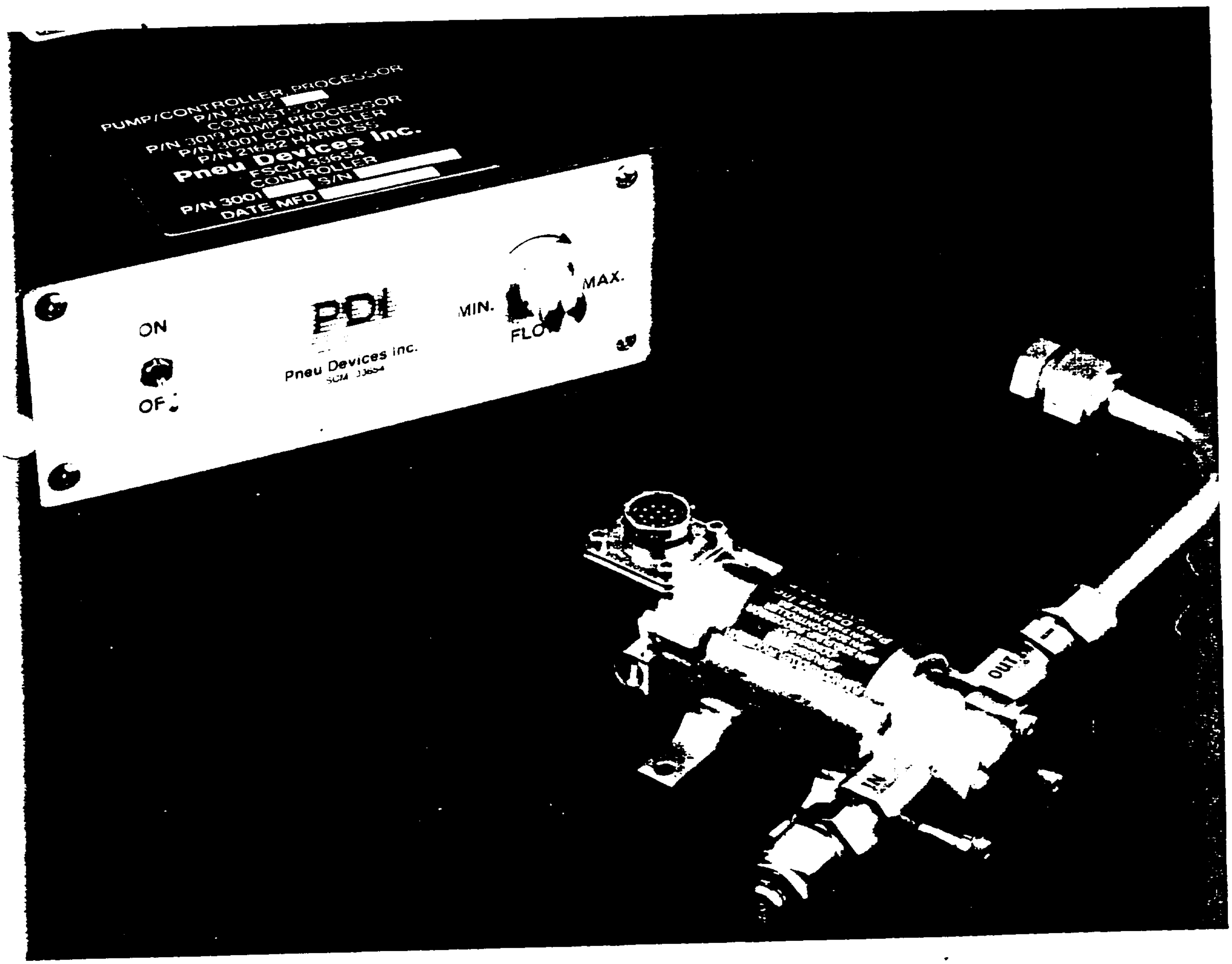


FIGURE 3-1, HFS Gear Pump Assembly, M/N 2992

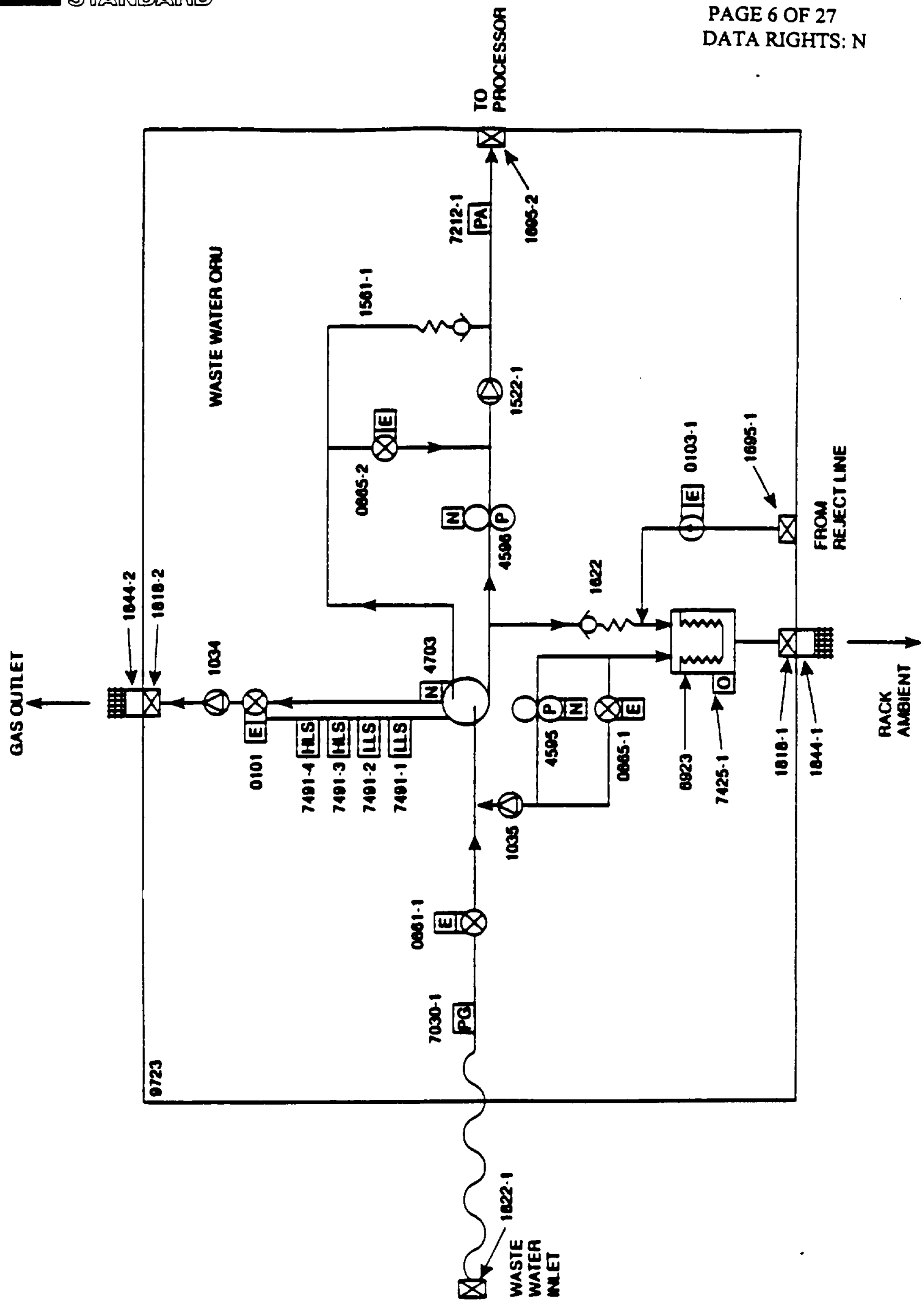


FIGURE 4-1, SCHEMATIC – Water Processor WWORU

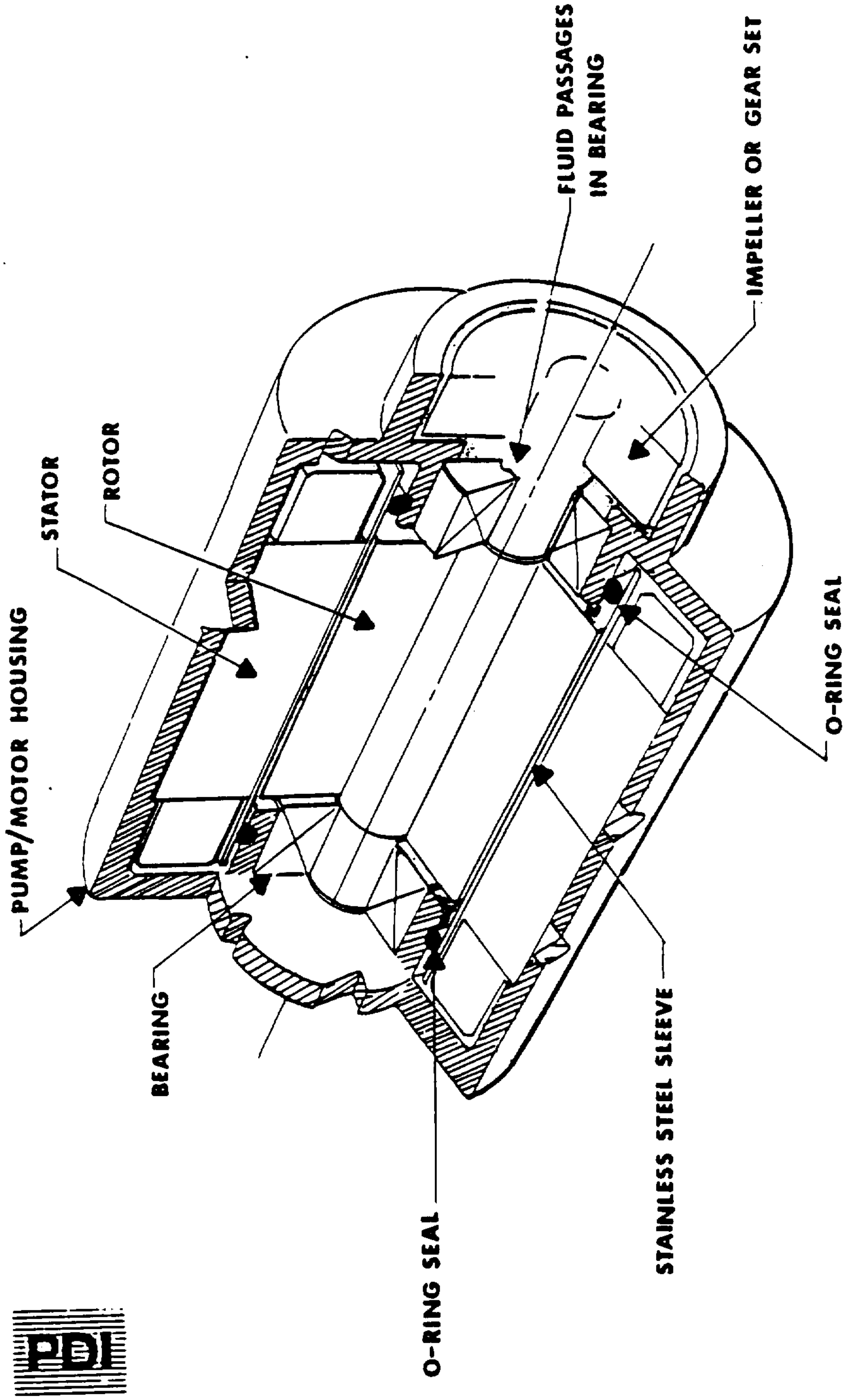
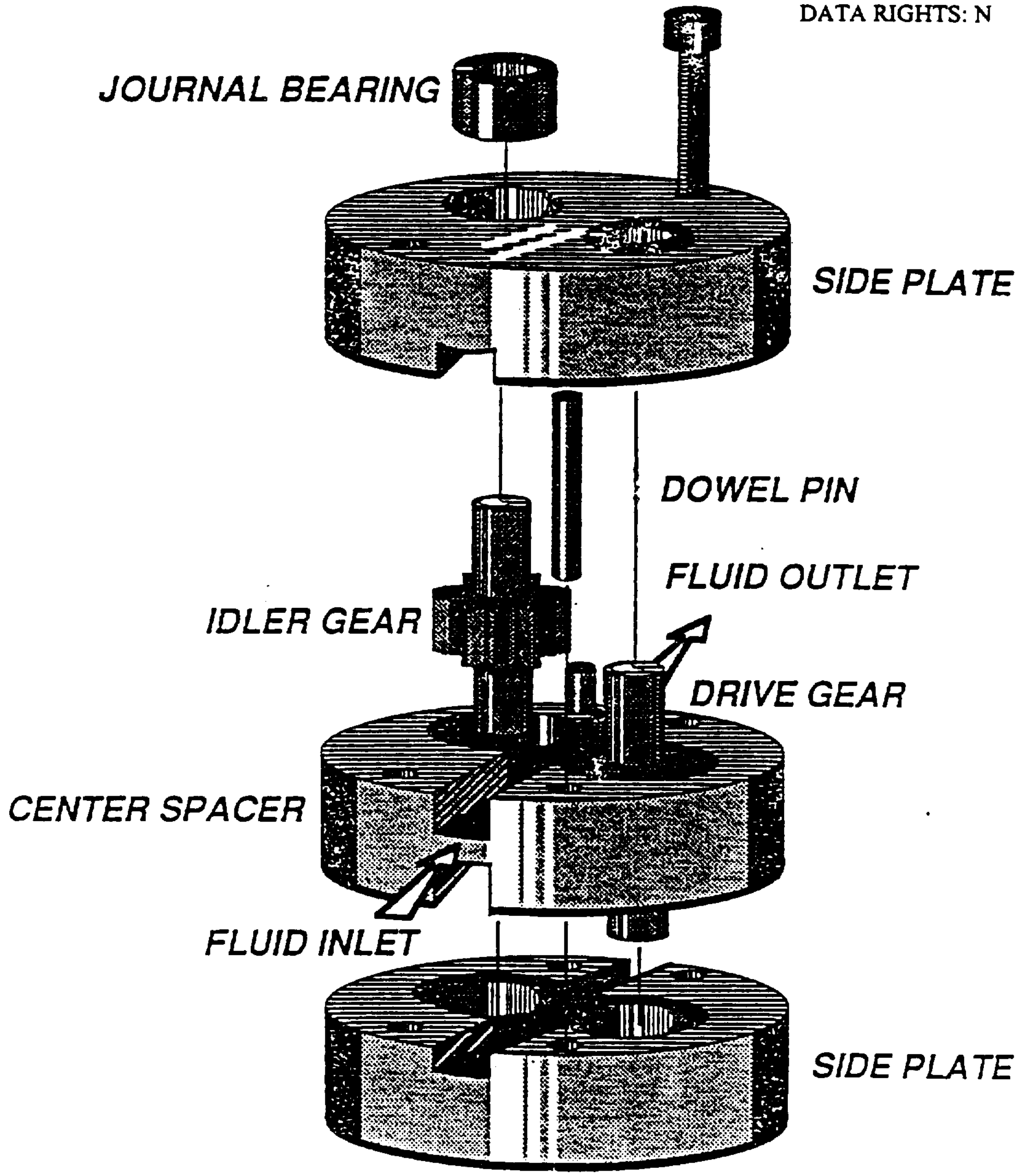


FIGURE 4-2, Cross Section, HFS's Motor Assembly



PDI

FIGURE 4-3, Cross Section, HFS's Gear Cartridge Assembly

5. Objective

The objective of this program has been to continue the development of the HFS M/N 2992 gear pump to establish the pump configuration necessary to meet the ISS WP system requirements. This has required SSI and HFS to work together to select and evaluate several new materials required for the gear cartridge assembly. The primary goal of the program was to develop a cartridge assembly with significantly improved corrosion resistance while still meeting the mechanical requirements for the pump.

6. Development Efforts

The development efforts on this program were initiated in March 94 and have concluded with the completion of this Final Report in July 95. The program schedule is shown in **FIGURE 6-1**. Several major efforts were conducted through out the program. Initially, two HFS's gear pumps M/N 2992 were transferred to this contract from the Space Station Freedom Program. These pump motor assemblies were returned to HFS to be used in evaluating various pump cartridge configurations. The first gear materials evaluated included Inconel 718 and 15-5 PH stainless steel. These gear materials were tested during Aug. and Sept 94. Following the conclusion of these tests, a program review meeting was conducted at HFS's facility, in Santa Barbara, CA on Oct 25 & 26, 1994 with NASA, SSI and HFS personnel present. This meeting resulted in the development of a new action plan to continue the gear pump development. Three major tests were developed to further evaluate improvements in gear life performance. These included 1) operating a 15-5 PH SS gear set at lower speeds to determine if any improvement in life performance could be determined, 2) fabricate and test a borided Inconel 718 set of gears and 3) fabricate and test a borided cobalt alloy Stellite 6B set of gears. The stellite gears were manufactured for a larger pump M/N 2941 in order to operate this pump at approximately 1500 rpm. This pump would be used to further evaluated lower operating speeds. The test plan for this effort is provided in Appendix I: Process Pump Test Plan.

The three options listed above were fabricated and tested from January through June 95. The information obtained is described in the following sections. All of the pump fabrication, the 15-5 PH SS low speed test and the initial check out of the two borided gear sets were conducted at HFS's facility. The actual performance maps and waste water life testing were conducted at SSI's facility. The testing at SSI was initiated on April 25 with the Inconel 718 M/N 2992 performance map and was concluded on May 26, 1995 with the shut down of the borided Stellite 6B M/N 2941 life test. **Table 6-1** summarized the tests conducted which are described in the following sections.

Gear configuration	Initial 15-5 Gear Test	Initial 718 Gear Test	15-5 Low Speed Test	Borided 718 Gear Test	Borided 6B Gear Test
Test Location	HFS	HFS	HFS	SSI	SSI
Test Fluid	Waste Water	Clean Water	Clean Water	Waste Water	Waste Water
Speed (rpm)	3000	3000	2000 -2100	2100	1500
Pump M/N	2992	2992	2992	2992	2941
Operating Time (hrs)	188	0	257	87	425

TABLE 6-1, Gear Pump Test Summary

Dependencies :

Task Name	Start Date	Duration	End Date	Pct Achvd	Notes
2.0 PROCESS PUMP PROGRAM	15-Mar-94	329.0 d	17-Jul-95	100	
2.1 PROCESS PUMP UPGRADE	15-Mar-94	287.6 d	17-May-95	100	
RECEIVE CONTRACT DIRECTION	15-Mar-94	0.0	15-Mar-94	100	
ISSUE SALES ORDER/PD	17-Mar-94	2.0 d	18-Mar-94	100	
• FINALIZE NEW PUMP DESIGN	21-Mar-94	155.0 d	2-Nov-94	100	
REVISED PROGRAM PLAN @ HFS	9-Jan-95	89.9 d	17-May-95	100	
HS ISSUE ORDER TO HFS	9-Jan-95	10.0 d	23-Jan-95	100	
HFS REVISE PLAN DPT-2992	17-Jan-95	4.0 d	20-Jan-95	100	
• 15-5, 2992 LOW SPEED TEST	20-Jan-95	81.6 d	17-May-95	100	
718, 2992 PUMP	16-Jan-95	67.0 d	20-Apr-95	100	
HFS BORITE HARDEN 2nd SET 718	16-Jan-95	15.0 d	6-Feb-95	100	
BORITE HRD - 2nd SET BINDING	7-Feb-95	0.0	7-Feb-95	100	
INVESTIGATE BINDING/BORITING	8-Feb-95	9.0 d	21-Feb-95	100	
DECISION TO REDUE 3rd SET 718	22-Feb-95	0.0	22-Feb-95	100	
REMACHINE 3rd 718 SET	23-Feb-95	25.0 d	29-Mar-95	100	
HFS BORITE HARDEN 3rd SET 718	31-Mar-95	10.0 d	13-Apr-95	100	
ASSEMBLE 2992 PUMP	14-Apr-95	2.0 d	17-Apr-95	100	
HFS 718 PERFORMANCE TEST	17-Apr-95	2.0 d	18-Apr-95	100	
DELIVER 2992/718 PUMP - HS	19-Apr-95	2.0 d	20-Apr-95	100	
STELLITE 2941 PUMP	10-Jan-95	71.0 d	20-Apr-95	100	
PROCURE STELLITE CARTRIDGE	10-Jan-95	63.0 d	10-Apr-95	100	
ASSY STELLIET PUMP 2941	13-Apr-95	2.0 d	14-Apr-95	100	
CONDUCT TESTS ON 2941	17-Apr-95	3.0 d	19-Apr-95	100	
DELIVER 2941 PUMP TO HS	19-Apr-95	2.0 d	20-Apr-95	100	
2.2 PUMP TEST @ HS	11-Apr-94	310.0 d	17-Jul-95	100	
• TEST PLAN / RIG DEVELOPMENT	11-Apr-94	250.0 d	20-Apr-95	100	
HS TEST PROTOTYPE 718B PUMP	25-Apr-95	13.0 d	11-May-95	100	
PERFORM CLEAN H2O MAPS	25-Apr-95	1.0 d	25-Apr-95	100	
PERFORM REAL H2O LIFE TESTS	2-May-95	8.0 d	11-May-95	100	
HS TEST PROTOTYPE 2941 PUMP	1-May-95	19.9 d	26-May-95	100	
PERFORM CLEAN H2O MAPS	1-May-95	1.0 d	1-May-95	100	
PERFORM REAL H2O LIFE TESTS	2-May-95	18.9 d	26-May-95	100	
ANALYZE GEAR FAILURES	30-May-95	18.0 d	22-Jun-95	100	
DEVELOP PROGRAM FINAL REPORT	16-Jun-95	21.0 d	17-Jul-95	100	

94 Mar 1, Apr 1, May 2, Jun 1, Jul 1, Aug 1, Sep 1, Oct 3, Nov 1, Dec 1, 95 Jan 3, Feb 1, Mar 1, Apr 3, May 1, Jun 1, Jul 3

Detail Task / (Progress) / (Slack)
Summary Task / (Progress) / (Slack)
Baseline
Conflict
Resource delay
Milestone

Progress shows Percent Achieved on Actual

Scale: 5 days per character

FIGURE 6-1, Process Pump Development Program Schedule

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6.1 Gear Cartridge Modifications

6.1.1 Pump Configuration

The gear cartridge, shown in **FIGURE 4-3**, includes four major components. Two side plates, a center spacer and carbon graphite journal bearings. These components along with the drive and driven gears are a precision machined and matched assembly. Two dowel pins provide for the cartridge alignment and the socket head cap screws provide for assembly containment. Individual cartridges were fabricated for each gear set tested. The cartridge components are shown in **Figure 6-2.**

Following the originally tested configuration, which included nitrited 17-4 gears in the first quarter of 92, several cartridge improvements for corrosion resistance were identified in the SSI report SVME 2977 dated Sept 4, 1992. Based on this report the cartridge components were changed, for improved corrosion resistance, as follows:

- The side plates were manufactured from 316 SS per QQ-S-766 with the internal running faces being chrome plated per QQ-C-320, Class 2C to a thickness of .002/.003 inch.
- The center spacer was manufactured from 316 SS per QQ-S-766, passivated per QQ-P-35.
- The carbon graphite bearings were isolated from the side plates using primer per MIL-P-23377.

The cartridge assembly is press fit into a pump housing which also includes the motor assembly shown in **FIGURE 4-2**. The drive connection between the motor and the cartridge assemblies is accomplished by a mating spline. A typical drive gear spline is shown in **FIGURE 6-3.**

Temperature control of the pump motor assembly is accomplished by bleeding off some high pressure fluid and return it to the pump inlet through the motor. This fluid flows between the motor rotor and stator thereby removing the motor heat and is then passed through the carbon graphite motor bearings.

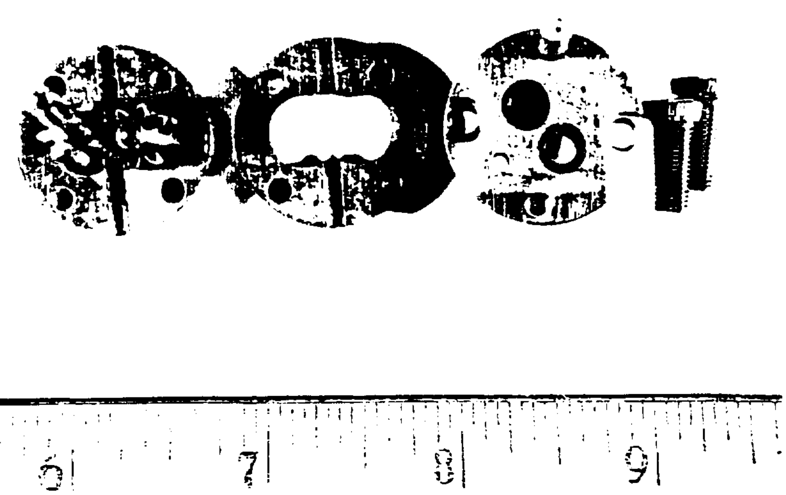

Figure 6-2, Pump Cartridge Components

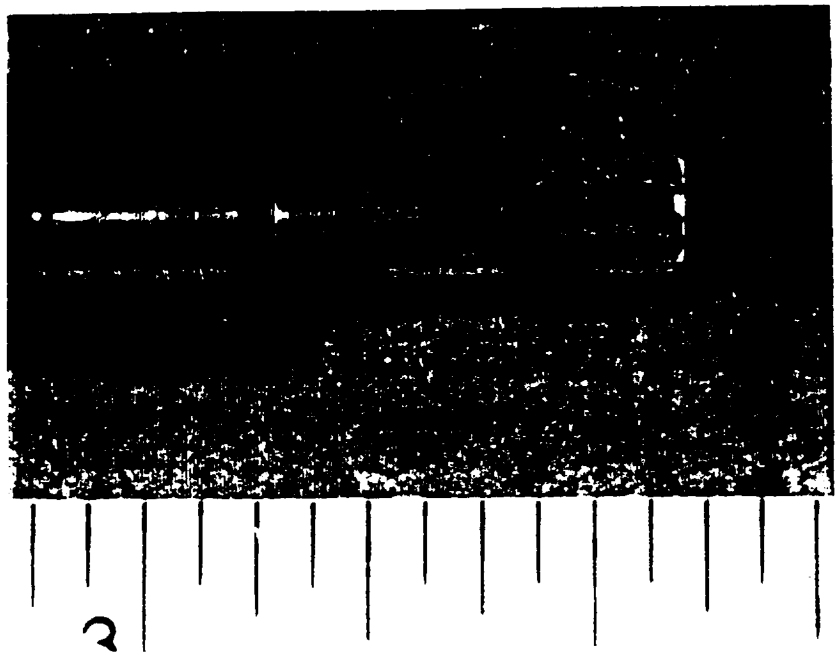

FIGURE 6-3, Drive Gear Spline

6.1.2 Effects of Testing on Cartridge Components

The initial testing of the cartridges with the Inconel 718 and 15-5 PH SS gears indicated that there was some damage between the gear end faces and cartridge end plate furthest from the motor end. Most of the side plate to gear damage occurred between the Inconel 718 gears and its chrome plated SS side plate. This pump test lasted for only several seconds until galling at this interface occurred and caused the pump to lock up. Further information on the Inconel 718 test results is described in section 6.2. Initial testing with the 15-5 PH SS gears and subsequent teardown evaluation also indicated some damage on the chrome plated SS side plates. This damage was not sufficient to cause the pump to lock up but was excessive for the amount of operating time, 188 hrs. Further discussion of the 15-5PH SS results is described in section 6.3.1. This cartridge damage is also further discussed in Appendix III: Examination of PDI Gear Pumps, Number SVME 3346, Dated October 13, 1994.

The later tests with the borided Inconel 718 and Stellite 6B gears, which are described in sections 6.4 and 6.5 respectively, showed no signs of mechanical damage or corrosion to the cartridge components. The conclusion from all of the cartridge results indicate that as long as the gear and end plate have sufficient hardness to prevent wear or galling, no significant damage will occur between the gear and side plate.

The carbon graphite bearings could not be sufficiently evaluated on this program due to the low operating times of the life tests. Further testing of the pump would be required to evaluate the bearing configuration capability in meeting the ISSWP requirements.

6.2 Inconel 718 2992 Pump

6.2.1 M/N 2992 Pump Configuration

The pump configuration for the 718 gear testing was the same as described in section 6.1.1

6.2.2 Test Results

HFS tested the Inconel 718 (ASM 5664) gear pump starting on Aug. 30, 1994. Process Pump M/N 2992, S/N 0002 was used for the test. After only 15 seconds of operation the pump appeared to be operating rough. The inspection, conducted on Aug. 31, revealed no significant gear damage and it was decided to reassemble the pump and continue the test. Prior to the reassembly the gears were lightly lapped with a 600 grit paper to remove any possible burrs. On Sept 1, the pump was reassembled and tested. The pump operated for approximately 30 second before it locked up. The teardown investigation revealed that significant galling had occurred. The galling was found between the side plate and the gear end faces along with between the drive faces of the gears. The galling at the gear end face appeared to cause the pump lock up. Further results are described in Appendix III: Examination of PDI Gear Pumps, Number SVME 3346, Dated October 13, 1994.

The conclusion from this test indicated that the surface hardness of the gears in a non-lubricating fluid was insufficient to provide proper wear resistance. The hardness of the Inconel 718 gears tested was approximately 40 - 41 Rc which when compared to a standard nitrided 17-4 PH SS gear material hardness of 58 - 65 Rc is relatively low. It was originally anticipated that the pump operating conditions would allow for lower gear surface hardness but the results indicated that this was not true.

6.3 Stainless Steel 15-5 2992 Pump

Evaluations were conducted on the two sets of 15-5 PH (AMS 5962) gears. The initial and low speed tests are described below. The pump configuration for all of the 15-5 PH SS gear testing was the same as described in section 6.1.1.

6.3.1 Test Results - Initial 15-5 2992

HFS conducted testing on the M/N 2992 S/N 0002 pump with the 15-5 PH SS gears from Aug. 26 through Sept 16, 1994. During this test the gear set accumulated a total of 188 hrs of test time, which was operated using waste water supplied by SSI. The testing on Aug. 26 was initiated with a two hour operational check out. Following this, on Aug. 29, the pump and cartridge assembly was disassembled to inspect the gears. This inspection found no galling and only a slight wear pattern on the gear teeth. This slight wear was judged to be normal. It was decided to proceed with the life test. All of the 15-5 PH SS gear performance results from this testing is shown in **TABLE 6-2.**

PROCESS PUMP M/N 2992, S/N 0002

DATE	OP	FLOW READING (gpm)	SPEED (rpm)	FLOW RATE (pph)	OUTLET PRESS (psig)	VOLTS (vdc)	CURRENT (amps)	POWER (watts)	PUMP EFF. (%)	PUMP TEMP (F)	NOTES
8/26/94	HFS	0.039	3000	19.52	70	120	0.146	17.52	6.58	78.00	Started pump test-only ran 2 hrs
9/8/94	HFS	0.036	2931	18.02	70	120	0.140	16.80	6.33	72.00	Restarted - 2.3 total hrs
9/9/94	HFS	0.034	2931	17.02	70	120	0.100	12.00	8.37	78.00	Total run time = 21 hrs
9/12/94	HFS	0.039	2931	19.52	70	120	0.100	12.00	9.60	76.00	Total run time = 94 hrs
9/13/94	HFS	0.034	2931	17.02	70	120	0.090	10.80	9.30	76.00	Total run time = 116 hrs
9/14/94	HFS	0.034	2931	17.02	70	120	0.090	10.80	9.30	76.00	Total run time = 139 hrs
9/15/94	HFS	0.030	2931	15.02	70	120	0.100	12.00	7.39	75.00	Total run time = 163 hrs
9/16/94	HFS	0.018	2931	9.01	70	120	0.100	12.00	4.43	83.00	Total run time = 188 hrs, stopped test

TABLE 6-2 PROCESS PUMP 15-5 PH SS DATA LOG

After the test was stopped at 188 hrs, the pump was disassembled and the cartridge assembly was inspected. The inspection revealed that the drive faces of both gears had significant wear which led to the pump's performance decrease. Further results are described in Appendix III: Examination of PDI Gear Pumps, Number SVME 3346, Dated October 13, 1994. Similar to the conclusion reached on the Inconel 718 gears the 15-5 PH gear surface hardness was too low to provide adequate life in the non-lubricating fluid.

6.3.2 Test Results - Low Speed 15-5 2992

At the program review meeting conducted at HFS in Oct 94, it was decided to evaluate what effect lower operating speeds would have on pump life. With an additional set of 15-5 PH SS gear already available, it was decided that a low cost and quick method of obtaining some quantitative results on this parameter would be to operate the 2992 pump at a reduced speed and evaluate any improvement in performance life. HFS conducted this test from Jan 20 to Feb. 23, 1995 accumulating a total of 257 hrs of operation before stopping the test. This test was stopped due to a significant performance reduction. **TABLE 6-3** shows the results obtained.

Following the test the pump and cartridge was disassembled and inspected. The inspection revealed that damage similar to the initial 15-5 PH SS had occurred. Further results are described in Appendix V: Materials Selection WP Gear Pump Report, Number SVME 3478, Dated June 23, 1995. Although the lower speed pump test operated approximately 37% longer, the initial 170 hrs were operated at a lower pressure (ie: 55 psig) and therefore, lower gear loading resulted. Also taking into account the fact that this test was conducted with a limited number of samples, the results indicate no significant improvements in life was achieved.

6.4 Borided Inconel 718 2992 Pump

6.4.1 M/N 2992 Pump Configuration

The pump configuration for the borided 718 gear testing was the same as described in section 6.1.1.

As a result of the earlier Inconel 718 and 15-5 PH gear tests, it was decided to fabricate gears with a surface hardness at least equal to that of a nitrited 17-4 PH (ie: Rc 58 - 65 min.). This was based on the earlier results and HFS's experience with other gear pump applications. After researching several materials and coatings, a borided Inconel 718 was selected to be evaluated for the 2992 configuration.
The boride surface treatment is a proprietary process performed by Materials Development Corp. (MDC) located in Medford, MA. HFS reviewed the application with MDC and the decision was made to harden the gears to a depth of .001". This surface treatment is relatively thin as compared to the previously tested nitrided 17-4 PH gears which HFS treats to a depth of .003 to .005". The boriding process was anticipated to cause dimensional swelling of the gears by approximately 10% of the hardened depth. HFS decided that since this indicated approximately a .0001" growth that no dimensional adjustment should be made. When the initial set of gears were borided the actual dimensional growth was closer to 25 to 35%. This larger growth caused the gears to bind when installed into the pump cartridge. As a result of the binding, this set was scrapped. This set was then examined by SSI to verify the coating thickness. During this review it was found that the coating was performed to the proper thickness and that the entire gear was coated. The investigation revealed that the dimensional growth is a function of not only the coating thickness but is very dependent on the component geometry. Also several areas of the gears, specifically the gear edges and spline, were not supposed to be hardened to prevent cracking at the edges. Both of these issues were corrected and an additional set was fabricated. Further discussion on the boriting process and

the results obtained can be found in Appendix V: Materials Selection WP Gear Pump Report, Number SVME 3478, Dated June 23, 1995.
The second set of borided gears was fabricated to reduced dimensions and completed by mid April 95.

PROCESS PUMP M/N 2992, S/N 0002

DATE	OP	FLOW READING (gpm)	SPEED (rpm)	FLOW RATE (pph)	OUTLET PRESS (psig)	VOLTS (vdc)	CURRENT (amps)	POWER (watts)	PUMP EFF. (%)	PUMP TEMP (F)	NOTES
		INITIAL PERFORMANCE MAP CONDUCTED									
1/20/95	N/A	N/A	2000	29.03	10	120	0.041	4.92	4.98		
1/20/95	N/A	N/A	2000	24.52	20	120	0.052	6.24	6.63		
1/20/95	N/A	N/A	2000	20.02	30	120	0.058	6.96	7.28		
1/20/95	N/A	N/A	2000	14.02	40	120	0.065	7.8	6.06		
1/20/95	N/A	N/A	2000	10.01	50	120	0.073	8.76	4.82		
1/20/95	N/A	N/A	2000	6.51	60	120	0.081	9.72	3.39		
1/20/95	N/A	N/A	2000	5.5	70	120	0.093	11.16	2.91		
1/20/95	N/A	N/A	2100	7.5	70	120	N/A	N/A	N/A		
1/20/95	N/A	N/A	2200	9.51	70	120	N/A	N/A	N/A		
1/20/95	N/A	N/A	2300	11.01	70	120	N/A	N/A	N/A		
		169 hr PERFORMANCE MAP CONDUCTED									
2/11/95	N/A	N/A	2000	25.02	10	120	0.039	4.68	4.51		
2/11/95	N/A	N/A	2000	20.02	20	120	0.043	5.16	6.55		
2/11/95	N/A	N/A	2000	20.02	30	120	0.047	5.64	8.98		
2/11/95	N/A	N/A	2000	15.02	40	120	0.052	6.24	8.12		
2/11/95	N/A	N/A	2000	15.02	50	120	0.057	6.84	9.26		
2/11/95	N/A	N/A	2000	10.01	60	120	0.062	7.44	6.81		
2/11/95	N/A	N/A	2000	5	70	120	0.073	8.76	3.37		
		LOW SPEED LIFE TEST CONDUCTED									
1/24/95	N/A	N/A	2000	13.01	55	120	0.064	7.68	7.86		STARTED TEST
1/27/95	N/A	N/A	2000	13.01	55	120	0.058	6.96	8.67		
1/30/95	N/A	N/A	2000	13.01	55	120	0.057	6.84	8.82		
1/31/95	N/A	N/A	2000	13.01	55	120	0.058	6.96	8.67		
2/2/95	N/A	N/A	2000	13.01	55	120	0.058	6.96	8.67		
2/4/95	N/A	N/A	2000	13.01	55	120	0.058	6.96	8.67		
2/10/95	N/A	N/A	2000	13.01	55	120	0.058	6.96	8.67		
2/14/95	N/A	N/A	2100	7.94	70	120	0.750	90.00	0.52		PRESSURE & SPEED INCREASED
2/16/95	N/A	N/A	2100	7.94	70	120	0.760	91.20	0.51		
2/23/95	N/A	N/A	0.00	0.00	0	120	N/A	N/A	N/A		257 hrs TOTAL LIFE TEST TIME

TABLE 6-3 PROCESS PUMP 15-5 PH SS LOW SPEED RESULTS

6.4.2 Test Results

HFS assembled the pump and conducted an initial check out test on each pump from April 17 to 18,1995. Pump, S/N 0001, was operated for approximately eight hours prior to delivery to SSI. The test results from before and after the eight hour run along with all of SSI initial performance and life test data are shown in Appendix II: Pump Test Results, M/N 2992 Borided 718. Pump S/N 0002 was performance checked at HFS and delivered to SSI and was not tested at SSI. This pump is currently in government stores.

The performance map at SSI was conducted on S/N 0001 on April 25, 1995. This pump map was conducted using the test schematic shown in **FIGURE 6-4** and utilized clean deionized water as the test fluid.

The initial performance data for the Inconel 718 pump showing pump flow rate and efficiency versus outlet pressure are shown in **FIGURE 6-5** and **FIGURE 6-6** respectively.

The pump life test was initiated on May 2, and continued through May 11, 1995. At the beginning of the test the pump was operating very smooth and quite. No noise readings were taken but the pump could not be heard over the back ground noise in the lab. The test was stopped as a result of a pump lock up which occurred on May 11, 1995 at 2:10 p.m. after 87 hours into the life test. Once the pump lock up was confirmed a teardown and inspection was conducted which revealed significant damage to the gear drive faces. The metallurgical examination found that the boride layer on the gear drive faces had been removed. Once the Borided surface was removed galling occurred resulting in the lock up. No corrosion or damage to the cartridge was found. Further discussion of this evaluation can be found in Appendix VI: Analysis of Borided Inconel 718 and Stellite 6B Gears, Report Number SVME3517, Dated July 14, 1995.

6.5 Borided Stellite 6B 2941 Pump

6.5.1 M/N 2941 Pump Configuration

The pump configuration for the 2941 gear pump testing was the same as described in section 6.1.1 except that the pump and gear cartridge was approximately 50% larger. This larger size allowed a lower pump operating speed. This lower speed, approximately 1500 rpm, was used to further evaluate the impact of reduced speed on the pump operating life. Wire EDM was used to machine the Stellite 6B gear profiles. This process was used because the conventional hobbing was not feasible for the gears. These gears were machined to the same percent dimensional reduction as the Inconel 718 gears.
This pump was provided by HFS on consignment to provide a low cost test bed. The pump housing and controller for the M/N 2941 have been returned to HFS.

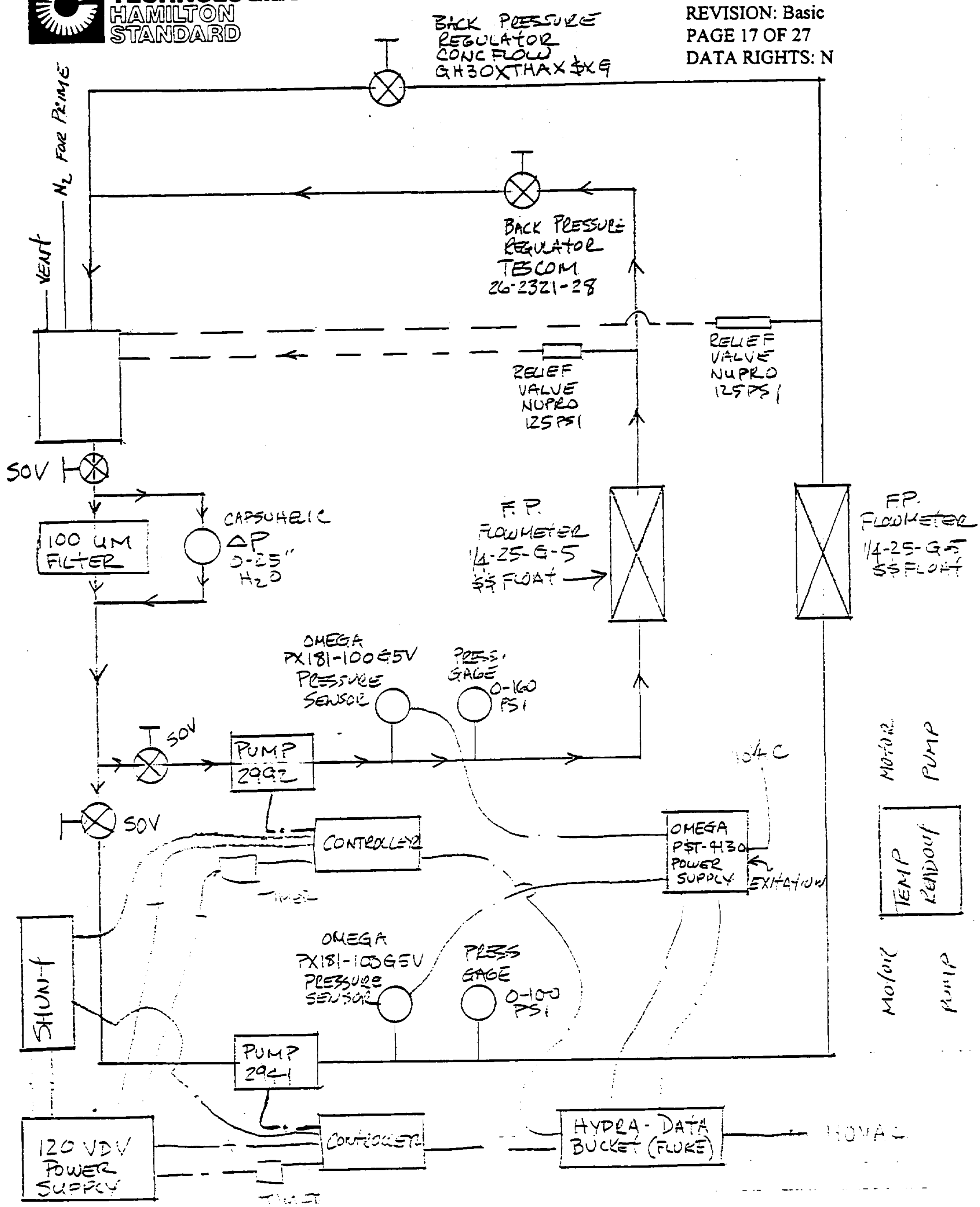

FIGURE 6-4, SSI Test Rig Schematic

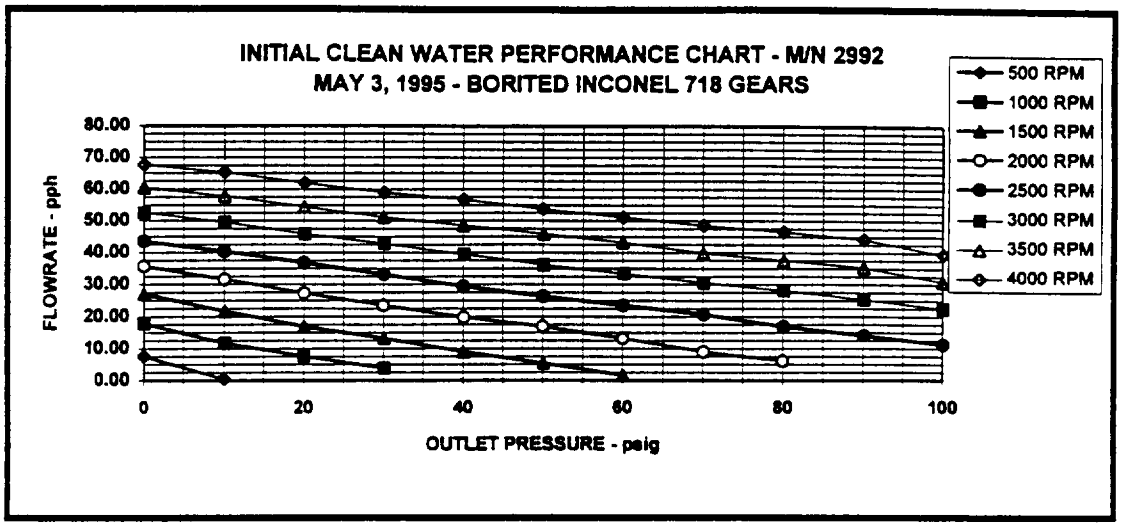

FIGURE 6-5, 2992 Clean Water Performance Chart, Flow rate Vs Outlet Pressure

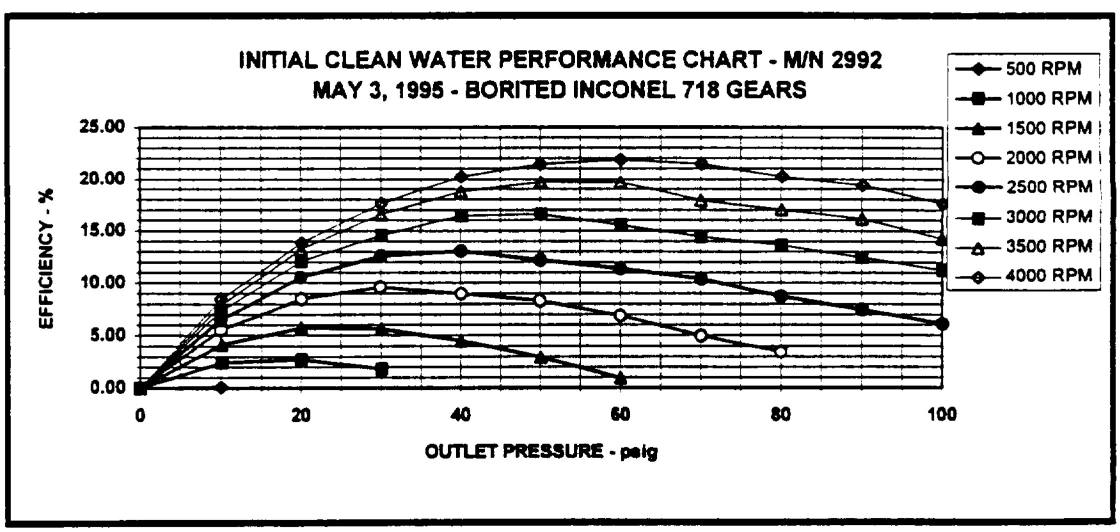

FIGURE 6-6, 2992 Clean Water Performance Chart, Efficiency vs. Outlet Pressure

6.5.2 Test Results

HFS assembled the pump and conducted an initial check out test on from April 13 to 18,1995. Pump, S/N 33654-002, was operated for approximately eight hours prior to delivery to SSI. The test results from before and after the eight hour run along with all of SSI initial performance map and life test data are shown in Appendix IV: Pump Test Results, M/N 2941 Borided Stellite 6B.

The initial performance map at SSI was conducted on May 1, 1995. This pump map was conducted using the test schematic shown in **FIGURE 6-4** and utilized clean deionized water as the test fluid. The performance data obtained is shown in **Figure 6-7** and **Figure 6-8**.

The pump life test was initiated on May 2, and continued through May 26, 1995. This pump was tested in parallel with the M/N 2992 Borided Inconel 718 pump described in section 6.4. At the beginning of the test the pump was operating smooth but unlike the M/N 2992 pump, this pump was clearly audible. No noise readings were taken but the pump could be easily heard over the back ground noise in the lab. An interim clean water performance check conducted on May 15, 1995 indicated a slight decrease in performance. Following this check the waste water was changed out with a fresh batch and the life test was continued.

The test was stopped on May 26, 1995 after 424.75 hours into the life test. This pump test was stopped in order to investigate if any damage had or was in the process of occurring to the Stellite 6B gears. This decision was based on evidence found on the Inconel 718 gears along with the decrease in pump performance. The intent of the early shut down was to find some evidence of possible boride coating failure, possibly in process, on the Stellite 6B gears. The pump performance, as can be seen in Appendix IV, had decreased from the start of the test. Specifically, the power had increased approximately 10% and the outlet pressure gauge had become unstable. This gauge was now bouncing a total of approximately 20 psig. Also the noise and vibration from the pump appeared to have increased. This gauge and noise information indicated that possible internal gear damage may have occurred.

A teardown and inspection was conducted which revealed significant damage to the gear drive faces. This damage was similar to that found on the Inconel 718 gears. Upon the metallurgical examination it was found that the boride layer on the gear drive faces had been removed. Once the Borided surface was removed wear of the gears occurred. The wear/damage to the gears caused an increase to the pump backlash which is believed to have caused the gauge instability and increased pump vibration and noise. This increased backlash also is believed to have caused the decrease in pump performance.

The examination of both the Inconel 718 and Stellite 6B gears in the areas near the edge of the removed boride showed cracks were present. These cracks likely indicate the coating was not sufficient to withstand the gear loading.

No corrosion or damage to the cartridge was found. Further discussion can be found in Appendix VI: Analysis of Borided Inconel 718 and Stellite 6B Gears, Report Number SVME3517, Dated July 14, 1995

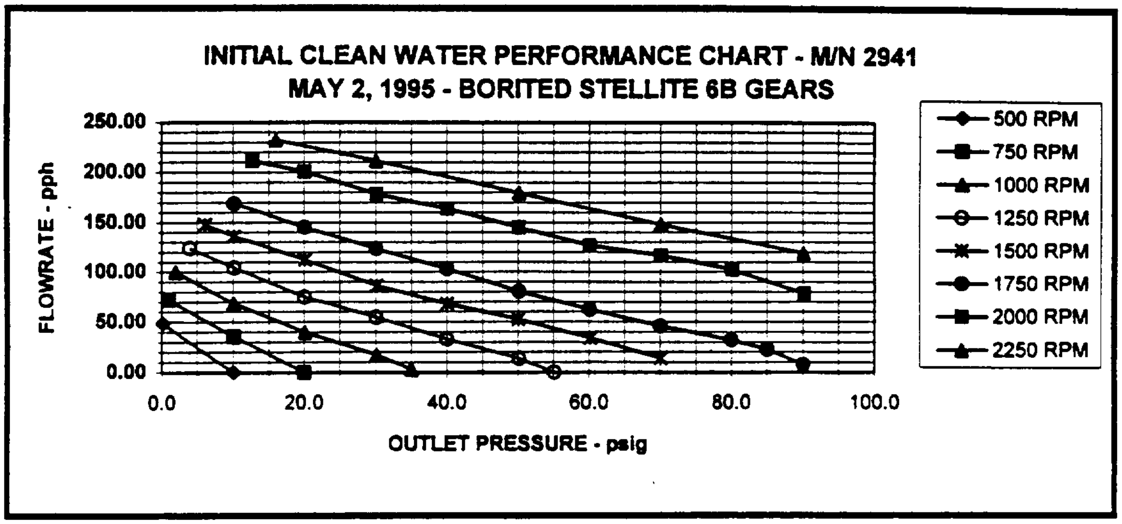

FIGURE 6-7, 2941 Clean Water Performance Chart, Flow rate Vs. Outlet Pressure

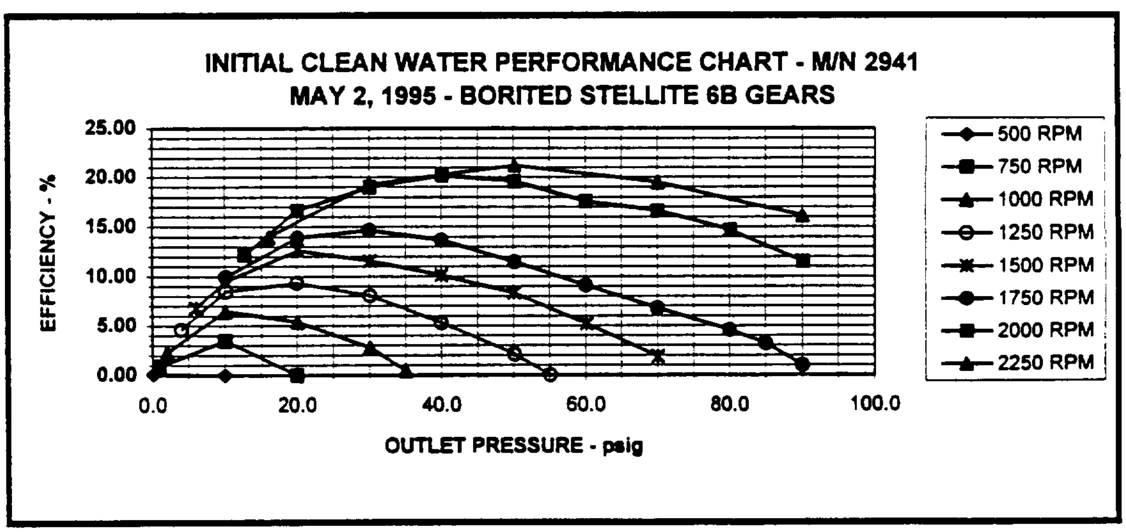

FIGURE 6-8, 2941 Clean Water Performance Chart, Efficiency Vs. Outlet Pressure

7. Observations & Conclusions

7.1 Observations

Several observations have been reached concerning this Process Pump development program. These are:

- No foreign contaminants were responsible for any of the pump / gear failures.
- All of the improvements to the cartridge components appear to have been successful.
- No signs of corrosion were evident on any of the materials tested.

7.2 Conclusions

Several conclusions have been reached concerning this Process Pump development program. These are:

- The combination of the thin boride diffusion depth of 0.001" and the very hard/brittle nature of the boride zone led to cracking and removal of the boride layer.
- Borided gears are insufficient for this gear pump application.
- There is no apparent improvement in life performance anticipated with a pump speed reduction of approximately 500 to 600 rpm. Therefore, it would be better to use the 2992 pump configuration in any further development of this pump. This will permit the use of the higher efficiency device.
- A Gear pump may not be the proper technology for the ISS WP application.

8. Recommendations

Based on the conclusions above and along with the fact that the WP still requires a positive displacement pump, further Process Pump development is recommended.

SSI recommends an additional pump development program of twelve to fifteen months. This new program would include several phases. The first phase would include approximately four month for a design study followed by prototype manufacturing and tests phases. Some of the following issues would be the basis of the pump design phase:

- Investigate alternate pump technology.
- Develop alternate M/N 2992 gear pump modifications.

The output of the design phases would be a report including a trade study and recommendations for the manufacturing and test phases. The recommendations may include several alternate paths for further development and test. This may be desirable so as to be able to test the possible alternate pump technologies.

Continued development efforts related to this pump are essential to minimize technical and programmatic risks to the ISS WP. Currently, the ISS WP development is scheduled to be restarted beginning in early GFY 98. This would allow approximately two years for continued development to resolve the pump performance issues with out impacting the ISS program.

9. Appendix I: Process Pump Test Plan

TPION - 01
Revision A

SPACE STATION WATER PROCESSOR
PROCESS PUMP

TEST PLAN

CONTRACT # NAS8-38250-12

Prepared for
ION ELECTRONICS
6767 MADISON PIKE
HUNTSVILLE, AL 35806

Date issued
June 1994

Revised
April 1995

Prepared by
UNITED TECHNOLOGIES CORPORATION
HAMILTON STANDARD SPACE
SYSTEMS INTERNATIONAL INC.
WINDSOR LOCKS, CONNECTICUT 06096

Approved by

7-12-95

ENGINEER MANAGER

PROGRAM MANAGER

UNITED TECHNOLOGIES
HAMILTON STANDARD

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UNITED TECHNOLOGIES
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PROCESS PUMP TEST PLAN REVISION LOG

Revision Date	Revision Description
April 12, 1995	Extensively revised to incorporate the testing for both the borite hardened gear pumps with Inconel 718 (M/N 2992) and Stellite 6B (M/N 2941) gear material.

1.0 Introduction:

This test plan has been developed to evaluate the improvements in the Space Station Water Processor (WP) Process Pump. The Process Pump, item 4596, is an integral component in the Waste Water Orbital Replacement Unit (WWORU) of the WP. The schematic is shown in Figure 1.0-1. This ORU is responsible for receiving, degassing, and storage of the Space Station waste water as well as it provides the system flow and pressure. The Process Pump provides the 15 pph minimum system flow rate and operating pressure of approximately 65 psig.

This test plan defines the tests necessary to evaluate two new gear materials as well as several other minor modifications to the pumps. These modifications are intended to extend the operational life of the pumps.

Two pumps, originally purchased on the Space Station Program and now transferred to NASA contract # NAS8-38250-12, will be used as the test pumps for this program.

The pump modifications and the initial evaluation will be conducted at the pump suppliers facility while the final testing will be conducted at Hamilton Standard Space Systems International's, HSSSI, Engineering Laboratory facilities.

2.0 Background:

The Process Pump in the WP, along with all the other WWORU components, must be capable of surviving the harsh environment provided by the waste waters. In addition, the pump must have an operational life of ten years. As a result of these significant challenges for the pump design, a development program was conducted a HSSSI as part of the Space Station Program.

Two Process Pumps, supplier model # 2992, serial # 0001 and 0002, were procured and received at HSSSI in the first quarter of 1992. These pumps are a gear pump configuration with an integral 120 vdc canned motor. The gears were made of nitrited 17-4PH stainless steel. A variable speed motor controller with speed sensor was also received, with each pump.

Process Pump s/n 0001 was performanced mapped and then life tested. The life test was initiated on March 2, 1992 and was concluded on May 20, 1992 as a result of a high motor temperature and a no flow condition. After a series of evaluations the failure was determined to be the result of a low carbon steel plug in the test rig which corroded and in turn caused the pump to lock up. During the evaluations several additional findings were observed relating to the pump's corrosion resistant capabilities.

Over the past two years HSSSI has continued to work with the pump supplier which resulted in the development of recommendations to improve the pump life. A major area of development that remains is with the gear material. This test program will evaluate two different gear materials, Inconel 718 and Stellite 6B.

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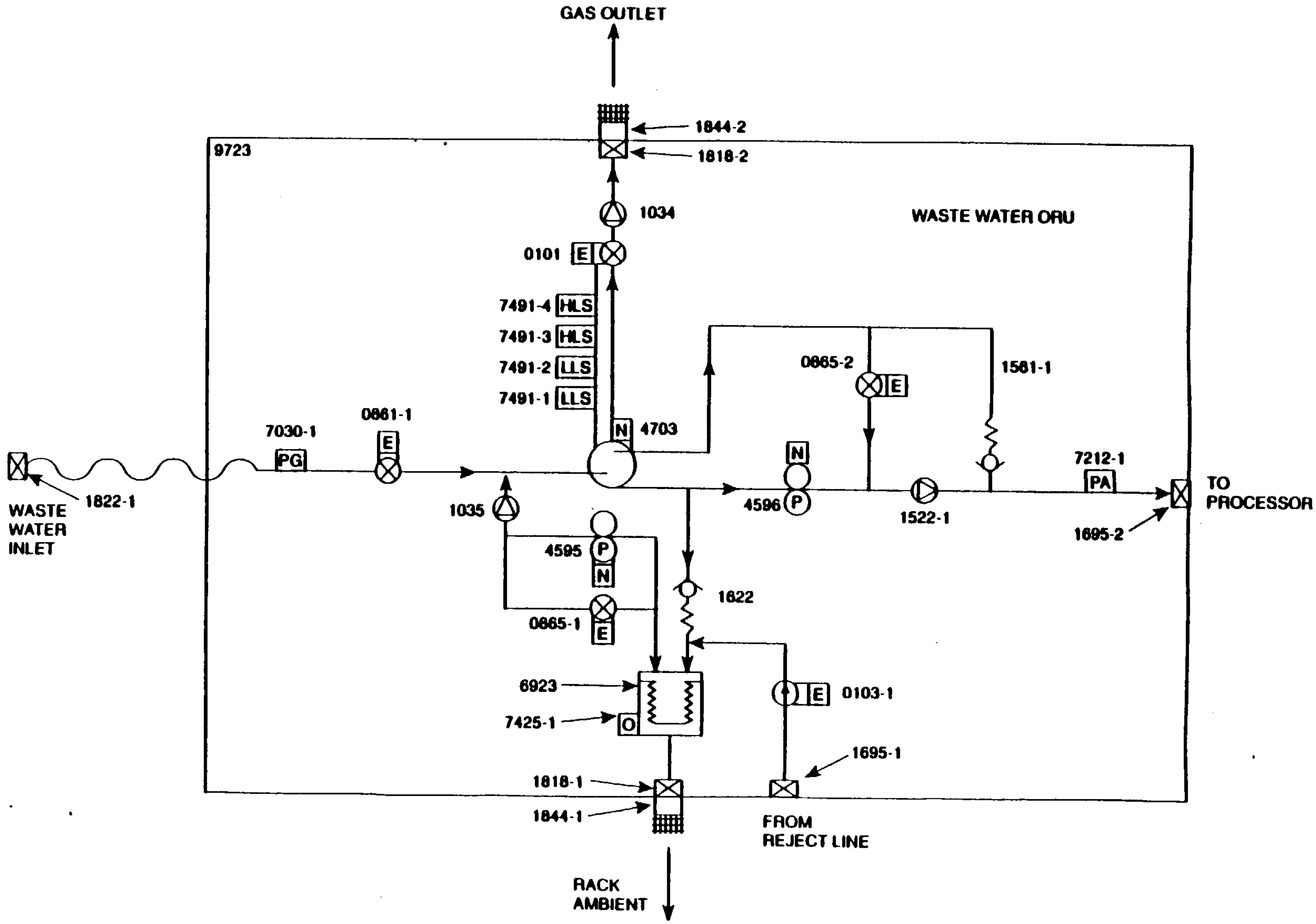

Figure 1.0-1 Water Processor Waste Water ORU

3.0 Test Description:
The following sections identify the test objectives and the test program schedule.

3.1 Test Objectives:
The objective of this test plan is to evaluate the life performance of the WP Process Pump toward its requirement of ten year life. Two Process Pumps will be used in parallel tests to evaluate the improvements. Two sets of gears will be manufactured from two materials. One set of gears will be made from Inconel 718 and one from Stellite 6B. The Inconel gear set will be tested in the previous procured model pump (M/N 2992) and the Stellite gear set will be evaluated and a larger pump configuration (M/N 2941). The 2941 pump and motor housing is being provided to HS on consignment from the pump supplier, Howden Fluid Systems (HFS).
An initial performance test will be conducted at the suppliers facility on each of the pump assemblies prior to delivery to HS.

The life testing at HSSSI will be conducted to provide approximately 600 - 1000 hours of operation on real waste water. Performance maps will be conducted throughout the testing to monitor any change in pump performance.

3.2 Test Schedule:
The revised test program schedule is attached in Figure 3.2-1. The programs for the Process Pump supplier as well as HSSSI's efforts are identified.

4.0 Test Conditions:
4.1 Performance Verification:
Performance verification of the pumps will consist of monitoring pump performance at series of operating conditions. The operating conditions to be run on the 2992 pump are defined in Table 4.1-1. The entire set of operating conditions will be run prior to and following the life test as defined in section 4.2.

	Outlet Operating Pressure (psig)										
Speed(rpm)	0	10	20	30	40	50	60	70	80	90	100
500	X	X	--	--	--	--	--	--	--	--	--
1000	X	X	X	X	--	--	--	--	--	--	--
1500	X	X	X	X	X	--	--	--	--	--	--
2000	X	X	X	X	X	X	--	--	--	--	--
2500	X	X	X	X	X	X	X	X	X	X	--
3000	X	X	X	X	X	X	X	X	X	X	X
3500	X	X	X	X	X	X	X	X	X	X	X
4000	X	X	X	X	X	X	X	X	X	X	X
MAX. rpm	X	X	X	X	X	X	X	X	X	X	X

Table 4.1-1 2992 Performance Verification Operating Conditions

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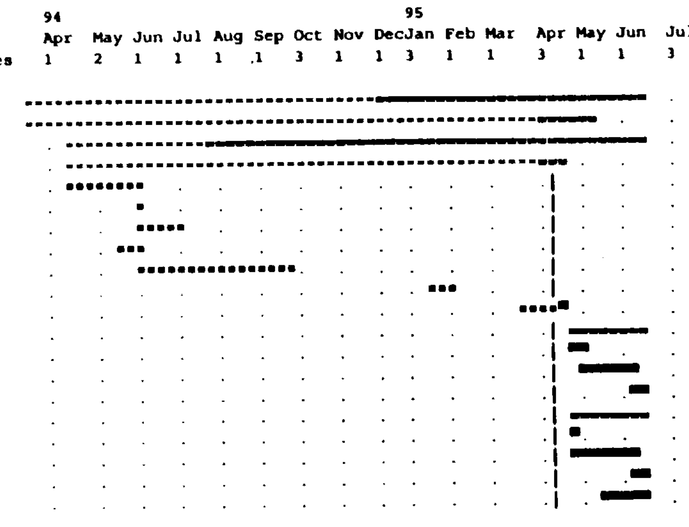
Schedule Name : PROCESS PUMP DEVELOPMENT SCHEDULE
Responsible : D. PARKER
As of Date : 13-Apr-95 Schedule File : PUMP495

Dependencies : PERFORM CLEAN H2O MAPS

Task Name	Start Date	Duration	End Date	Pct Achvd	Notes
2.0 PROCESS PUMP PROGRAM	15-Mar-94	308.0 d	15-Jun-95	56	
+ 2.1 PROCESS PUMP UPGRADE	15-Mar-94	282.1 d	10-May-95	89	
2.2 PUMP TEST @ HS	11-Apr-94	289.0 d	15-Jun-95	23	
TEST PLAN / RIG DEVELOPMENT	11-Apr-94	250.0 d	20-Apr-95	93	
DEVELOP HS TEST PLAN	11-Apr-94	38.0 d	2-Jun-94	100	
ISSUE TEST PLAN TO ION	2-Jun-94	2.0 d	3-Jun-94	100	
RECEIVE PLAN APPROVAL	3-Jun-94	20.0 d	30-Jun-94	100	
DESIGN HS TEST RIGS	16-May-94	12.0 d	1-Jun-94	100	
ORDER/RECEIVE HS TEST RIG HDW	2-Jun-94	78.0 d	28-Sep-94	100	
FAB HS TEST RIGS	16-Jan-95	12.0 d	1-Feb-95	90	
ISSUE REVISED TEST PLAN	20-Mar-95	24.0 d	20-Apr-95	60	
HS TEST PROTOTYPE 718 PUMP	26-Apr-95	33.0 d	12-Jun-95	0	
PERFORM CLEAN H2O MAPS	26-Apr-95	3.0 d	28-Apr-95	0	
PERFORM REAL H2O LIFE TESTS	1-May-95	28.0 d	8-Jun-95	0	
PERFORM POST - CLEAN H2O MAPS	9-Jun-95	2.0 d	12-Jun-95	0	
HS TEST PROTOTYPE 2941 PUMP	21-Apr-95	36.0 d	13-Jun-95	0	
PERFORM CLEAN H2O MAPS	21-Apr-95	4.0 d	27-Apr-95	0	
PERFORM REAL H2O LIFE TESTS	27-Apr-95	30.0 d	9-Jun-95	0	
PERFORM POST - CLEAN H2O MAPS	9-Jun-95	2.0 d	13-Jun-95	0	
DEVELOP PROGRAM FINAL REPORT	15-May-95	23.0 d	15-Jun-95	0	



Detail Task — (Progress) — (Slack)
Summary Task — (Progress) — (Slack)
Baseline — Conflict — Resource delay — Δ Milestone
Progress shows Percent Achieved on Actual
Scale: 5 days per character

TIME LINE Gantt Chart Report, Strip 1

Figure 3.2-1 Test Program Schedule

The operating conditions to be run on the 2941 pump are defined in Table 4.1-2. Again, the entire set of operating conditions will be run prior to and following the life test as defined in section 4.2.

	Outlet Operating Pressure (psig)										
Speed(rpm)	0	10	20	30	40	50	60	70	80	90	100
750	X	X	X	X	X	X	X	X	X	X	X
1000	X	X	X	X	X	X	X	X	X	X	X
1250	X	X	X	X	X	X	X	X	X	X	X
1500	X	X	X	X	X	X	X	X	X	X	X
1750	X	X	X	X	X	X	X	X	X	X	X
MAX. rpm	X	X	X	X	X	X	X	X	X	X	X

Table 4.1-2 2941 Performance Verification Operating Conditions

Every fourteen days of life test operation the test rig(s) will be flushed with clean water and a limited performance check conducted on each pump.

This check will consist of operating the pumps at the following conditions which will be used to track any performance changes through the life test:

Pump Model	Speed (rpm)	Outlet pressure (psig)
2992	2000	40
2992	2500	50
2992	3000	60
2992	3500	70
2941	~~500~~ 1250	40
2941	~~1000~~ 1500	50
2941	~~1250~~ 1750	60
2941	~~1500~~ 2000	70

All of the performance verification conditions will be conducted with clean deionized water. This will eliminate any variability in the pumping fluid for performance checks.

The information to be recorded at each operating condition is identified in Table 4.1-3

4.2 Life Test:

Following the initial pump performance mapping, as described in section 4.1, the two pumps will be operated in parallel on the test rig identified in section 5.0. The waste water used for the life testing is identified in section 4.3.

The operating conditions for the test will be as follows:

1. 70 psig outlet pressure
2. Flow rate of 15.0 to 16.0 pph
3. Operating cycle to be 5.5 hours on, 0.5 hours off
4. Operating time to be 24 hours per day, 7 days per week

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Table 4.1-3 Performance Verification Operating Results

Process Pump Model Number 2992

Date	Time	Operator	Pump Serial #	Speed (rpm)	Flowmeter Reading	Flow (pph)	Pressure (psig)	Voltage (vdc)	Current (amp)	Power (W)	Pump Temp (F)	Motor Temp (F)	Amb Temp (F)	Notes

Over the approximately 30 days of testing this operating cycle will provide 140 starts and 660 hours of operation.
The waste water will be changed every fourteen days initially. This time frame may be adjusted either shorter or longer as required.
The water changes is/are to coincide with the limited performance checks as identified in section 4.1.

4.3 Life Test Waste Water:
The waste water to be used for the life testing will consist of shower, handwash, distilled urine, and mouth wash water. The actual make up of the waste water is defined in Table 4.3-1. Igepon soap 6503-45-4 and Crest toothpaste will be used for the testing. The igepon soap formulation is identified in Table 4.3-2.
Oxone and sulfuric acid will be used to pretreat the distilled urine. The oxone and sulfuric acid pretreat concentrations are 5.0 and 2.3 grams/liter of urine respectively. Deionized water will be used to simulate the urinal flush water. The percentage of pretreated urine to flush water is 75% and 25% respectively.
Each waste water batch will be monitored and the data recorded for TOC, TC, conductivity and Ph.

5.0 Test System/Environment:
5.1 Test System:
The system test schematic show in Figure 5.0-1 will be used for both the performance verification and life testing of the pumps at HSSSI.
The two pumps will be operated in parallel on the closed loop test rig. A common waste tank with a mixer along with a 100 micron filter will be utilized. All other components of the test rig will be independent. This test system will minimize the rig cost and set up time while allowing completely independent pump operation.
Thermocouples will be attached to the exterior pump surface and to the motor windings for thermal monitoring throughout all of the testing. Manual back pressure regulators and rotometers will be used to set the pressure and monitor flow respectively.

5.2 Test Environment:
All tests will be conducted at a normal ambient conditions of approximately: Temperature 70 +- 5 F, Atmospheric Pressure 14.7 +- .3 psi, Relative Humidity 30 - 80%.

6.0 Supplier Test Program
The supplier will conduct the initial performance testing at their facility. The two pumps will be assembled using the different gear materials. One pump will use a gear set of Inconel 718 and the other will use the Stellite 6B material.
These two pumps will then be tested as described in the supplier test plan provided in Attachment A.
At the conclusion of their testing, the pumps, test results along with the pump inspections findings will be submitted to HSSSI.

Waste Water	Space Station (lb/day)	Space Station (% Total)	Test Water (% Total)
Shower Water (Igepon 6503-45-4)	24.00	20.20	50.10
Oral Hygiene (Crest Regular Flavor Toothpaste)	3.20	2.70	2.70
Urine Distillate (Oxone/H2SO4 Pretreat)	13.24 (4)	11.10	14.80
Urine Flush	4.40	3.70	(5)
Handwash	24.00	20.20	(1)
Fuel Cell	11.74	9.90	32.40 (3)
Wet Shave	3.52	3.00	(1)
Humidity Condensate	24.00	20.20	(2)
Samples/Checks	2.72	2.30	(2)
Wash Cloth Bath	8.00	6.70	(1)
Total	118.82	100	100

(1) This water is included in the shower water
(2) This water is included in the fuel cell water
(3) Deionized water will be used to simulate this water
(4) Pretreat with 5 grams of oxone and 2.3 grams of sulfuric acid (H2SO4) into 6.25 cc of water per liter of raw urine
(5) Mix 33.3% urine flush (DI water) into urine prior to distillation

Table 4.3-1 Pump Life Test Waste Water

Shower/Handwash Ingredients	Formulation 6503-45-4 % by weight
sodium-n-coconut acid-n-methyl taurate (SCMT) (24% active)	98.75
lecipur 95-F (soybean lecithin)	.50
luviquat FC-500 (polyquaternium 16)	.75

Table 4.3-2 Igepon Soap Test Formulation

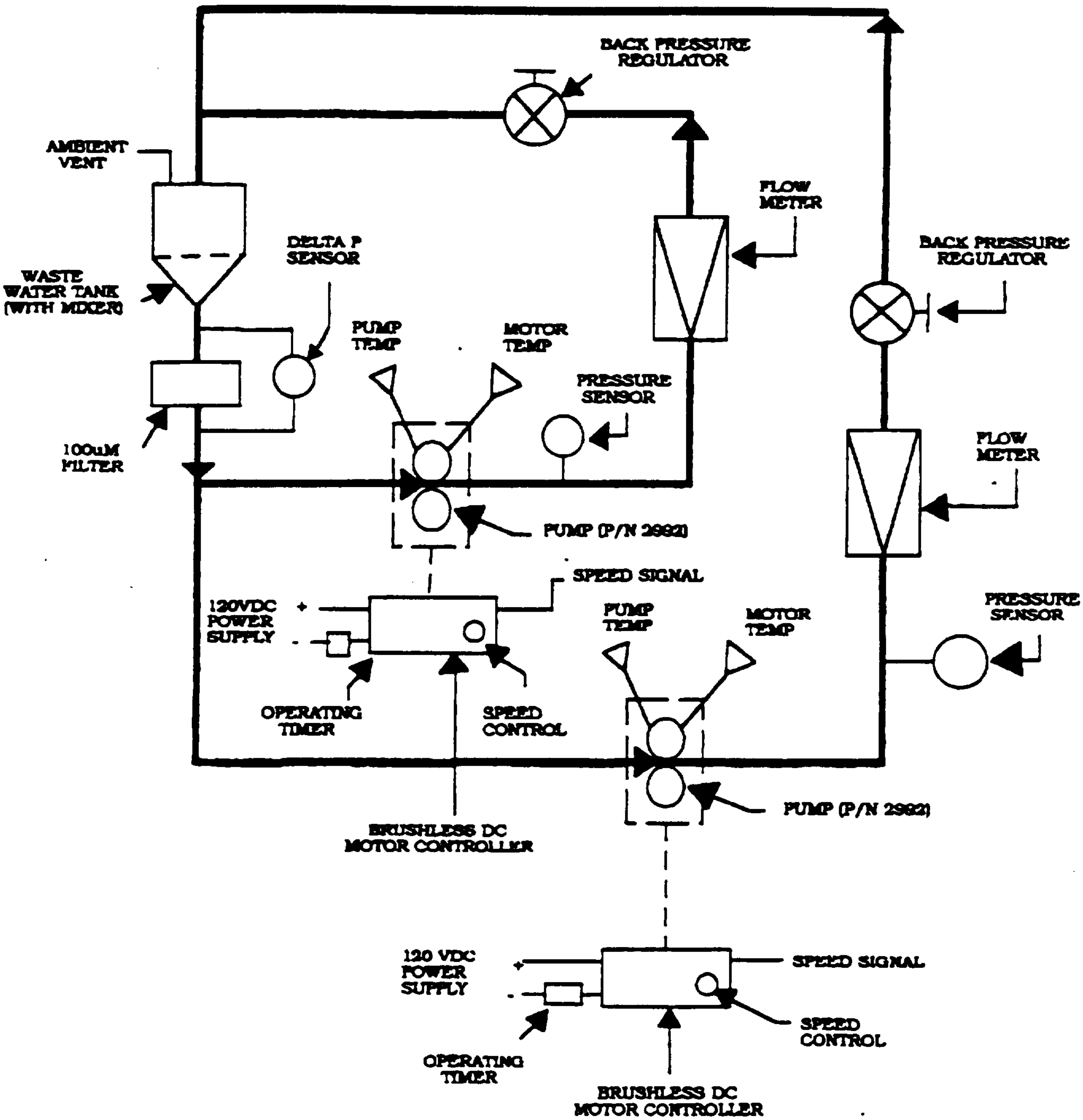

Figure 5.0-1 System Test Schematic

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APPENDIX A

PDI Test Plan

2.3 Insulation Resistance

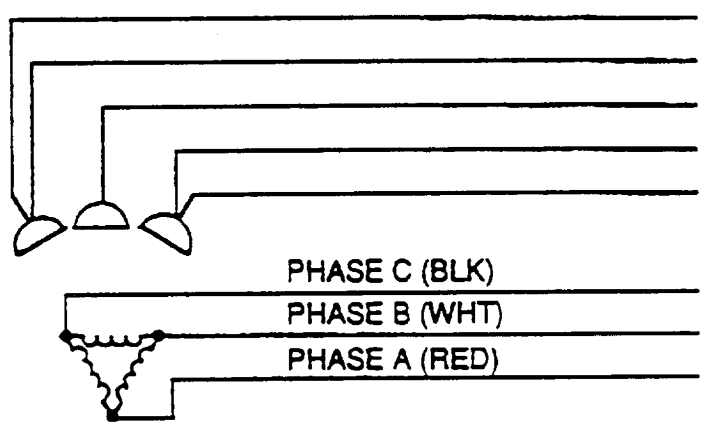
2.3.1 Testing Location: The motor manufacturer shall conduct the insulation resistance test at his facility and provide certification for each unit shipped to PDI. In addition, PDI will conduct an insulation resistance test, after canning, at the time of final Acceptance Testing.

2.3.2 Test 1: The motor manufacturer shall measure the insulation resistance between all lead wires shown in schematic (Phase A, B & C) and the Stator assembly, P/N 21597 (Model No. 3019) in accordance with MIL-STD-202, Method 302, Condition B.

2.3.3 Test 2: PDI shall measure the insulation resistance between all lead wires shown in schematic (Phase A, B & C) and any point on the unit housing in accordance with MIL-STD-202, Method 302, Condition B, and record the results.

2.3.4 Criteria: Insulation resistance shall not be less than 100 megohms.

CAUTION: **Do not insulation resistance test the controller or the hall effects leads.**



2.4 Proof Pressure

2.4.1 Test Set-Up: Install pump (P/N 3019) in the Test Set-Up of Figure I with the outlet port plugged and connected to a hydraulic hand pump.

2.4.2 Open the shutoff valve and close the dump valve.

2.4.3 Pressurize the unit to 247 psid, close shutoff valve and hold for 5 minutes, observing for leakage.

2.4.4 Open the dump valve, reduce the pressure to 0 psid, and remove the unit from the test set-up.

2.4.5 Criteria: There shall be no leakage or deformation on any surface during any portion of the test.

2.5 <u>Performance Test</u>

2.5.1 Test #1: Install the unit in the Test Set-Up of Figure II.

2.5.1.1 Actuate the motor with 120 Vdc.

2.5.1.2 Adjust the inlet pressure to achieve 10.2 psia

2.5.1.3 Adjust the system restrictor valve until 40 psid is achieved across the pump.

2.5.1.4 Maintain the fluid temperature between +65°F to +113°F throughout the test. Record the actual fluid temperature. A_5

2.5.1.5 Operate the test specimen for 30 minutes minimum, recording the required data on the Test Data Sheet at the end of that time interval.

2.5.1.6 Criteria: The pump shall produce .030 to .036 gpm at 40 psid differential pressure with an inlet pressure of 10.2 psia and a fluid temperature of +108°F to +118°F, while consuming 53 watts maximum.

2.5.2 Test #2: Install the unit in the Test Set-Up of Figure II.

2.5.2.1 Actuate the motor with 120 Vdc.

2.5.2.2 Adjust the inlet pressure to achieve 10.2 psia

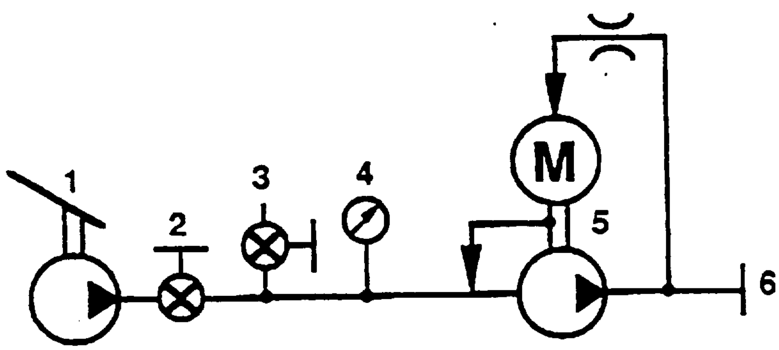
2.5.2.3 Adjust the system restrictor valve until 96 psid is achieved across the pump.

2.5.2.4 Maintain the fluid temperature between +65°F to +113°F throughout the test. Record the actual fluid temperature. A_6

2.5.2.5 Operate the test specimen for 30 minutes minimum, recording the required data on the Test Data Sheet at the end of that time interval.

2.5.2.6 Criteria: The pump shall produce .030 to .036 gpm at 96 psid differential pressure with an inlet pressure of 10.2 psia and a fluid temperature of +108°F to +118°F, while consuming 53 watts maximum.

APPLICATION		REVISION			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED
	ATP 2992				



1. PUMP, HAND
2. VALVE, SHUT-OFF
3. VALVE, DUMP
4. GAUGE, PRESSURE: 0-400 PSI
5. TEST SPECIMEN 3019
6. PLUG, OUTLET PORT

UNLESS OTHERWISE SPECIFIED		NAME	DATE
REMOVE ALL BURRS AND SHARP EDGES SURFACE FINISH √ DIMENSIONS APPLY AFTER MT. TR. AND FINISH ALL DIAMETERS TO BE CONCENTRIC WITHIN .005TIR TOLERANCES: .XX ±.03 ANGLES ±0°30' .XXX ±.010	DRN	J. F. Z.	10/91
	CHK	RD	10/91
	APPR	[illegible]	10/31/91
MATERIAL / HEAT TREAT / FINISH			

Pneu Devices Inc.
72 Santa Felicia Dr., Santa Barbara, CA 93117-2893

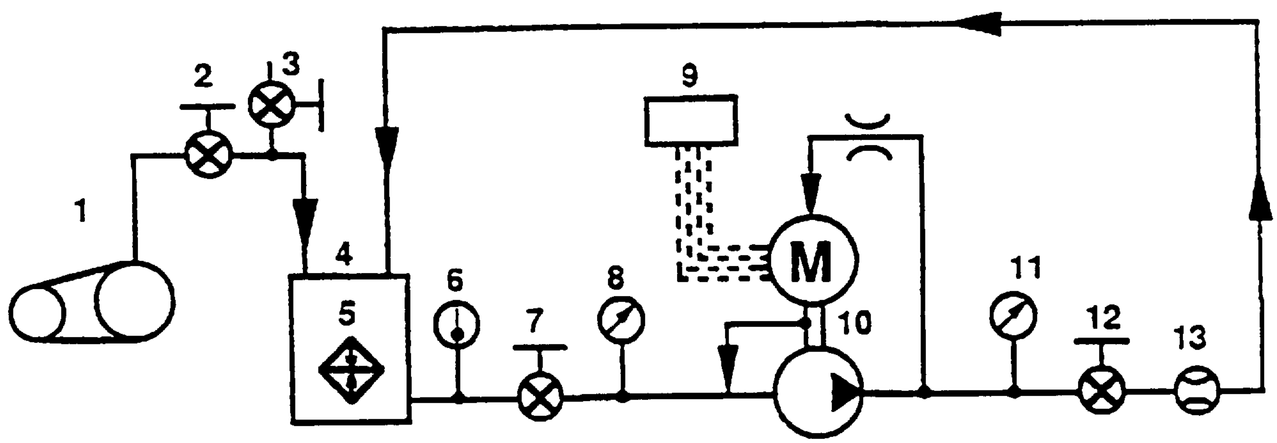
PROOF PRESSURE
TEST SET-UP

SIZE	CODE IDENT NO.	
A	33654	FIGURE I
SCALE	WEIGHT	SHEET 9

DIETERICH POST REORDER NO. 141426

APPLICATION		REVISION			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED
	ATP 2992				

1. PUMP, VACUUM
2. VALVE, SHUT-OFF
3. VALVE, BLEED
4. FLUID RESERVOIR
5. HEATER
6. GAUGE, TEMPERATURE
7. VALVE, INLET SHUT-OFF
8. GAUGE, INLET COMPOUND: 30-0-30
9. POWER SUPPLY: 120 VDC
10. TEST SPECIMEN 2992
11. GAUGE, DISCHARGE: 0-150 PSIG
12. VALVE, SYSTEM RESTRICTOR
13. METER, FLOW



UNLESS OTHERWISE SPECIFIED	NAME	DATE
REMOVE ALL BURRS AND SHARP EDGES SURFACE FINISH √ DIMENSIONS APPLY AFTER MT. TR. AND FINISH ALL DIAMETERS TO BE CONCENTRIC WITHIN .005TIR TOLERANCES: .XX ±.03 ANGLES ±0°30' .XXX ±.010	DRN J.F.Z.	10/91
	CHK RO	10/91
	APPR [illegible]	10/31/91
MATERIAL / HEAT TREAT / FINISH		

Pneu Devices Inc.
72 Santa Felicia Dr., Santa Barbara, CA 93117-2893

PERFORMANCE / SPEED CONTROL TEST SET-UP

SIZE	CODE IDENT NO.	
A	33654	FIGURE II
SCALE	WEIGHT	SHEET 10

10. Appendix II: Pump Test Results, M/N 2992 Borided 718

SPACE STATION PROCESS PUMP DATA LOG | **INITIAL CLEAN WATER PERFORMANCE TEST AT HS**

M/N 2992 | **S/N 0001** | **BORITE HARDENED INCONEL 718 GEARS**

DATE	TIME	OPERATOR	FLOWMETER READING (gpm)	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (psig)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
4/25/95	2:30pm	ESD/DSP	3.00	500	7.60	0	120	0.029	3.44	0.00				TEMPS NOT RECORDED DURING
4/25/95		ESD/DSP	1.10	500	0.48	10	120	0.031	3.76	0.11				PERFORMANCE TESTING, THE
4/25/95		ESD/DSP	5.75	1000	17.92	0	120	0.031	3.73	0.00				MOTOR TEMP WAS APPROX.
4/25/95		ESD/DSP	4.10	1000	11.73	10	120	0.034	4.08	2.45				SEVERAL DEGREES ABOVE
4/25/95		ESD/DSP	3.00	1000	7.60	20	120	0.039	4.72	2.72				AMBIENT
4/25/95		ESD/DSP	2.00	1000	3.85	30	120	0.045	5.40	1.81				
4/25/95		ESD/DSP	8.20	1500	27.11	0	120	0.034	4.04	0.00				
4/25/95		ESD/DSP	6.75	1500	21.67	10	120	0.037	4.45	4.15				
4/25/95		ESD/DSP	5.50	1500	16.98	20	120	0.042	5.00	5.73				
4/25/95		ESD/DSP	4.50	1500	13.23	30	120	0.050	5.95	5.63				
4/25/95		ESD/DSP	3.40	1500	9.10	40	120	0.057	6.85	4.49				
4/25/95		ESD/DSP	2.40	1500	5.35	50	120	0.065	7.75	2.92				
4/25/95		ESD/DSP	1.40	1500	1.60	60	120	0.072	8.68	0.93				
4/25/95		ESD/DSP	10.50	2000	35.74	0	120	0.037	4.39	0.00				
4/25/95		ESD/DSP	9.40	2000	31.61	10	120	0.040	4.84	5.54				
4/25/95		ESD/DSP	8.25	2000	27.30	20	120	0.045	5.44	8.51				
4/25/95		ESD/DSP	7.25	2000	23.55	30	120	0.052	6.20	9.59				
4/25/95		ESD/DSP	6.25	2000	19.80	40	120	0.062	7.45	8.98				
4/25/95		ESD/DSP	5.50	2000	16.98	50	120	0.072	8.62	8.31				
4/25/95		ESD/DSP	4.50	2000	13.23	60	120	0.081	9.71	6.90				
4/25/95		ESD/DSP	3.40	2000	9.10	70	120	0.090	10.82	4.97				
4/25/95		ESD/DSP	2.60	2000	6.10	80	120	0.100	11.96	3.44				
4/25/95		ESD/DSP	12.60	2500	43.62	0	120	0.039	4.73	0.00				
4/25/95		ESD/DSP	11.75	2500	40.43	10	120	0.044	5.26	6.50				
4/25/95		ESD/DSP	10.80	2500	36.87	20	120	0.049	5.88	10.58				
4/25/95		ESD/DSP	9.80	2500	33.11	30	120	0.056	6.66	12.60				
4/25/95		ESD/DSP	8.80	2500	29.36	40	120	0.063	7.60	13.05				
4/25/95		ESD/DSP	8.00	2500	26.36	50	120	0.076	9.12	12.20				
4/25/95		ESD/DSP	7.25	2500	23.55	60	120	0.087	10.46	11.39				
4/25/95		ESD/DSP	6.50	2500	20.73	70	120	0.098	11.80	10.39				
4/25/95		ESD/DSP	5.50	2500	16.98	80	120	0.109	13.10	8.75				
4/25/95		ESD/DSP	4.75	2500	14.17	90	120	0.120	14.39	7.48				
4/25/95		ESD/DSP	4.00	2500	11.36	100	120	0.131	15.70	6.11				

SPACE STATION PROCESS PUMP DATA LOG
M/N 2992 **S/N 0001**

INITIAL CLEAN WATER PERFORMANCE TEST AT HS
BORITE HARDENED INCONEL 718 GEARS

DATE	TIME	OPERATOR	FLOWMETER READING (gpm)	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (psig)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
4/25/95		ESD/DSP	15.00	3000	52.62	0	120	0.043	5.14	0.00				
4/25/95		ESD/DSP	14.20	3000	49.62	10	120	0.048	5.74	7.31				
4/25/95		ESD/DSP	13.20	3000	45.87	20	120	0.054	6.42	12.08				
4/25/95		ESD/DSP	12.40	3000	42.87	30	120	0.062	7.44	14.58				
4/25/95		ESD/DSP	11.50	3000	39.49	40	120	0.068	8.11	16.45				
4/25/95		ESD/DSP	10.60	3000	36.12	50	120	0.077	9.18	16.61				
4/25/95		ESD/DSP	9.90	3000	33.49	60	120	0.091	10.90	15.57				
4/25/95		ESD/DSP	9.10	3000	30.49	70	120	0.104	12.47	14.45				
4/25/95		ESD/DSP	8.50	3000	28.24	80	120	0.117	13.98	13.64				
4/25/95		ESD/DSP	7.75	3000	25.42	90	120	0.129	15.48	12.47				
4/25/95		ESD/DSP	7.00	3000	22.61	100	120	0.141	16.97	11.24				
4/25/95		ESD/DSP	17.10	3500	60.50	0	120	0.046	5.57	0.00				
4/25/95		ESD/DSP	16.40	3500	57.88	10	120	0.052	6.23	7.88				
4/25/95		ESD/DSP	15.50	3500	54.50	20	120	0.058	6.95	13.25				
4/25/95		ESD/DSP	14.60	3500	51.12	30	120	0.065	7.79	16.62				
4/25/95		ESD/DSP	13.90	3500	48.50	40	120	0.073	8.72	18.76				
4/25/95		ESD/DSP	13.20	3500	45.87	50	120	0.082	9.84	19.69				
4/25/95		ESD/DSP	12.50	3500	43.24	60	120	0.093	11.12	19.67				
4/25/95		ESD/DSP	11.60	3500	39.87	70	120	0.110	13.14	17.92				
4/25/95		ESD/DSP	11.00	3500	37.62	80	120	0.124	14.92	17.03				
4/25/95		ESD/DSP	10.40	3500	35.37	90	120	0.139	16.62	16.16				
4/25/95		ESD/DSP	9.20	3500	30.86	100	120	0.152	18.22	14.29				
4/25/95		ESD/DSP	19.00	4000	67.63	0	120	0.051	6.06	0.00				
4/25/95		ESD/DSP	18.40	4000	65.38	10	120	0.055	6.55	8.42				
4/25/95		ESD/DSP	17.50	4000	62.00	20	120	0.063	7.58	13.85				
4/25/95		ESD/DSP	16.70	4000	59.00	30	120	0.071	8.50	17.59				
4/25/95		ESD/DSP	16.10	4000	56.75	40	120	0.079	9.48	20.23				
4/25/95		ESD/DSP	15.30	4000	53.75	50	120	0.088	10.56	21.47				
4/25/95		ESD/DSP	14.60	4000	51.12	60	120	0.099	11.83	21.87				
4/25/95		ESD/DSP	13.90	4000	48.50	70	120	0.111	13.36	21.45				
4/25/95		ESD/DSP	13.40	4000	46.62	80	120	0.130	15.54	20.26				
4/25/95		ESD/DSP	12.75	3952	44.18	90	120	0.145	17.34	19.35				rpm REDUCED DUE TO LOAD
4/25/95		ESD/DSP	11.50	3845	39.49	100	120	0.158	18.92	17.61				rpm REDUCED DUE TO LOAD

		SPACE STATION PROCESS PUMP DATA LOG							**INITIAL CLEAN WATER PERFORMANCE TEST AT HS**					
		M/N 2992		**S/N 0001**					**BORITE HARDENED INCONEL 718 GEARS**					
DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (psig)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
4/25/95		ESD/DSP	22.20	4717	79.63	1	120	0.056	6.67	1.21				BACK PRESSURE FROM TEST RIG
4/25/95		ESD/DSP	21.50	4662	77.01	10	120	0.061	7.37	8.83				
4/25/95		ESD/DSP	20.30	4610	72.51	20	120	0.068	8.20	14.98				
4/25/95		ESD/DSP	19.40	4539	69.13	30	120	0.076	9.08	19.27				
4/25/95		ESD/DSP	18.40	4475	65.38	40	120	0.084	10.02	22.04				
4/25/95		ESD/DSP	17.50	4404	62.00	50	120	0.092	11.03	23.72				
4/25/95		ESD/DSP	16.40	4323	57.88	60	120	0.101	12.16	24.10				
4/25/95		ESD/DSP	15.10	4233	53.00	70	120	0.112	13.46	23.27				
4/25/95		ESD/DSP	13.80	4083	48.12	80	120	0.131	15.70	20.70				
4/25/95		ESD/DSP	12.60	3962	43.62	90	120	0.145	17.44	19.00				
4/25/95	4:30pm	ESD/DSP	11.50	3860	39.49	100	120	0.158	18.97	17.56				
				HOWDEN FLUID SYSTEMS (HFS) INITIAL PERFORMANCE TEST CONDUCTED AT HFS										
4/17/95	N/A	RN	N/A	3000	25.03	40	120	0.076	9.10	9.28				**PRIOR TO 8 hr RUN, S/N 0001**
4/17/95	N/A	RN	N/A	3000	35.04	40	120	0.068	8.10	14.60				**FOLLOWING 8 hr RUN, S/N 0001**
4/19/95	N/A	RN	N/A	3000	60	40	120	0.092	11.00	18.40				**S/N 0002, NO 8 hr RUN**
														S/N 0002 WAS NOT TESTED AT HS

SPACE STATION PROCESS PUMP DATA LOG | **REAL WATER LIFE TEST AT HS**

M/N 2992 | **S/N 0001** | **BORITE HARDENED INCONEL 718 GEARS**

DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (psig)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/2/95	15:15	ESD/DSP	N/A	N/A	N/A	70	120	N/A	N/A	N/A	N/A	N/A	N/A	STARTED TEST
5/2/95	15:40	ESD/DSP	5.90	2127	18.48	70	120	N/A	N/A	N/A	N/A	N/A	N/A	NO POWER OR TEMP METERS
5/2/95	16:15	ESD/DSP	5.90	2122	18.48	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/3/95	13:30	ESD/DSP	6.00	2125	18.86	70	120	N/A	N/A	N/A	N/A	N/A	N/A	FILTER DELTA P = 0.0
5/3/95	14:15	ESD/DSP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	SHUTDOWN-FLOW METER LEAK
5/3/95	14:45	ESD/DSP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	RESTARTED- LEAK FIXED
5/3/95	14:45	ESD/DSP	5.50	2098	16.98	71	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/3/95	15:30	ESD/DSP	5.50	2101	16.98	71	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/3/95	16:15	ESD/DSP	5.75	2100	17.92	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/4/95	7:50	ESD	6.50	2095	20.73	70	120	N/A	N/A	N/A	N/A	N/A	N/A	19.5 hrs TOTAL LIFE TEST TIME
5/4/95	7:55	ESD	0.00	0.00	0.00	0	0.00	N/A	N/A	N/A	N/A	N/A	N/A	30 MIN SHUTDOWN
5/4/95	8:30	ESD	6.50	2089	20.73	70	120	N/A	N/A	N/A	N/A	N/A	N/A	RESTARTED
5/4/95	9:30	ESD	5.90	1935	18.48	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/4/95	10:30	ESD	5.75	1942	17.92	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/4/95		ESD	0.00	0.00	0.00	0	0.00	N/A	N/A	N/A	N/A	N/A	N/A	CURRENT METER INSTALLED
5/4/95	11:15	ESD	5.75	1945	17.92	70	120	N/A	N/A	N/A	N/A	N/A	N/A	RESTARTED
5/4/95	12:45	ESD	5.50	1956	16.98	70	120	0.076	9.12	11.06	N/A	N/A	N/A	
5/4/95	15:00	ESD	5.50	1952	16.98	70	120	0.076	9.12	11.05	78.60	82.90	75.00	RIG FILTER DP = 8"H2O
5/4/95	15:45	ESD	5.50	1958	16.98	70	120	0.076	9.14	11.02	80.40	83.40	76.40	
5/4/95	16:15	ESD	6.25	2116	19.80	70	120	0.077	9.24	12.66	80.30	83.20	75.40	26.0 hrs TOTAL LIFE TEST TIME
5/5/95	8:00	ESD	6.50	2105	20.73	70	120	0.079	9.48	12.88	78.30	80.80	72.20	41.75 hrs TOTAL LIFE TEST TIME
5/5/95	N/A	ESD	0.00	0.00	0.00	0	120	N/A	N/A	N/A	N/A	N/A	N/A	SHUTDOWN FOR 30 MIN
5/5/95	8:35	ESD												RESTARTED- NO READINGS
5/5/95	9:15	ESD	6.25	2105	19.80	70	120	0.077	9.29	12.57	77.80	80.50	72.40	
5/5/95	11:30	ESD	6.25	2107	19.80	70	120	0.079	9.44	12.36	75.90	81.00	73.30	
5/5/95	13:15	ESD	0.00	0.00	0.00	0	120	N/A	N/A	N/A	N/A	N/A	N/A	SHUTDOWN FOR 30 MIN
5/5/95	13:15	ESD	6.25	2108	19.80	70	120	0.079	9.49	12.30	77.00	81.00	72.80	
5/5/95	13:45	ESD												RESTARTED- NO READINGS
5/5/95	14:00	ESD	6.50	2101	20.73	70	120	0.078	9.41	13.00	77.50	81.20	74.10	
5/5/95	16:00	ESD	6.25	2105	19.80	70	120	0.078	9.36	12.45	76.20	81.70	73.50	47.5 hrs TOTAL LIFE TEST TIME

		SPACE STATION PROCESS PUMP DATA LOG							REAL WATER LIFE TEST AT HS					
		M/N 2992		S/N 0001					BORITE HARDENED INCONEL 718 GEARS					
DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (psig)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
														SHUTDOWN FOR THE WEEKEND
5/7/95	14:00	ESD	6.00	2115	18.86	70	120	0.075	9.05	12.32	74.20	76.30	72.50	RESTARTED, FILTER DP = 3"H2O
5/8/95	8:00	ESD	5.00	2103	15.11	70	120	0.077	9.24	9.63	74.00	79.80	71.20	65.5 hrs TOTAL LIFE TEST TIME
5/8/95	8:00	ESD	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	SHUTDOWN FOR 30 MIN
5/8/95	8:30	ESD	5.75	2105	17.92	70	120	0.079	9.48	11.12	74.80	80.00	71.90	RESTARTED
5/8/95	11:00	ESD	4.75	2128	14.17	70	120	0.076	9.12	9.13	75.80	84.80	73.10	
5/8/95	12:30	ESD	4.75	2129	14.17	70	120	0.075	9.05	9.19	77.30	85.50	73.20	
5/8/95	12:30	ESD	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	SHUTDOWN FOR 30 MIN
5/8/95	13:00	ESD	6.00	2470	18.86	70	120	0.077	9.22	12.08	76.80	82.70	75.10	RESTARTED
5/8/95	15:30	ESD	5.75	2486	17.92	70	120	0.079	9.48	11.16	78.50	82.20	75.20	
5/8/95	15:30	ESD	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	SHUTDOWN FOR 30 MIN
5/8/95	16:00	ESD	5.75	2470	17.92	70	120	0.080	9.56	11.06	78.00	82.60	75.50	RESTARTED
5/9/95	8:10	DSP	N/A	0	0.00	0	120	N/A	N/A	N/A	N/A	N/A	N/A	SHUT DOWN PUMP - NO FLOW,
5/9/95														SUSPECT CLOGGED INLET LINE
5/9/95	10:30	DSP	5.00	1996	15.11	70	120	0.075	9.00	9.91	74.10	80.20	73.20	RESTARTED - CLEANED LINE
5/9/95	11:30	ESD	5.75	2467	17.92	70	120	0.077	9.26	11.43	75.40	84.20	73.40	
5/9/95	13:15	ESD	5.75	2467	17.92	70	120	0.078	9.36	11.31	77.10	85.10	73.70	78.25 hrs TOTAL LIFE TEST TIME
														SHUTDOWN - MOVED RIG &
														CHANGED FILTER
5/10/95	14:00	ESD												RESTARTED - NO READINGS
5/10/95	14:30	ESD	5.90	2262	18.48	70	120	0.080	9.56	11.40	75.10	84.80	74.90	
5/10/95	16:15	ESD	5.75	2263	17.92	70	120	0.082	9.78	10.82	75.90	87.80	75.20	SHUTDOWN FOR THE NIGHT
5/11/95	8:00	ESD	5.90	2245	18.48	70	120	0.083	10.00	10.86	72.80	72.80	72.80	RESTARTED
5/11/95	10:30	ESD	6.00	2304	18.86	70	120	0.096	11.56	9.65	77.60	86.40	74.40	
5/11/95	14:00	DSP	6.00	2300	18.86	70	120	0.097	11.64	9.59	N/A	89.00	N/A	PUMP NOISY AND VIBRATING
														POWER HAS INCREASED - 28%
5/11/95	14:10	ESD	0.00	0.00	0.00	0	120	0.640	76.80	0.00	N/A	90.10	N/A	PUMP LOCK UP - TRIED RESTART
														AND NO FLOW / HIGH CURRENT
														87.0 hrs TOTAL LIFE TEST TIME

11. Appendix III: Examination of PDI Gear Pumps, Number SVME 3346, Dated October 13, 1994

Internal Correspondence

UNITED TECHNOLOGIES HAMILTON STANDARD

SVME 3346
October 13, 1994

Memo to: D. Parker (4 copies)

cc: J. Gruber, J. Varsik, C. Flugel

From: Bill Schultz WRS

Subject: **Examination of PDI Gear Pumps**

References: -SVME 2977, "Examination of Components removed from Failed PDI Gear Pump", Dated 9/4/92
-SVME 3071, "Initial Comments on Proposed Materials for PDI Water Processor Feed Pump", Dated 3/8/93

Summary

Testing of PDI Gear Pumps equipped with CRES 15-5 and Nickel Alloy 718 gears has demonstrated that neither of these materials is adequate for use in this application. Alternate materials need to be evaluated for this application. Acceptable alternate materials must possess a very hard surface (≅ 55 HRC) for resistance to the type of wear observed on the 15-5 gears. In addition, adequate corrosion resistance in "gray" water is required.

Background

In 1992 a test was run with a PDI Gear Pump with nitrided CRES 17-4PH gears (nitrided 17-4 hardness ≅ 55 HRC). The gear teeth, except for the leading edges of the involutes, and the spline were nitrided. This pump seized after approximately 1500 hours (estimated) of operation while pumping "gray" water. The pump seized due to corrosion products from a carbon steel plug which was upstream of the pump. During examination of the pump, corrosion of the nitrided surfaces of the 17-4 gears was observed. The corrosion was primarily evident on the spline of the drive gear. Since the pump is required to operate for approximately 30,000 hours, it was decided that a more corrosion resistant gear material would be necessary. At that time it was believed that these gears were very lightly loaded, and that a softer material would be adequate. A hard surface is generally required for resistance to the type of wear generally observed on gears. Recommended candidates were CRES A-286 and Nickel Alloy 718 (Reference SVME 2977).

Other candidates were also evaluated (Reference SVME 3071). CRES 15-5PH Condition H1025 (hardness = 35 - 42 HRC per AMS5862) and Nickel Alloy 718 [hardness = 341 HB min (≅ 36.6 HRC min) per AMS5664] gears were tested. With the 718 gears, the pump ran for 15 seconds before seizing. It was then disassembled, and the interfacing surfaces of the gears and the top an bottom plates were lightly lapped with 600 grit paper. The pump was reassembled and ran for approximately 30 seconds before seizing. PDI's initial evaluation of the pump cartridge indicated that the drive gear had started to seize to the bottom plate (Figure 1).

With the 15-5 gears, the pump ran for approximately 188 hours with "gray" water before being shut down due to severely degraded performance. PDI's initial evaluation of the pump cartridge indicated black slimy residue throughout the interior of the cartridge and wear on the gear teeth. The pump cartridges of both pumps were then sent to HS for examination.

Examination of the Cartridge with the 718 Gears

Initial visual examination of the pump cartridge components revealed scoring at the surfaces of the drive gear that interface with the bottom plate (Figure 2) and the top plate. The only other unusual feature was that the gear involutes did not appear to be symmetric (Figure 2). Scoring was also present on the bottom plate in the area that interfaces with the drive gear (Figure 2).

Scanning Electron Microscope (SEM) examination of the bottom plate revealed scoring of the chrome plate and localized deposits rich in nickel and iron. It is likely that chromium was also present, but it was impossible to determine because chromium from the chrome plate on the bottom plate interfered with the chemistry determination. The source of the nickel and iron on this surface is likely the 718 gear (718 is a nickel/chromium/iron alloy). Figure 3 shows the scoring and one area of the nickel/iron rich deposits on the bottom plate. The nickel/iron rich deposits were generally found within the diameter of the root of the gear teeth.

SEM examination of the bottom plate side of the drive gear revealed the following:

* Severe scoring (Figure 4).
* Damage to the leading edges of the gear teeth, particularly near the tips (Figure 4).
* Areas of smeared metal (Figure 5).
* A "stepped" surface which appears to be a by-product of the manufacturing (Figure 6).

SEM examination of the top plate side of the drive gear revealed minor scoring and minor damage to the leading edges of the gear teeth (Figure 7). SEM examination of the drive gear teeth, the driven gear, the center-spacer, the journal bearings on both the top and bottom plates, and the top plate revealed no unusual features.

Both of the gears were hardness tested to verify that they were heat treated to the proper condition. The drive gear hardness was $\cong$ 42 HRC. The driven gear was $\cong$ 41 HRC. Both meet the requirements for 718 ($\cong$ 36.6 HRC min).

Examination of the Cartridge with the 15-5 Gears

Initial visual examination confirmed PDI's findings. Significant damage to the gear teeth was present. A significant amount of black-brown residue was present throughout the pump cartridge, The end cap was supplied along with the pump cartridge, and black-brown contamination was also present within it (Figure 8). A small area of black-brown contamination was also present on the outer face of the top plate. Scoring on both sides of each gear (Figures 9 & 10) along with on the top and bottom plates was present (Figures 11).

SEM examination of the drive gear revealed the following:

* Extensive wear of the drive faces of the teeth (Figure 12). The wear appeared to have been caused by sliding under high contact loads.
* Significant contamination on the non-drive sides and in the roots of the teeth (Figure 12). Energy Dispersive X-ray (EDX) analysis of the contamination showed that it is copper rich.
* Scoring of the bottom plate side, but no damage to the leading edges (Figure 13).
* A "stepped" surface which appears to be a by-product of the machining of the gears on the bottom plate side of the gears (Figure 13).
* Minimal scoring of the top plate side of the teeth.

SEM examination of the bottom plate revealed significant scoring of the chrome plate, particularly near the inner diameter of the drive gear (Figure 14). No evidence of transferred gear material was found.

EDX analysis of the contamination in the end cap revealed that it contained silicon, aluminum, sulfur, and phosphorous (Figure 8). EDX analysis of the journal bearings revealed the presence of silicon, aluminum, sulfur, and phosphorous in an organic background (Figure 15). These results indicate that the contamination was wear products from the journal bearings. Only limited SEM examination of the journal bearings was possible. The journals were circumferentially scored, but it did not appear to be excessive (Figure 15).

EDX analysis of the contamination on the outer face of the top plate revealed that it was similar to the contamination found in the end cap.

SEM examination of the driven gear revealed extensive wearing of the driven faces of the teeth (Figure 16). The wear appears to be due to sliding under high contact loads. Significant contamination was present on the non-drive faces and in the roots of the teeth (Figure 16). EDX analysis of the contamination revealed that it is copper rich. Minimal scoring of the bottom plate and top plate sides of the teeth was present.

Examination of the top plate and the center spacer revealed no unusual features.

Both of the gears were hardness tested to verify that they were heat treated to the proper condition. The drive gear hardness was $\cong$ 40 HRC. The driven gear was $\cong$ 34 HRC. The hardness of the driven gear was slightly below the requirements for 15-5 H1025 ($\cong$ 35 - 42 HRC).

After the examination, the cartridge was reassembled, and the gears were initially found to be locked. It was then disassembled and examination did not indicate anything unusual. Upon reassembly, the gears could be rotated freely by hand, but there did appear to be intermittent interference.

Discussion

Cartridge with the 718 Gears

The presence of nickel and iron (and probably chromium) on the chrome plate appears to indicate that the pump with the 718 gears seized due to galling of the 718 to the chrome plate. In order for such galling to occur some load thrusting the gear into the bottom plate must be present. The source of such loading is not known. It should be noted that nickel alloys are generally very susceptible to galling.

Possible sources for the loading include:

1) A load created by differential pressures within the pump.

2) A load created by interference due to inaccurate machined dimensions on the gears. As shown in Figure 7, the bottom plate side of the drive gear had an unusual "stepped" appearance near its ID. This area would have been difficult to inspect, so an outage may not have been caught.

3) Inaccurate dimensions in the area discussed in 2) which may have caused a tilt in the rotational axis of the gears. Such a tilt could cause the damage observed on the leading edges of the gear teeth. The fact that the damage was most severe near the tips seems to support this possibility.

The particles of metal dislodged from the leading edges may then have become trapped between the gears and the bottom plate. Such particles would likely result in the high contact loads needed for galling to occur. It is likely that these particles became smeared on the face of the gear (Figure 5).

4) Any combination of 1), 2), and/or 3).

In summary, it appears that the galling resistance of 718 is not adequate for use in this pump. A thrust load or misalignment of the drive gear may have contributed to this premature failure. In theory, there are not supposed to be any thrust loads on the gears, but this does not appear to be the case. Since no foreign material was found in the cartridge, contamination does not appear to have played any part in the seizing of this pump.

It is also likely that the wear resistance of 718 would not be adequate for this application. 718 and 15-5 have similar hardness, and for resistance to this type of wear, high surface hardness is generally required.

Cartridge with the 15-5 Gears

The degraded performance was mainly due to the gear teeth wear damage. The black-brown contamination may have contributed somewhat by causing drag between the gears and the top and bottom plates.

The wear damage on the gears appears to be due to sliding under high loads and not due to abrasive/particulate-assisted wear. Therefore, the black-brown contamination does not appear to have contributed to the gear teeth damage.

The source of the black-brown contamination is unknown. 15-5 contains a small amount of copper, but corrosion or wear products from 15-5 would likely also contain iron and chromium. There was no evidence of selective attack of the copper in the 15-5. No other components of the pump cartridge contain copper, so it appears that the copper must have arisen from an external source.

The contamination in the end cap and on the outer face of the top plate appears to be wear products from the bearings. The limited SEM examination of the bearings did reveal scoring, but it did not appear to be very severe. It does not appear that this contamination affected the performance of the pump, but it does raise a concern about the performance life of the bearings.

The scoring of the bottom plate and the bottom plate side of the drive gear likely had minimal impact on the performance of the pump. It is interesting to note that the scoring is very severe near the ID of the gear. This correlates well with the "stepped" area of the bottom plate side of the drive gear. Even though the scoring is severe, galling did not occur. 15-5 is generally considered to be more resistant to galling than 718. It is also interesting to note that almost no scoring is present on the top plate. Clearly there is a load pushing the drive gear toward the bottom plate. As stated earlier the source of this load is not known.

The intermittent interference observed when the cartridge was reassembled may also be related to the "stepped" area on the bottom plate side of the drive gear. The intermittent interference may indicate a dimensioning or tolerance problem in the cartridge.

The hardness of the driven gear was slightly under the requirements for 15-5 H1025. It is unclear why this is the case. Hardness testing is not an exact technique for checking the properties of a material, and it is likely that the tensile properties of the material meet the procurement specification. Since both gears were severely worn, it does not appear that the hardness of the driven gear contributed to the pump's degraded performance.

In summary, the testing has demonstrated that the wear resistance of 15-5 is not adequate for this application. For resistance to this type of wear, high surface hardness is generally required. In addition, the contamination found in the cartridge does not appear to have contributed to the degraded performance.

Summary and Recommendations

The 718 gears seized due to galling with the chrome plated bottom plate. Nickel alloys generally have very poor resistance to galling. The source of the load needed to cause such galling is unidentified. The 718 did not run long enough for gear face damage to occur, but it is likely that such damage would have occurred if the pump was run longer. Surface Hardness generally is the controlling factor for this type of wear. 15-5 and 718 have similar hardness, and 15-5 was severely damaged in this application.

The 15-5 gears were severely worn due to sliding under high contact loads. This resulted in degradation of pump performance. Since surface hardness is generally the main factor in resistance to this type of wear, the damage clearly indicates that 15-5 is not hard enough for use in this application.

The earlier testing with nitrided CRES 17-4 gears indicated that these gears likely possessed adequate wear resistance (i.e. adequate surface hardness) for use in this application, but they did not possess adequate corrosion resistance. The testing discussed here indicates that a very hard surface ($\cong$ 55 HRC) is required on the gear teeth. <u>Therefore, the main action required is to research alternate gear materials which will be possess adequate hardness and corrosion resistance</u>.

A number of other issues were raised by this round of testing. These issues need to be resolved in order to adequately proceed with the next test phase. The issues include:

1) What is the source of the axial load on the drive gear?

2) What is the source of the copper rich contamination? The test rig at PDI should be inspected for possible sources.

3) Is the "stepped" condition on the sides of the gear teeth acceptable? The sides of the gear teeth should be inspected for possible dimensional discrepancies. Discrepancies in this area may have contributed to the seizing of the 718 gear(s).

4) Are the non-symmetrical involutes a problem?

5) Do the cartridges have a dimensional or tolerance problem which contributed to the seizing of the 718 gears and the intermittent interference observed with the reassembled 15-5 gear cartridge?

6) Was the generation of wear products from the bearings usual and will the bearings exhibit adequate life?

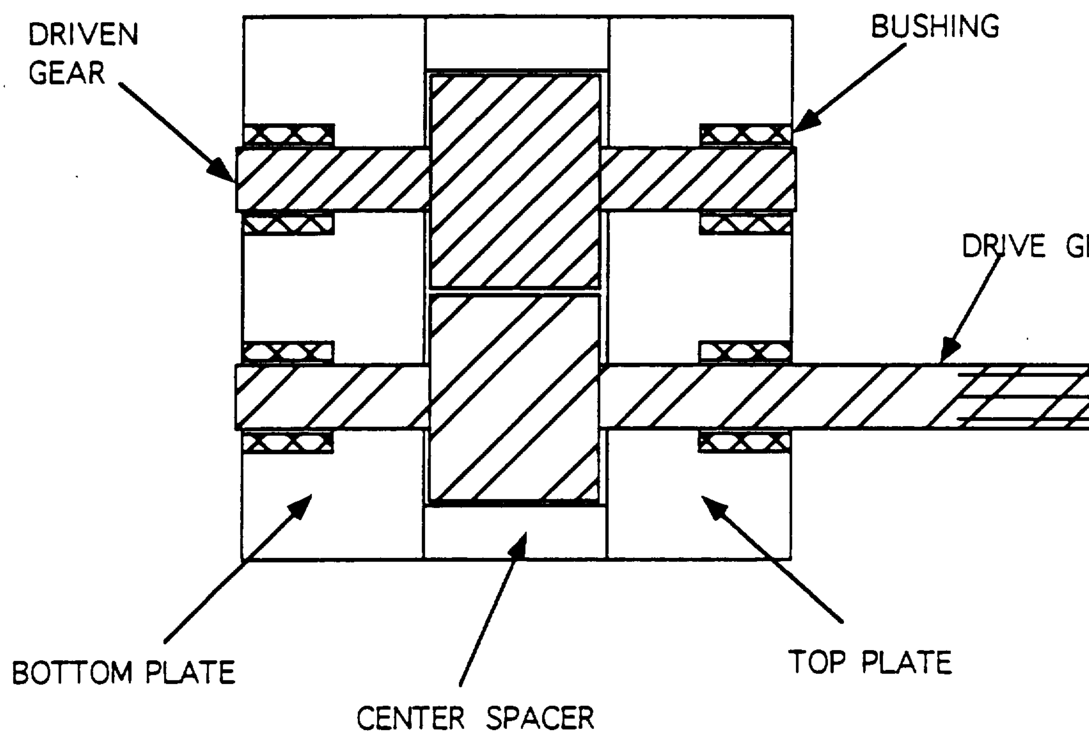
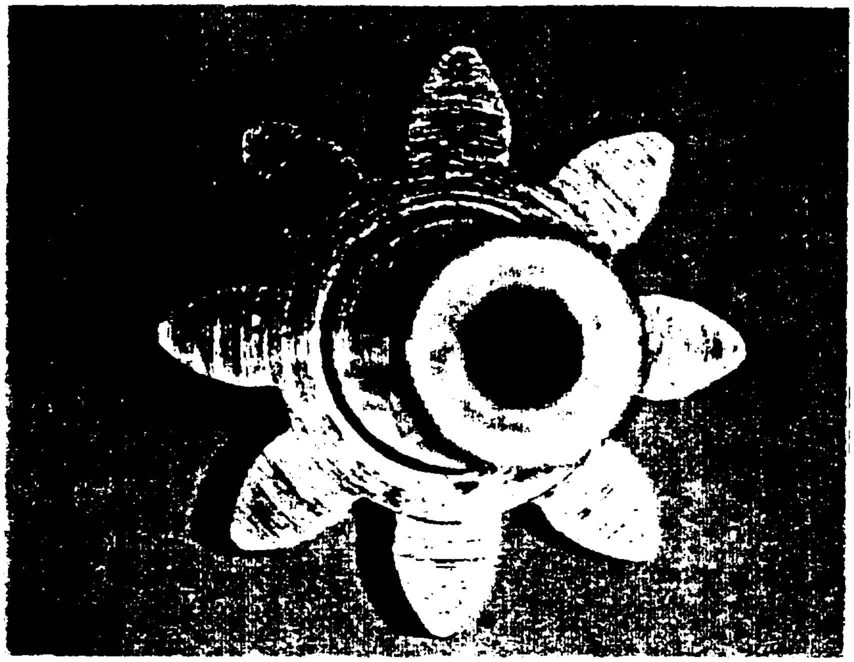


FIGURE 1: Cross-section of the Pump Cartridge.



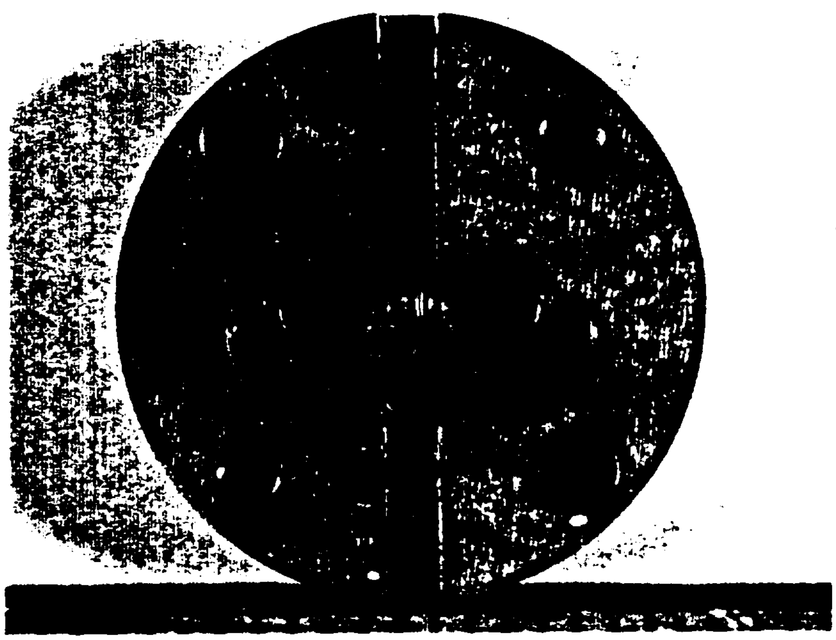


FIGURE 2: TOP: Bottom plate side of the 718 drive gear showing scoring and what appears to be non-symmetrical involutes.
BOTTOM: Bottom plate showing scoring in the area that interfaces with the 718 drive gear.

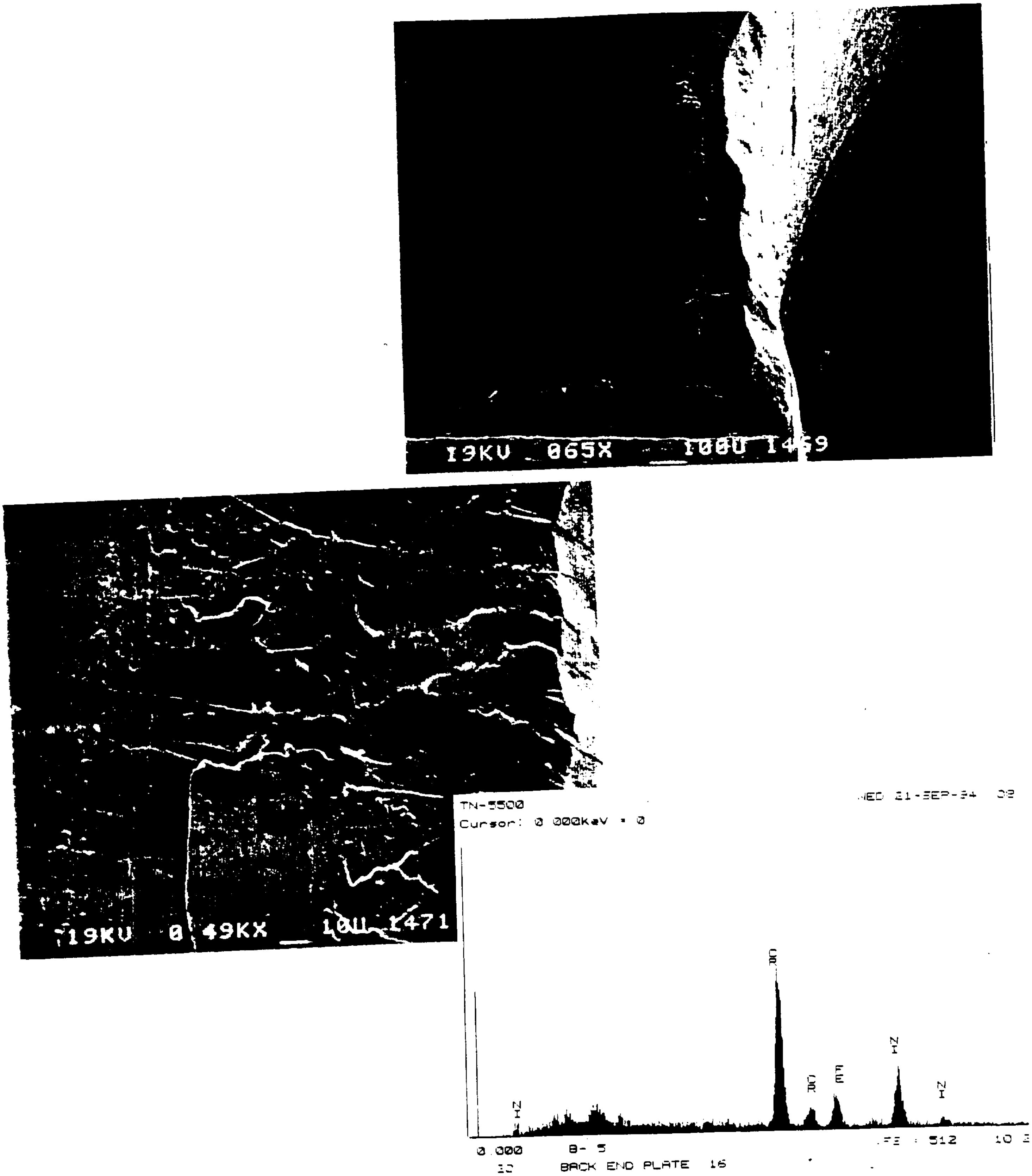
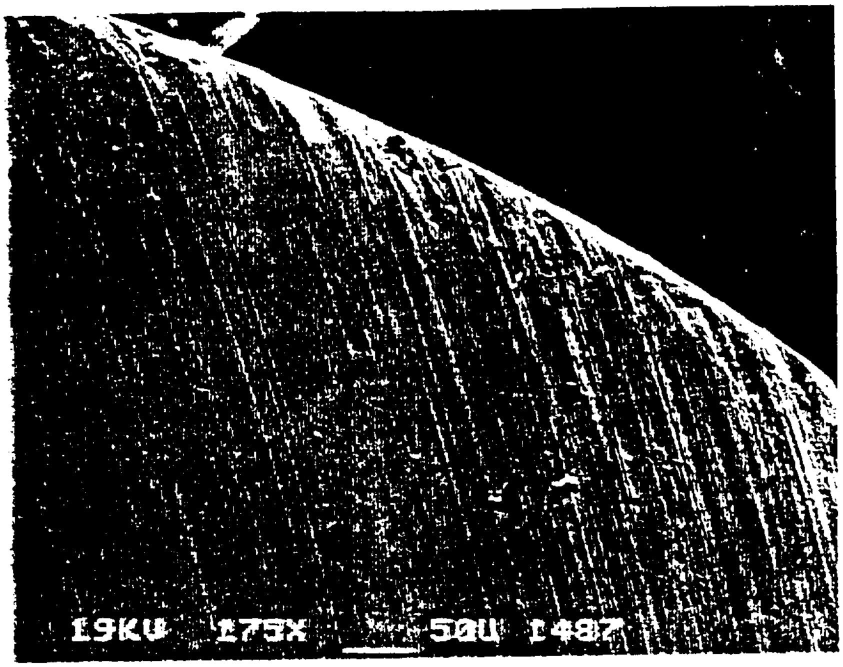


FIGURE 3: Bottom plate at the 718 drive gear interface showing scoring and transferred material. The EDX analysis for the indicated area of transferred material is also shown.



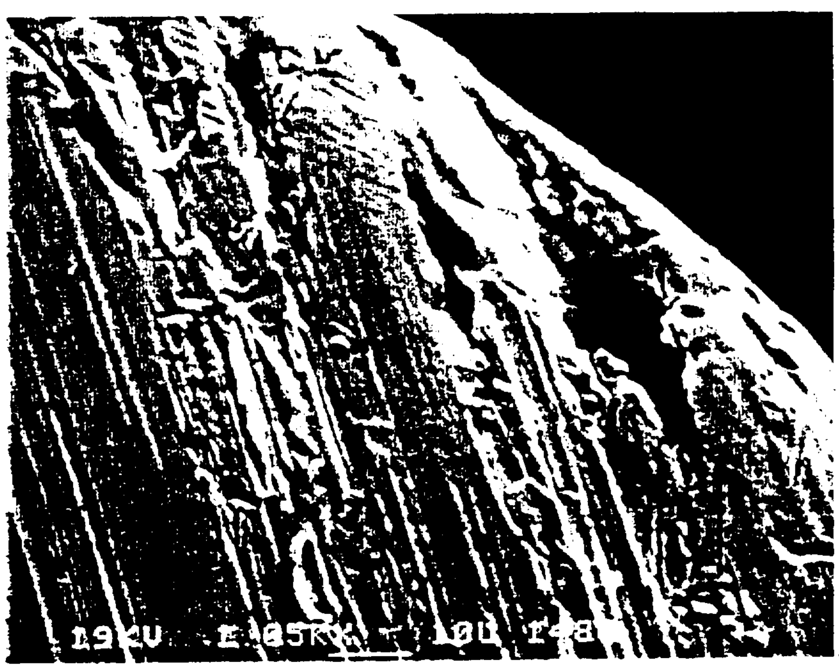


FIGURE 4: The bottom plate side of the 718 drive gear showing severe scoring and damage to the leading edge of the tooth.

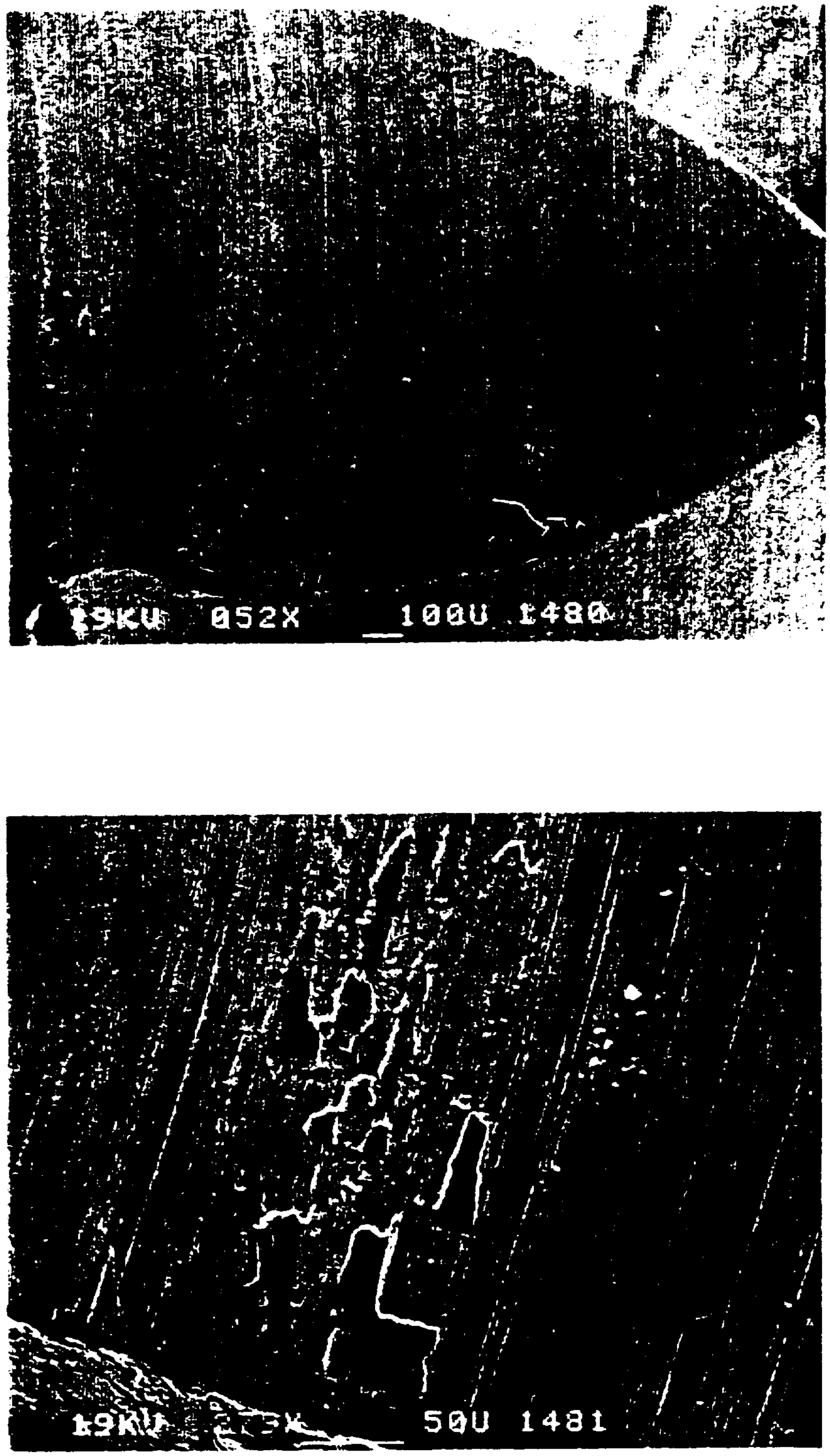


FIGURE 5: Bottom plate side of the 718 drive gear showing areas of smeared metal.

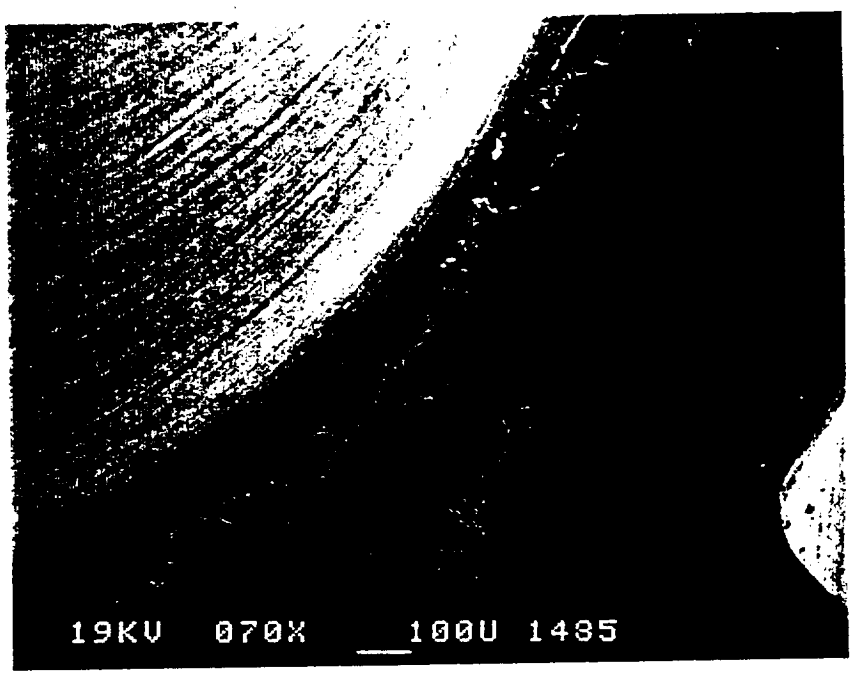


FIGURE 6: Bottom plate side of the 718 drive gear showing the "stepped" surface at the ID of the teeth.

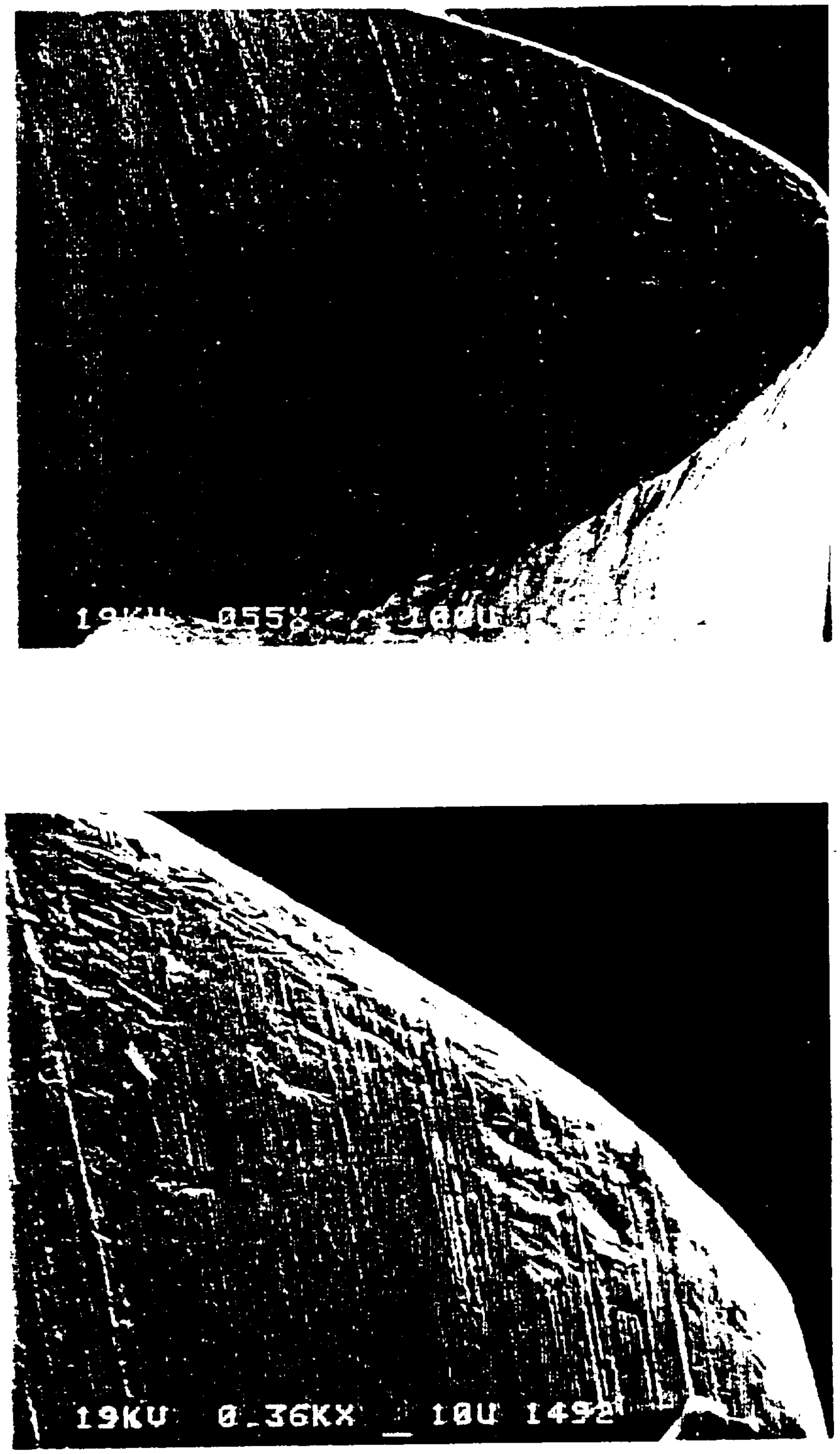


FIGURE 7: Top plate side of the 718 drive gear showing minor scoring and minor damage to the leading edge of the tooth.

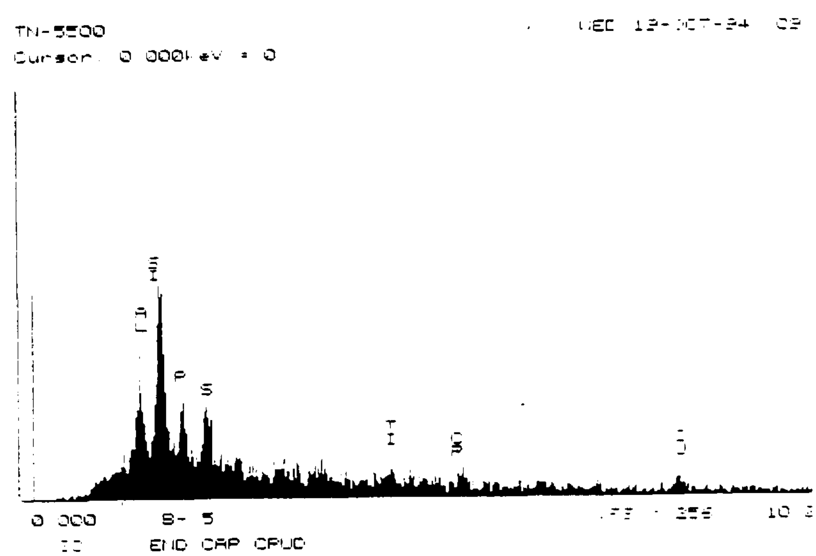


FIGURE 8: End cap from the 15-5 gear cartridge showing the black-brown contamination. An EDX analysis of the contamination is also shown.

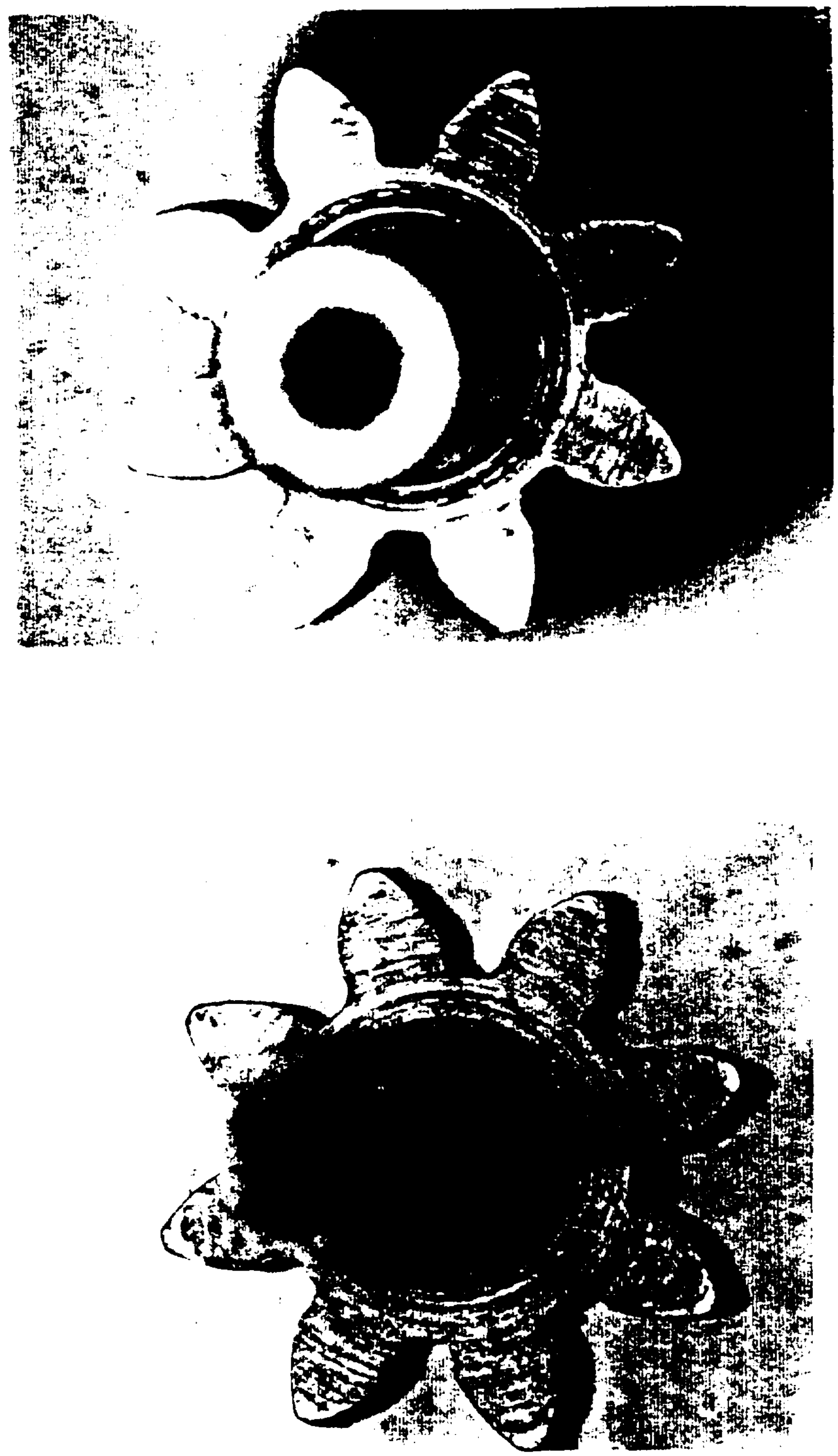


FIGURE 9: 15-5 drive gear showing scoring of the bottom plate side (top photo) and of the top plate side (bottom photo).

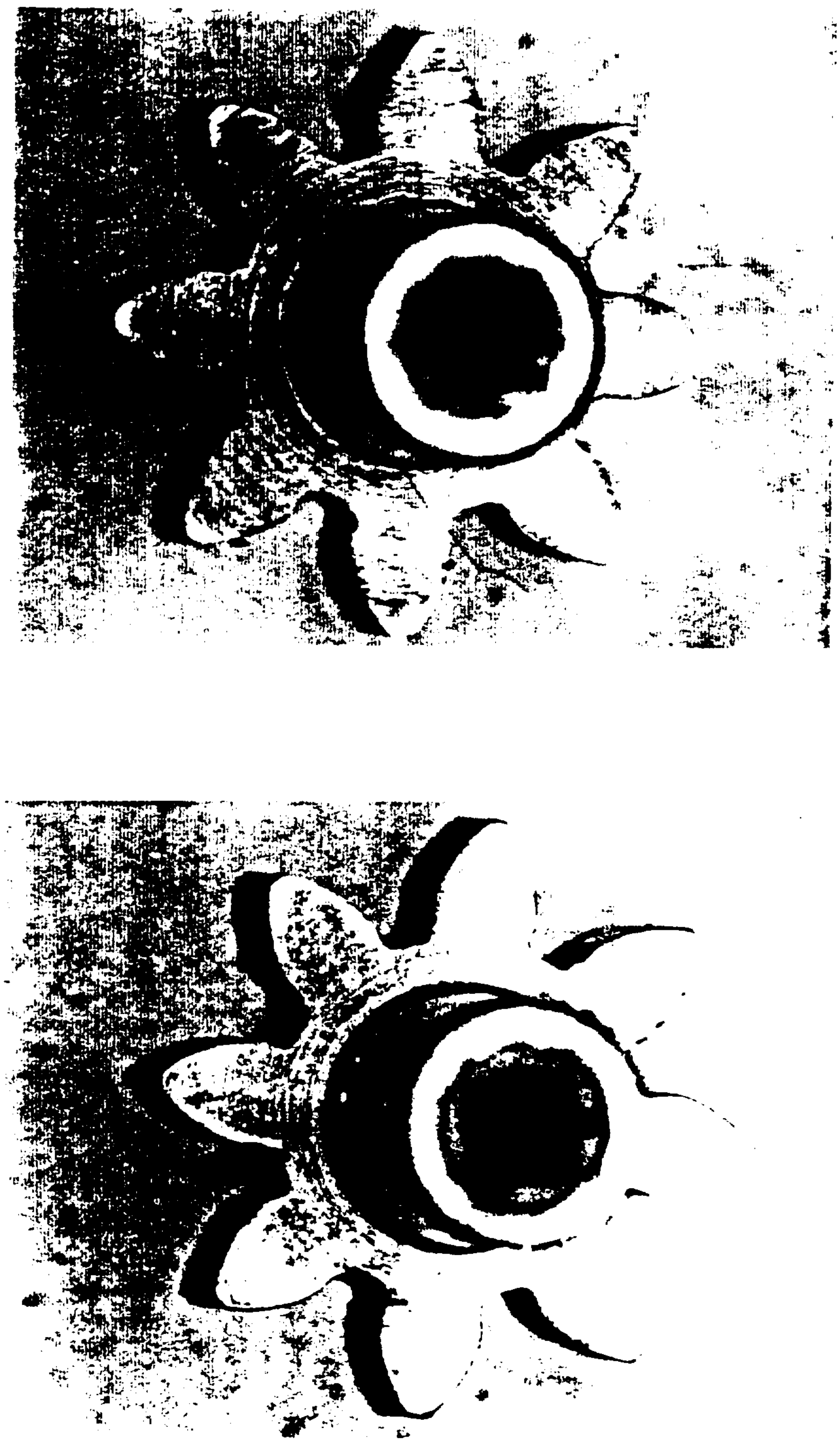


FIGURE 10: 15-5 driven gear showing scoring of the bottom plate side (top photo) and of the top plate side (bottom photo).

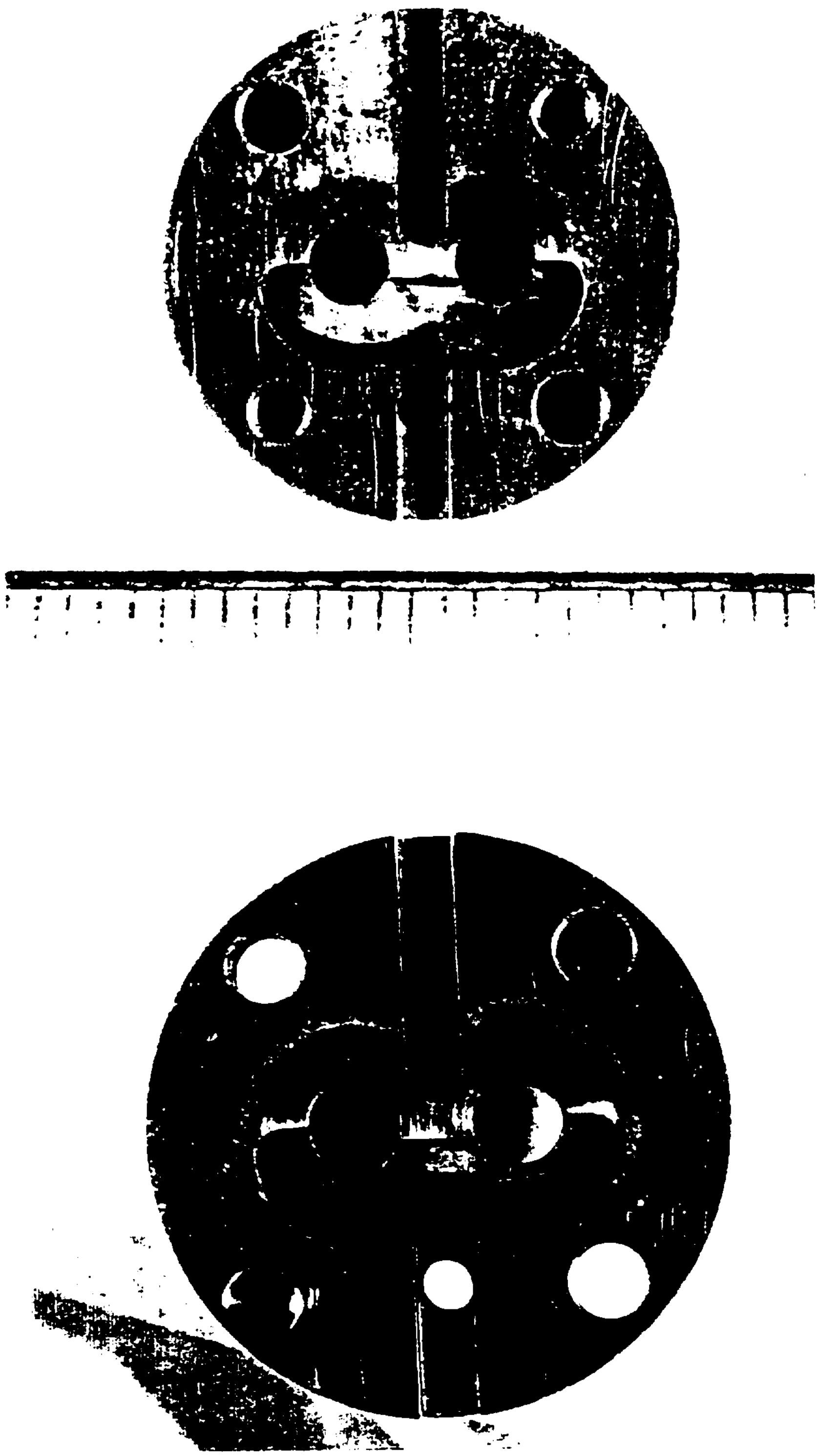


FIGURE 11: TOP: Bottom plate showing scoring at the interfaces with the 15-5 gears.
BOTTOM: Top plate showing scoring at the interfaces with the gears.

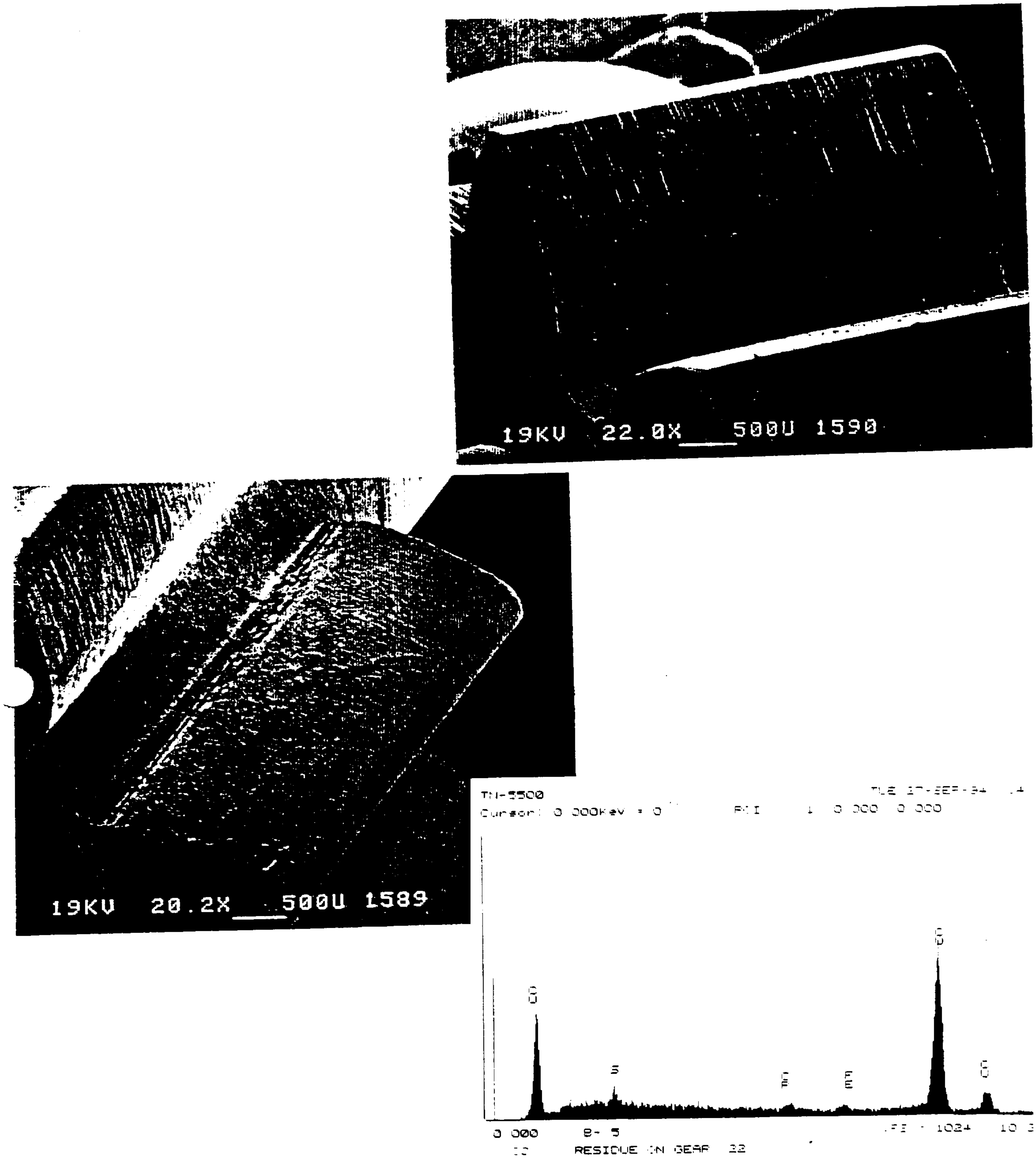


FIGURE 12: 15-5 drive gears showing wear damage on the drive faces (top photo) and collected contamination on the non-driven faces (bottom photo). An EDX analysis of the contamination is also shown.

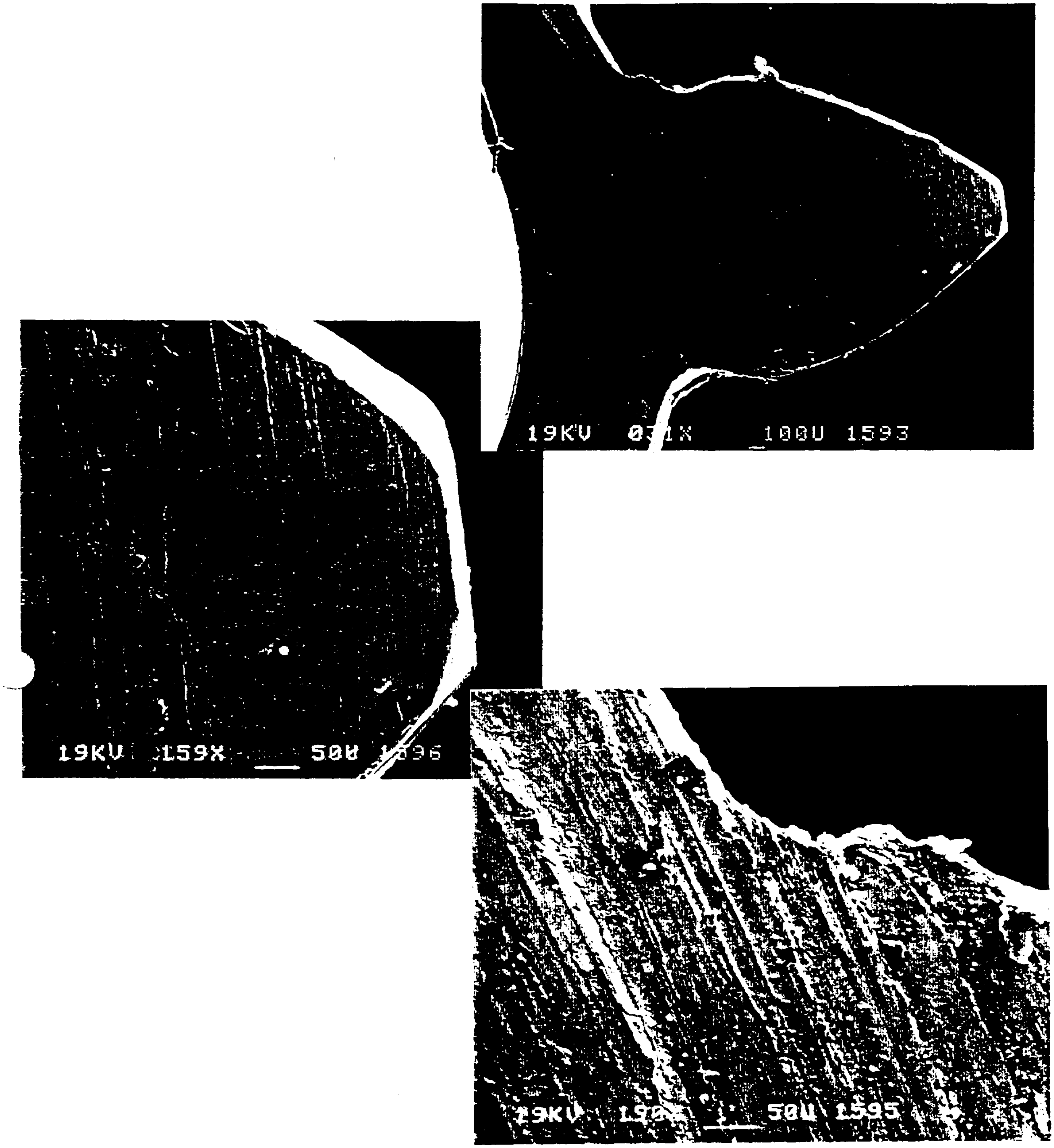


FIGURE 13: 15-5 drive gear showing scoring of the bottom plate side. Note that there is no damage to the leading edges. Also, note the "stepped" appearance near the ID of the teeth.

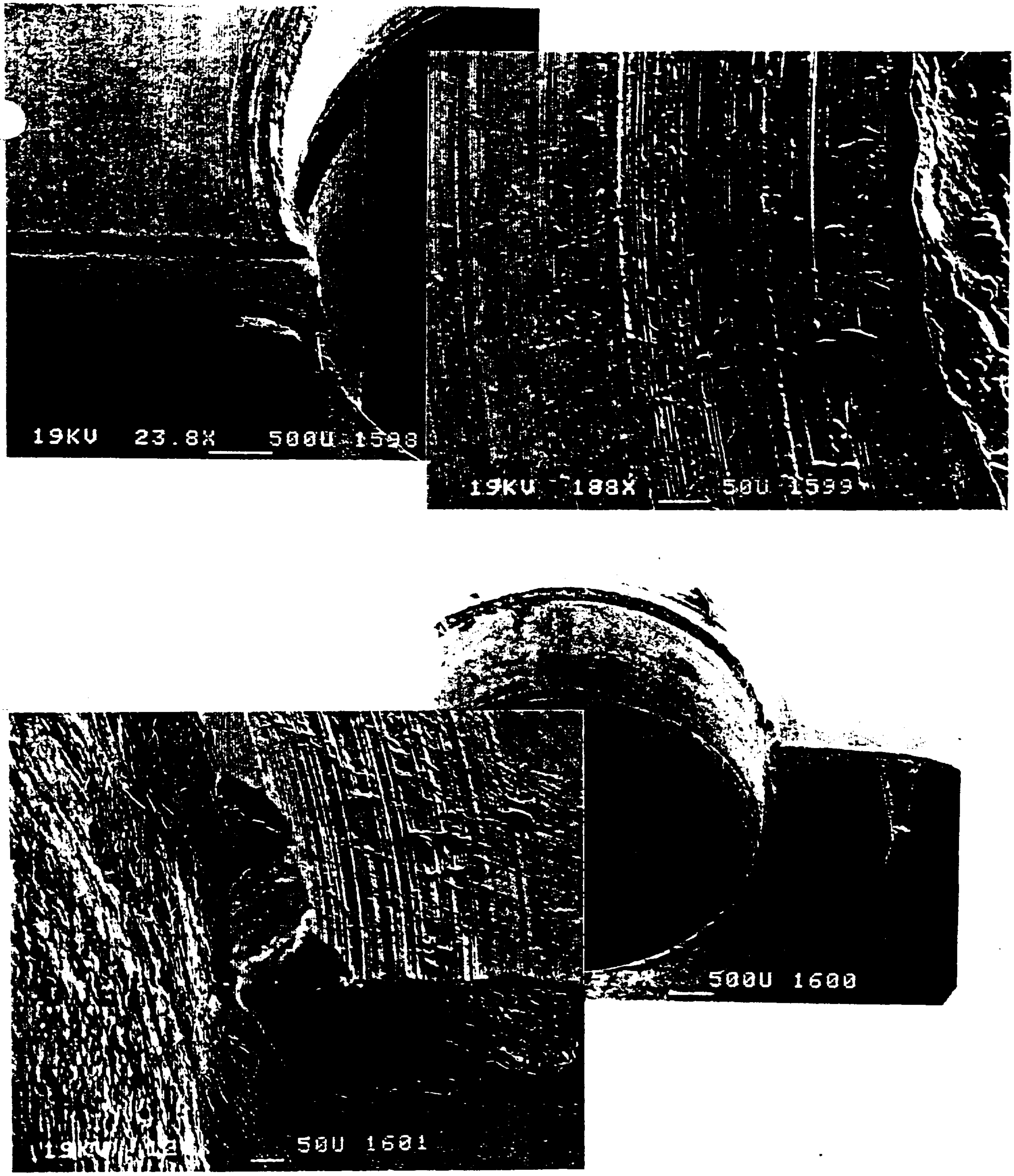
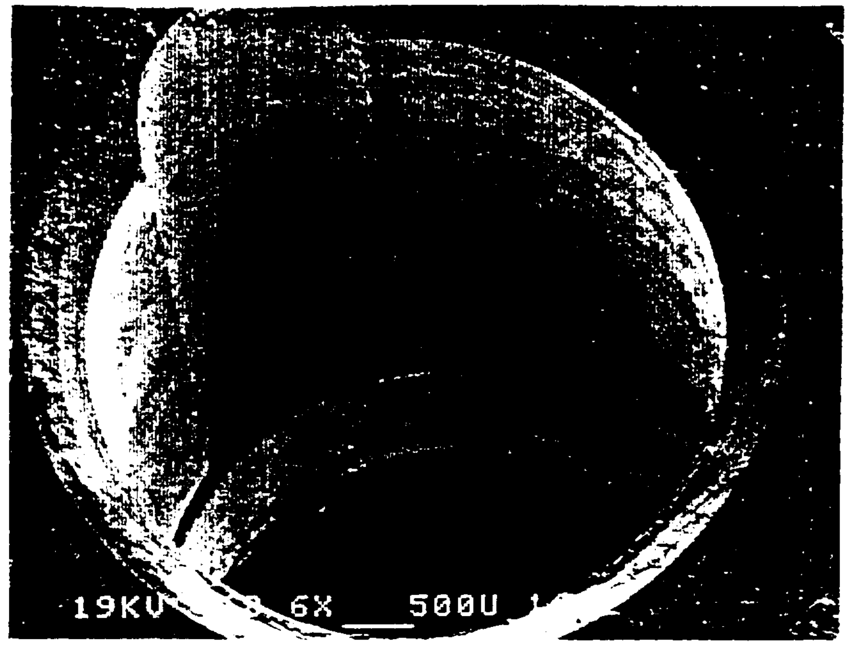
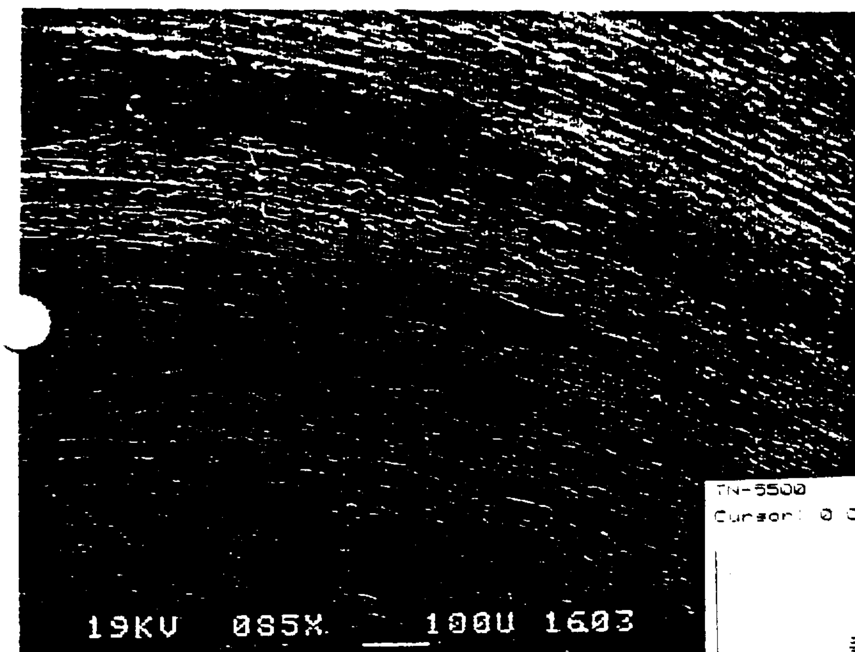


FIGURE 14: Bottom plate showing scoring at the interface with the 15-5 drive gear.





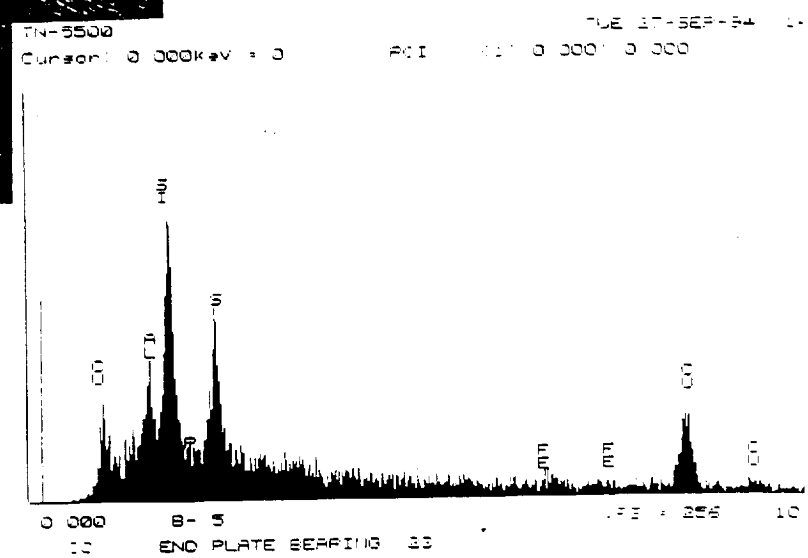
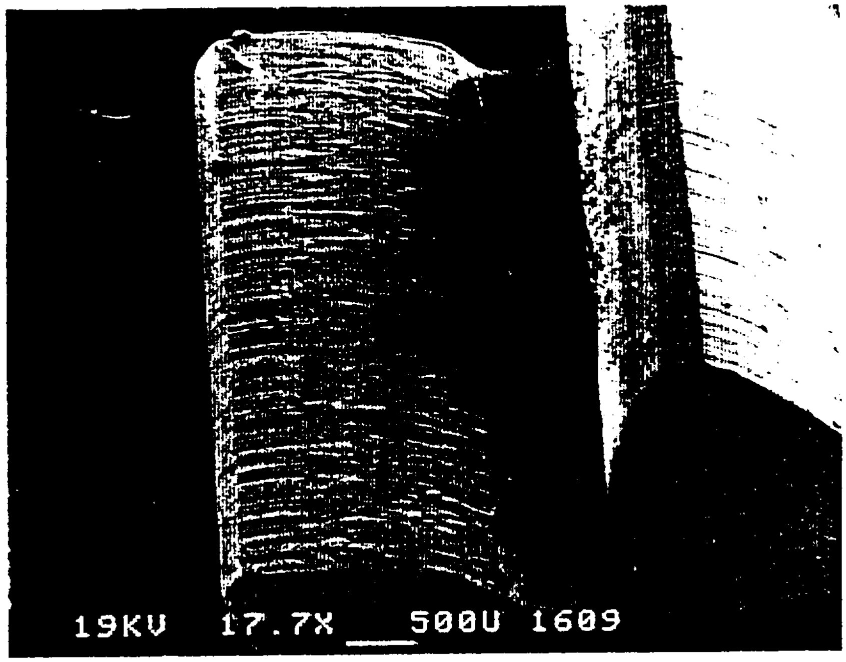


FIGURE 15: Typical area of the journal bearings from the 15-5 gear cartridge showing circumferential scoring. A typical EDX analysis of the journal bearing material is also shown.



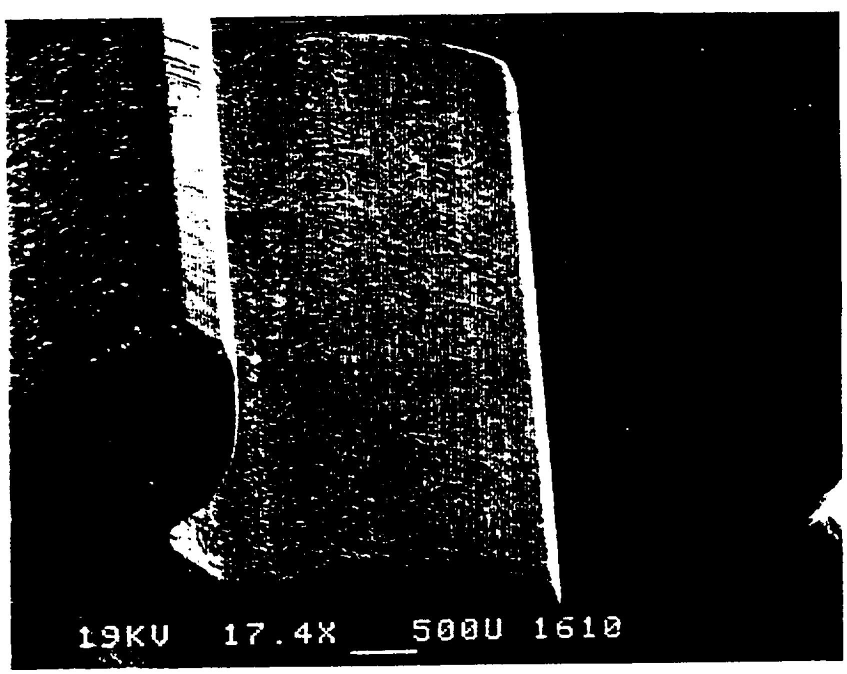


FIGURE 16: 15-5 driven gear showing wear damage on the driven faces and collected contamination on the non-driven faces.

12. Appendix IV: Pump Test Results, M/N 2941 Borided Stellite 6B

SPACE STATION PROCESS PUMP DATA LOG — INITIAL CLEAN WATER PERFORMANCE MAP AT HS

M/N 2941 — S/N 33654-002 — BORITE HARDENED STELLITE 6B GEARS

DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/1/95	8:30 AM	EDS/DSP	14.00	505	48.87	0.13	120	0.047	5.60	0.10				
5/1/95		EDS/DSP	0.00	505	0.00	10.00	120	0.071	8.51	0.00				
5/1/95		EDS/DSP	20.25	751	72.32	0.93	120	0.053	6.34	0.90				
5/1/95		EDS/DSP	10.50	751	35.74	10.04	120	0.073	8.72	3.47				
5/1/95		EDS/DSP	0.00	751	0.00	20.00	120	0.098	11.74	0.00				
5/1/95		EDS/DSP	760.00	1005	100.47	1.98	120	0.062	7.47	2.25				FLOWRATE IN ml/min
5/1/95		EDS/DSP	19.20	999	68.38	10.05	120	0.074	8.92	6.50				
5/1/95		EDS/DSP	11.60	996	39.87	20.08	120	0.104	12.48	5.41				
5/1/95		EDS/DSP	5.60	989	17.36	30.08	120	0.133	15.97	2.76				
5/1/95		EDS/DSP	1.75	1007	2.91	35.00	120	0.151	18.12	0.47				
5/1/95		EDS/DSP	940.00	1254	124.27	4.00	120	0.076	9.08	4.62				FLOWRATE IN ml/min
5/1/95		EDS/DSP	790.00	1249	104.44	10.16	120	0.088	10.55	8.49				FLOWRATE IN ml/min
5/1/95		EDS/DSP	21.00	1250	75.13	20.01	120	0.113	13.57	9.34				
5/1/95		EDS/DSP	15.50	1255	54.50	30.06	120	0.143	17.16	8.05				
5/1/95		EDS/DSP	9.75	1246	32.93	40.00	120	0.174	20.83	5.33				
5/1/95		EDS/DSP	4.60	1258	13.61	50.10	120	0.226	27.12	2.12				
5/1/95		EDS/DSP	0.00	1254	0.00	55.09	120	0.282	33.86	0.00				MOTOR TEMP WAS INCREASING
5/1/95		EDS/DSP	1120.00	1504	148.06	6.10	120	0.093	11.18	6.81				FLOWRATE IN ml/min
5/1/95		EDS/DSP	1030.00	1501	136.17	10.08	120	0.102	12.20	9.49				FLOWRATE IN ml/min
5/1/95		EDS/DSP	850.00	1495	112.37	20.09	120	0.126	15.07	12.63				FLOWRATE IN ml/min
5/1/95		EDS/DSP	24.00	1501	86.39	30.08	120	0.158	18.97	11.55				
5/1/95		EDS/DSP	19.10	1494	68.00	40.00	120	0.189	22.70	10.11				
5/1/95		EDS/DSP	15.00	1510	52.62	50.04	120	0.222	26.68	8.33				
5/1/95		EDS/DSP	10.00	1501	33.87	60.15	120	0.276	33.16	5.18				
5/1/95		EDS/DSP	4.75	1506	14.17	70.06	120	0.373	44.71	1.87				
5/1/95		EDS/DSP	1280.00	1750	169.22	10.12	120	0.121	14.51	9.96				Flowrate in ml/min, rig min DP = 8psi
5/1/95		EDS/DSP	1100.00	1742	145.42	20.03	120	0.147	17.65	13.92				FLOWRATE IN ml/min
5/1/95		EDS/DSP	935.00	1748	123.61	30.00	120	0.178	21.34	14.66				FLOWRATE IN ml/min
5/1/95		EDS/DSP	780.00	1743	103.12	40.00	120	0.212	25.44	13.68				FLOWRATE IN ml/min
5/1/95		EDS/DSP	22.40	1750	80.38	50.10	120	0.247	29.64	11.46				
5/1/95		EDS/DSP	17.60	1742	62.38	60.07	120	0.289	34.70	9.11				
5/1/95		EDS/DSP	13.30	1741	46.25	70.00	120	0.335	40.15	6.80				
5/1/95		EDS/DSP	9.50	1754	31.99	80.02	120	0.394	47.24	4.57				

		SPACE STATION PROCESS PUMP DATA LOG						INITIAL CLEAN WATER PERFORMANCE MAP AT HS						
				M/N 2941		S/N 33654-002		BORITE HARDENED STELLITE 6B GEARS						
DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/1/95		EDS/DSP	7.00	1750	22.61	85.03	120	0.423	50.72	3.20				
5/1/95	11:30am	EDS/DSP	3.00	1740	7.60	90.00	120	0.495	59.40	0.97				
5/1/95	1:00pm	EDS/DSP	1600.00	2002	211.52	12.64	120	0.154	18.50	12.19				
5/1/95		EDS/DSP	1520.00	1999	200.94	20.00	120	0.170	20.35	16.66				
5/1/95		EDS/DSP	1350.00	1996	178.47	30.04	120	0.198	23.80	19.00				
5/1/95		EDS/DSP	1240.00	1993	163.93	40.04	120	0.229	27.48	20.15				
5/1/95		EDS/DSP	1100.00	2008	145.42	50.02	120	0.261	31.33	19.58				
5/1/95		EDS/DSP	960.00	2000	126.91	60.00	120	0.304	36.49	17.60				
5/1/95		EDS/DSP	885.00	2003	117.00	70.00	120	0.346	41.52	16.64				
5/1/95		EDS/DSP	775.00	2005	102.46	80.08	120	0.393	47.12	14.69				
5/1/95		EDS/DSP	21.90	2002	78.51	90.06	120	0.431	51.70	11.54				
5/1/95		EDS/DSP	1760.00	2250	232.67	16.00	120	0.187	22.48	13.97				
5/1/95		EDS/DSP	1600.00	2244	211.52	30.00	120	0.232	27.82	19.24				
5/1/95		EDS/DSP	1360.00	2257	179.79	50.09	120	0.298	35.80	21.22				
5/1/95		EDS/DSP	1120.00	2247	148.06	70.05	120	0.375	44.96	19.46				
5/1/95		EDS/DSP	900.00	2257	118.98	90.05	120	0.467	56.00	16.14				
Howden	**Fluid**	**Systems**	**Performance**	**Data**										
4/13/95	N/A	RN	N/A	3000	270.30	40.00	120	0.313	37.60	24.26				Prior to 8 hr run, fluid temp = 65 F
4/18/95	N/A	RN	N/A	3000	260.30	40.00	120	0.358	43.00	20.42				Following 8 hr run, fluid temp = 78 F

SPACE STATION PROCESS PUMP DATA LOG — M/N 2941 — S/N 33654-002

REAL WATER LIFE TEST AT HS

BORITE HARDENED STELLITE 6B GEARS

DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/2/95	15:15	EDS/DSP												STARTED TEST
5/2/95	15.50	EDS/DSP	5.00	1530	15.11	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/2/95	16:15	EDS/DSP	5.50	1538	16.98	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/3/95	13:30	EDS/DSP	5.50	1533	16.98	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/3/95	14:15	EDS/DSP												SHUTDOWN - REPAIR LEAK IN RIG
5/3/95	14:45	EDS/DSP	5.25	1601	16.04	70	120	N/A	N/A	N/A	N/A	N/A	N/A	RESTARTED
5/3/95	15:30	EDS/DSP	4.50	1606	13.23	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/3/95	16:15	EDS/DSP	4.50	1607	13.23	70	120	N/A	N/A	N/A	N/A	N/A	N/A	3.75 hrs TOTAL LIFE TEST TIME
5/4/95	7:50	EDS	4.75	1609	14.17	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/4/95	7:55	EDS	0.00	0.00	0.00	0	0.00	N/A	N/A	N/A	N/A	N/A	N/A	SHUTDOWN FOR 30 min
5/4/95	8:30	EDS	4.25	1595	12.29	70	120	N/A	N/A	N/A	N/A	N/A	N/A	RESTARTED
5/4/95	8:35	EDS	5.00	1635	15.11	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/4/95	10:30	EDS	5.75	1623	17.92	70	120	N/A	N/A	N/A	N/A	N/A	N/A	
5/4/95	N/A	EDS	0.00	0.00	0.00	0	0.00	N/A	N/A	N/A	N/A	N/A	N/A	INSTALLED CURRENT METER
5/4/95	11:15	EDS	5.00	1695	15.11	70	120	N/A	N/A	N/A	N/A	N/A	N/A	RESTARTED
5/4/95	12:45	EDS	5.00	1724	15.11	70	120	0.297	35.64	2.49	N/A	N/A	N/A	
5/4/95	15:00	EDS	5.00	1725	15.11	70	120	0.296	35.57	2.50	84.60	85.10	75.00	FILTER DP = 8" H2O
5/4/95	15:45	EDS	4.75	1725	14.17	70	120	0.297	35.68	2.33	85.60	85.60	76.40	FILTER DP = 8" H2O
5/4/95	16:15	EDS	4.75	1763	14.17	70	120	0.251	30.08	2.78	85.60	86.10	75.40	FILTER DP = 8" H2O
5/5/95	8:00	EDS	5.25	1773	16.04	70	120	0.308	36.96	2.57	82.80	82.50	72.20	
5/5/95	8:05	EDS	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	SHUTDOWN FOR 30 min
5/5/95	8:35	EDS	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	RESTARTED
5/5/95	9:15	EDS	5.00	1767	15.11	70	120	0.308	36.90	2.43	82.60	82.60	72.40	
5/5/95	11:30	EDS	6.00	1777	18.86	70	120	0.304	36.52	3.07	82.60	82.60	73.30	
5/5/95	13:15	EDS	6.00	1779	18.86	70	120	0.304	36.48	3.07	82.70	83.20	72.80	
5/5/95	13:15	EDS	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	SHUTDOWN FOR 30 min
5/5/95	13:45	EDS	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	RESTARTED
5/5/95	14:00	EDS	5.25	1745	16.04	70	120	0.301	36.13	2.64	82.60	83.00	74.10	
5/5/95	16:00	EDS	5.75	1780	17.92	70	120	0.301	36.06	2.95	83.10	83.60	73.50	48.75 hrs TOTAL LIFE TEST TIME
5/5/95	16:00	EDS	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	SHUTDOWN FOR WEEKEND

SPACE STATION PROCESS PUMP DATA LOG — **REAL WATER LIFE TEST AT HS**

M/N 2941 — **S/N 33654-002** — **BORITE HARDENED STELLITE 6B GEARS**

DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/7/95	14:00	EDS	5.75	1730	17.92	70	120	0.296	35.48	2.98	77.50	76.80	72.50	RESTARTED, FILTER DP = 3"H2O
5/8/95	8:00	EDS	5.00	1757	15.11	70	120	0.291	34.93	2.54	81.70	78.10	71.20	66.75 hrs TOTAL LIFE TEST TIME
5/8/95	8:00	EDS	0.00	0.00	0.00	0	0.00	0.000	0.00	0.00	0.00	0.00	0.00	SHUTDOWN FOR 30 min
5/8/95	8:30	EDS	5.75	1770	17.92	70	120	0.289	34.67	3.03	81.00	78.60	71.90	RESTARTED
5/8/95	11:00	EDS	6.00	1790	18.86	70	120	0.297	35.59	3.12	81.50	79.00	73.10	
5/8/95	12:30	EDS	6.00	1791	18.86	70	120	0.297	35.58	3.12	82.80	81.40	73.20	SHUTDOWN FOR 30 min
5/8/95	13:00	EDS	5.00	1770	15.11	70	120	0.295	35.40	2.52	82.60	81.20	75.10	RESTARTED
5/8/95	15:30	EDS	5.75	1789	17.92	70	120	0.298	35.72	2.98	83.80	80.30	75.20	SHUTDOWN FOR 30 min
5/8/95	16:00	EDS	5.25	1768	16.04	70	120	0.294	35.32	2.68	83.50	82.20	75.50	RESTARTED
5/9/95	8:10	DSP	0.00	N/A	0.00	0	120	N/A	0.00	0.00	120.00	120.00	74.00	PUMP OPERATING, NO FLOW ,
														SHUTDOWN INLET LINE CLOGGED
														89.75 hrs TOTAL LIFE TEST TIME
														RESTARTED, LINE CLEANED
5/9/95	10:53	EDS/DSP												
5/9/95	11:00	EDS/DSP	5.00	1860	15.11	70	120	0.327	39.24	2.28	79.50	77.60	74.20	
5/9/95	11:30	EDS	5.75	1871	17.92	71	120	0.325	38.98	2.73	79.40	78.00	73.40	
5/9/95	13:15	EDS	5.75	1873	17.92	70	120	0.324	38.83	2.74	79.00	77.30	73.70	SHUTDOWN, MOVED RIG
														RESTARTED, NO READINGS
5/10/95	14:00	EDS												
5/10/95	14:30	EDS	5.50	1680	16.98	70	120	0.302	36.18	2.77	79.60	78.00	74.90	
5/10/95	16:15	EDS	5.75	1693	17.92	70	120	0.297	35.58	2.97	79.70	77.40	75.20	SHUTDOWN FOR THE NIGHT
5/11/95	8:00	EDS	5.50	1684	16.98	70	120	0.294	35.30	2.84	72.80	72.80	72.80	RESTARTED
5/11/95	10:30	EDS	5.00	1635	15.11	70	120	0.317	37.98	2.36	81.30	80.90	74.40	
5/11/95	13:00	EDS												SHUTDOWN, NO READINGS
5/12/95	8:30	EDS	5.25	1748	16.04	70	120	0.314	37.70	2.52	72.60	72.60	72.60	RESTARTED
5/12/95	10:00	EDS	5.75	1750	17.92	70	120	0.315	37.75	2.81	80.10	81.40	73.20	
5/12/95	13:30	EDS	4.75	1755	14.17	70	120	0.310	37.18	2.25	84.50	85.10	75.70	
5/12/95	15:00	EDS	5.50	1777	16.98	71	120	0.313	37.50	2.70	84.20	84.90	74.20	
5/12/95	16:00	EDS	5.25	1777	16.04	70	120	0.308	36.98	2.56	84.00	84.90	74.10	
5/12/95	16:00													106.75 hrs TOTAL LIFE TEST TIME

SPACE STATION PROCESS PUMP DATA LOG — **REAL WATER LIFE TEST AT HS**

M/N 2941 — **S/N 33654-002** — **BORITE HARDENED STELLITE 6B GEARS**

DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/14/95	13:50	EDS	2.50	1783	5.73	63	120	0.277	33.24	0.92	95.20	94.80	73.00	FILTER DP = 2.75 "H20
5/14/95	14:00	EDS	5.75	1871	17.92	70	120	0.304	36.42	2.91	80.60	80.70	73.30	RESET CONDITIONS
5/15/95	8:00	EDS	2.75	1876	6.67	69	120	0.299	35.90	1.08	85.40	85.80	71.40	170.75 hrs TOTAL LIFE TEST TIME
														SHUTDOWN, CLEAN & FLUSH
														WATER,
5/15/95	11:00	EDS	0.00	1200	0.00	32	120	0.320	38.45	0.00	77.20	77.20	71.10	CLEAN WATER PERFORMANCE
5/15/95		EDS	3.00	1510	7.60	50	120	0.201	24.11	1.33	77.20	77.20	71.10	CLEAN WATER PERFORMANCE
5/15/95		EDS	2.75	1752	6.67	60	120	0.256	30.74	1.10	77.20	77.20	71.10	CLEAN WATER PERFORMANCE
5/15/95	12:30	EDS	8.75	2008	29.18	70	120	0.328	39.36	4.38	77.20	77.20	71.10	CLEAN WATER PERFORMANCE
5/15/95	14:00	EDS												RESTARTED, NEW WASTE H2O
5/15/95	14:00	EDS	5.75	1852	17.92	70	120	0.300	36.01	2.94	75.08	74.50	71.40	
5/15/95	15:30	EDS	6.00	1873	18.86	70	120	0.304	36.50	3.05	75.50	76.80	71.60	SHUTDOWN FOR 30 min
5/15/95	16:00	EDS	5.50	1853	16.98	70	120	0.302	36.18	2.77	75.90	75.50	71.60	RESTARTED & RESET
5/16/95	8:00	EDS	5.75	1878	17.92	70	120	0.309	37.02	2.86	81.20	82.20	72.20	190.25hrs TOTAL LIFE TEST TIME
5/16/95	8:00	EDS												SHUTDOWN FOR 30 min
5/16/95	8:30	EDS	5.50	1853	16.98	70	120	0.304	36.46	2.75	79.30	77.20	71.40	RESTARTED
5/16/95	10:15	EDS	5.50	1876	16.98	70	120	0.307	36.86	2.72	81.30	81.90	72.70	
5/16/95	13:00	EDS	5.75	1878	17.92	70	120	0.301	36.10	2.93	82.90	83.70	74.40	SHUTDOWN FOR 30 min
5/16/95	13:30	EDS	5.25	1860	16.04	70	120	0.306	36.66	2.59	81.70	82.80	73.60	RESTARTED
5/16/95	15:30	EDS	5.25	1880	16.04	70	120	0.309	37.03	2.56	83.90	84.20	74.70	SHUTDOWN FOR 30 min
5/16/95	16:00	EDS	5.25	1858	16.04	70	120	0.307	36.83	2.57	82.20	82.70	74.80	RESTARTED
5/17/95	8:00	EDS	5.00	1888	15.11	70	120	0.309	37.02	2.41	83.20	84.00	71.40	213.25 hrs TOTAL LIFE TEST TIME
5/17/95	8:30	EDS	5.00	1888	15.11	70	120	0.306	36.70	2.43	80.00	81.10	71.40	RESTARTED AFTER 30 min OFF
5/17/95	10:15	EDS	5.00	1886	15.11	70	120	0.307	36.80	2.42	82.20	82.00	71.80	FILTER DP = 4 "H2O
5/17/95	12:30	EDS	5.25	1890	16.04	70	120	0.308	36.95	2.57	82.40	83.50	73.50	SHUTDOWN FOR 30 min
5/17/95	13:00	EDS	4.75	1875	14.17	70	120	0.306	36.70	2.28	83.40	84.50	73.20	RESTARTED
5/17/95	15:30	EDS	5.00	1888	15.11	70	120	0.308	36.98	2.42	83.50	83.70	73.60	SHUTDOWN FOR 30 min
5/17/95	16:00	EDS	5.00	1878	15.11	70	120	0.305	36.61	2.44	82.40	82.40	73.60	RESTARTED

SPACE STATION PROCESS PUMP DATA LOG — **REAL WATER LIFE TEST AT HS**

M/N 2941 — **S/N 33654-002** — **BORITE HARDENED STELLITE 6B GEARS**

DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/18/95	8:00	EDS	5.75	1906	17.92	70	120	0.310	37.19	2.85	81.70	81.70	72.00	235.75 hrs TOTAL LIFE TEST TIME
5/18/95	8:30	EDS	5.00	1930	15.11	70	120	0.314	37.64	2.37	79.80	80.10	72.40	RESTARTED AFTER 30 min OFF
5/18/95		NOTE:	ON RESTART THE PUMP CONDITIONS ARE BELOW EXPECTATIONS.											
5/18/95			AS THE PUMP WARMS UP THE SPEED SEEMS TO INCREASE ALONG WITH THE FLOW											
5/18/95														
5/18/95	10:15	EDS	5.00	1925	15.11	70	120	0.313	37.54	2.37	83.20	83.30	73.50	
5/18/95	13:00	EDS	5.50	1933	16.98	70	120	0.314	37.70	2.66	83.30	83.60	73.40	SHUTDOWN FOR 30 min
5/18/95	13:30	EDS	3.50	1906	9.48	70	120	0.309	37.03	1.50	78.70	78.70	73.80	RESTARTED
5/18/95	14:00	EDS	4.00	1932	11.36	70	120	0.312	37.48	1.79	84.80	83.00	73.80	
5/18/95	14:30	EDS	4.00	1933	11.36	70	120	0.314	37.66	1.78	84.80	83.00	74.20	
5/18/95	15:00	EDS	4.00	1936	11.36	70	120	0.313	37.51	1.79	85.00	85.00	74.20	
5/18/95	15:30	EDS	4.25	1934	12.29	70	120	0.312	37.44	1.94	85.10	83.60	74.30	SHUTDOWN FOR 30 min
5/18/95	16:00	EDS	3.50	1912	9.48	70	120	0.311	37.26	1.50	84.00	84.00	73.80	RESTARTED
5/18/95	16:15	EDS	5.50	1945	16.98	70	120	0.316	37.90	2.65	84.00	84.50	74.10	
5/19/95	8:00	EDS	6.50	1953	20.73	70	120	0.319	38.26	3.20	83.70	83.30	71.50	258.75 hrs TOTAL LIFE TEST TIME
5/19/95	8:30	EDS	5.00	1918	15.11	70	120	0.311	37.37	2.39	80.60	80.60	71.90	RESTARTED AFTER SHUTDOWN
5/19/95	9:00	EDS	5.00	1916	15.11	70	120	0.313	37.52	2.38	82.40	82.40	71.80	
5/19/95	10:45	EDS	5.50	1923	16.98	70	120	0.315	37.81	2.65	82.40	82.30	71.70	
5/19/95	13:00	EDS	5.50	1921	16.98	70	120	0.315	37.79	2.66	82.10	81.90	71.70	SHUTDOWN FOR 30 min
5/19/95	13:30	EDS	5.00	1898	15.11	70	120	0.309	37.06	2.41	79.60	77.50	72.20	RESTARTED
5/19/95	14:15	EDS	5.50	1920	16.98	70	120	0.314	37.67	2.67	81.60	81.20	71.10	
5/19/95	15:00	EDS	5.75	1922	17.92	70	120	0.314	37.66	2.81	81.60	82.30	72.70	SHUTDOWN FOR 30 min
5/19/95	15:30	EDS	5.50	1635	16.98	70	120	0.344	41.32	2.43	N/A	N/A	N/A	RESTARTED, UNCLOGGED BPR
5/19/95	16:00	EDS	5.50	1818	16.98	70	120	0.326	39.11	2.57	N/A	N/A	N/A	264.75 hrs TOTAL LIFE TEST TIME
5/20/95	14:00	EDS	1.50	1590	1.98	69	120	0.383	45.94	0.25	103.30	130.00	73.00	287.25 hrs TOTAL LIFE TEST TIME
5/20/95		NOTE: VERY LOW FLOW - CURRENT UP, TURNED RPM UP AND BLACK SLUG WENT THROUGH FLOW METER.												
5/20/95		RESET CONDITIONS TEMPERATURE BACK TO NORMAL.												
5/20/95	14:15	EDS	5.75	1548	17.92	70	120	0.357	42.79	2.48	78.60	80.30	73.00	PRESSURE GAUGE STEADY
5/20/95		NOTE: CURRENT SEEMS TO BE DECREASING WITH TIME, FLOW METER SET TO 6.25 TO PROVIDE ADDITIONAL FLOW												

		SPACE STATION PROCESS PUMP DATA LOG						REAL WATER LIFE TEST AT HS						
				M/N 2941		S/N 33654-002		BORITE HARDENED STELLITE 6B GEARS						
DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/21/95	10:30	EDS	0.00	1602	-3.65	44	120	0.194	23.32	-0.59	140.00	123.70	73.00	
5/21/95		NOTE: VERY LOW FLOW - CURRENT UP, TURNED RPM UP AND BLACK SLUG WENT THROUGH FLOW METER.												
5/21/95		RESET CONDITIONS TEMPERATURE BACK TO NORMAL.												
5/21/95	10:45	EDS	5.50	1896	16.98	70	120	0.342	41.03	2.45	79.90	79.70	73.00	FILTER DP = 6.5 "H2O
5/21/95		NOTE: CURRENT SEEMS TO BE DECREASING WITH TIME, RESET FLOW TO 6.25 @ 1955rpm												PRESSURE GAUGE SLIGHTLY
5/21/95														ERRATIC
5/21/95	11:00	EDS	6.25	1935	19.80	70	120	0.345	41.42	2.82	79.20	80.20	73.00	
5/21/95	11:15	EDS	6.00	1923	18.86	70	120	0.342	40.98	2.72	79.80	80.10	73.00	
5/22/95	8:00	EDS	3.50	1927	9.48	70	120	0.318	38.11	1.47	84.40	84.00	71.60	330.25 hrs TOTAL LIFE TEST TIME
5/22/95	9:00	EDS	3.50	1926	9.48	70	120	0.318	38.11	1.47	84.40	85.60	71.80	FILTER DP 3.0 "H2O, SHUTDOWN
5/22/95	9:30	EDS	5.00	1940	15.11	70	120	0.324	38.82	2.30	79.30	79.80	73.50	RESTARTED AFTER 30 min
5/22/95	10:00	EDS	5.50	1963	16.98	70	120	0.325	38.96	2.58	83.40	83.00	73.50	
5/22/95	10:15	EDS	25.00	1994	90.14	35	120	0.201	24.12	11.03				BACK PRESSURE REDUCED TO
5/22/95		EDS												INCREASE FLOW & CLEAN RIG
5/22/95	10:30	EDS	5.50	1968	16.98	70	120	0.324	38.87	2.58	82.30	80.50	74.30	PRESSURE GAUGE SLIGHTLY
5/22/95														ERRATIC
5/22/95	12:45	EDS	6.00	1974	18.86	70	120	0.323	38.70	2.88	82.90	83.30	72.70	SHUTDOWN FOR 60 min
5/22/95	13:45	EDS	5.75	1938	17.92	70	120	0.320	38.45	2.75	77.50	77.50	72.80	RESTARTED
5/22/95	14:30	EDS	5.75	1970	17.92	70	120	0.323	38.71	2.73	82.60	83.40	73.00	
5/22/95	15:30	EDS	5.75	1972	17.92	70	120	0.322	38.68	2.74	83.40	84.00	73.00	SHUTDOWN FOR 30 min
5/22/95	16:00	EDS	5.50	1943	16.98	70	120	0.320	38.44	2.61	80.00	80.00	73.70	RESTARTED
5/22/95	16:15	EDS	5.75	1971	17.92	70	120	0.322	38.63	2.74	81.40	83.20	73.70	
5/23/95	8:00	EDS	5.75	1981	17.92	70	120	0.328	39.30	2.70	82.00	82.60	71.70	352.25 hrs TOTAL LIFE TEST TIME
5/23/95		EDS												PRESSURE GAUGE ERRATIC
5/23/95		EDS												SHUTDOWN FOR 30 min
5/23/95	8:30	EDS	5.75	1795	17.92	70	120	0.304	36.47	2.90	75.30	75.30	71.90	RESTARTED
5/23/95	10:15	EDS	5.75	1824	17.92	70	120	0.309	37.06	2.86	82.00	82.40	73.10	
5/23/95	11:30	EDS	5.75	1823	17.92	70	120	0.308	36.95	2.87	81.20	83.20	72.30	
5/23/95	13:00	EDS	5.75	1822	17.92	70	120	0.309	37.13	2.85	82.60	84.00	73.00	SHUTDOWN FOR 30 min
5/23/95	13:30	EDS	5.75	1795	17.92	70	120	0.303	36.32	2.92	80.00	80.50	74.70	RESTARTED
5/23/95	13:30													358.75 hrs TOTAL LIFE TEST TIME

		SPACE STATION PROCESS PUMP DATA LOG						REAL WATER LIFE TEST AT HS						
				M/N 2941		S/N 33654-002		BORITE HARDENED STELLITE 6B GEARS						
DATE	TIME	OPERATOR	FLOWMETER READING	SPEED (rpm)	FLOWRATE (pph)	OUTLET PRESSURE (PISG)	VOLTAGE (vdc)	CURRENT (amps)	POWER (watts)	EFFICENCY (%)	PUMP TEMP (F)	MOTOR TEMP (F)	AMB TEMP (F)	NOTES
5/23/95	14:30	EDS	5.75	1820	17.92	70	120	0.308	36.92	2.87	83.60	84.20	74.10	
5/23/95	15:30	EDS	5.50	1823	16.98	70	120	0.308	36.90	2.72	81.60	84.80	75.20	SHUTDOWN FOR 30 min
5/23/95	16:00	EDS	5.50	1940	16.98	70	120	0.323	38.70	2.59	83.40	84.20	75.60	RESTARTED
5/23/95	16:15	EDS	5.50	1955	16.98	70	120	0.322	38.69	2.59	83.10	84.60	75.50	
5/24/95	8:00	EDS	5.50	1955	16.98	70	120	0.326	39.11	2.56	81.30	83.50	72.60	374.75 hrs TOTAL LIFE TEST TIME
5/24/95	8:30	EDS	4.50	1925	13.23	70	120	0.317	38.09	2.05	79.70	79.70	73.10	RESTARTED AFTER 30 min OFF
5/24/95	8:45	EDS	5.50	1943	16.98	70	120	0.324	38.88	2.58	83.10	83.10	73.10	
5/24/95	9:15	EDS	5.50	1890	16.98	70	120	0.316	37.88	2.65	84.00	83.00	73.20	
5/24/95	10:30	EDS	5.25	1895	16.04	70	120	0.316	37.88	2.50	84.00	85.20	73.60	
5/24/95	11:30	EDS	5.50	1896	16.98	70	120	0.316	37.90	2.65	84.90	85.80	73.80	
5/24/95	13:00	EDS	5.00	1896	15.11	70	120	0.315	37.82	2.36	86.10	86.90	75.10	SHUTDOWN FOR 30 min
5/24/95	13:30	EDS	5.00	1885	15.11	70	120	0.315	37.82	2.36	79.30	79.30	75.20	RESTARTED
5/24/95	15:30	EDS	4.75	1910	14.17	70	120	0.317	37.99	2.20	87.00	87.40	75.80	SHUTDOWN FOR 30 min
5/24/95	16:00	EDS	4.75	1895	14.17	70	120	0.313	37.58	2.23	81.50	81.50	76.60	RESTARTED
5/24/95	16:15	EDS	5.75	1970	17.92	70	120	0.327	39.24	2.70	86.00	86.90	76.60	RESET
5/25/95	8:00	EDS	6.00	1972	18.86	70	120	0.324	38.84	2.87	81.20	84.00	73.00	SHUTDOWN FOR 30 min
5/25/95	8:30	EDS	5.50	1970	16.98	70	120	0.325	38.98	2.58	79.60	79.60	73.20	RESTARTED
5/25/95	9:30	EDS	7.00	1997	22.61	70	120	0.331	39.67	3.36	83.90	84.70	72.60	
5/25/95	9:30	EDS	5.50	1942	16.98	70	120	0.321	38.47	2.61	83.90	84.70	72.60	RESET
5/25/95	10:45	EDS	5.50	1967	16.98	70	120	0.323	38.76	2.59	83.60	84.00	73.40	
5/25/95	12:30	EDS	5.50	1969	16.98	70	120	0.323	38.78	2.59	83.10	85.00	72.70	SHUTDOWN FOR 30 min
5/25/95	13:00	EDS	4.50	1945	13.23	70	120	0.320	38.38	2.04	83.40	83.40	73.00	RESTARTED
5/25/95	14:30	EDS	5.75	1969	17.92	70	120	0.326	39.11	2.71	82.50	83.20	73.10	
5/26/95	8:00	EDS	5.75	1969	17.92	70	120	0.325	38.99	2.72	81.30	80.70	71.50	SHUTDOWN FOR 30 min
5/26/95	8:30	EDS	4.00	1935	11.36	70	120	0.315	37.78	1.78	76.50	76.50	70.90	RESTARTED
5/26/95	9:00	EDS	5.50	1990	16.98	70	120	0.323	38.80	2.59	80.30	81.70	71.10	
5/26/95	10:00	EDS	6.50	2001	20.73	70	120	0.321	38.51	3.18	80.80	81.60	72.40	
5/26/95	11:15	EDS	5.75	1970	17.92	70	120	0.325	39.00	2.71	80.80	82.30	72.20	
5/26/95	13:00	EDS	5.75	1972	17.92	70	120	0.325	38.99	2.72	81.60	81.80	73.00	STOPPED TEST - CHECK GEARS
5/26/95	13:00													424.75 hrs TOTAL LIFE TEST TIME

13. Appendix V: Materials Selection WP Gear Pump Report, Number SVME 3478, Dated June 23, 1995

ıternal Correspondence

UNITED TECHNOLOGIES HAMILTON STANDARD

SVME 3478
July 6, 1995

Memo to: Dave Parker

cc: J. Gruber, B. Bouchelle

From: Bill Schultz

SUBJECT: Materials Selection for Water Processor Gear Pumps

References: -SVME 3346, "Examination of PDI Gear Pumps"
-SVME 2977, "Examination of Components Removed from Failed PDI Gear Pump"
-SVME 3517, "Analysis of the Borided 718 and Borided 6B Gears from the Water Processor Pump"

Various materials have been evaluated for the gears for the Water Processor pump. This memo summarizes the current status of these evaluations. The overall status of the evaluations is summarized first, followed by a chronological review of the materials.

MATERIAL	SUMMARY
Nitrided 17-4 H1025	Testing in waste water stopped after ~1500 hours due to contamination from corrosion of a plug in the test rig. Corrosion of the gears had begun.
15-5 H1025	Testing in waste water stopped after ~188 hours due to poor performance. Severe scoring of the gear teeth had occurred.
718	Testing in clean water stopped after 45 seconds when the pump locked up. The 718 had galled to the chrome plated end plate.
15-5 H1025, low speed	Testing in clean water stopped after ~257 hours due to poor performance. Scoring of the gear teeth had occurred.
Oversized Borided 718	Boriding resulted in greater dimensional growth than expected. Testing not possible.
Borided 718	Testing in waste water stopped after ~87 hours when the pump locked up. The boride layer was gone from the gear drive faces. Severe scoring occurred, and the gears galled and seized.

during service. A contact through TelTech indicated that companies were using chrome plating on gears, but he was not able to provide any details. A contact through a Tech-Net course indicated that companies were using TiN on gears, but again no details were available.

Literature and discussions indicated that while nitriding and carburizing would increase the hardness of corrosion resistant materials, they both result in reduced corrosion resistance. Boriding of nickel base and cobalt base alloys results in increased hardness and little or no reduction in corrosion resistance. Boriding of stainless steels can result in reduced corrosion resistance. Based on this, borided nickel base and cobalt base alloys were investigated. Contacts that were particularly helpful include Dan Krouse (HS SSI/S&SS Materials Engineering), Clark Cooper (UTRC), Russ Beers (P&W/FL), and Frank Galligani and Paul Doherty (Materials Development Corp.(MDC) in Medford, MA).

MDC has provided boriding for an earlier SSI/S&SS investigation as well as for UTRC and P&W. MDC stated that the alloys they typically boride are nickel alloy 718 and cobalt alloy 6B. The process is proprietary, and MDC would not provide many details. It is an elevated temperature diffusion process which can under appropriate conditions result in depths of up to 3 - 4 mils. The typical depth used is about 1 mil due to practical processing limitations and residual stress build-up which occurs as the thickness is increased. The borided surface has a hardness of approximately 2000 HV (>>75 HRC). The coating generally produces dimensional growth of about 10% of the borided layer thickness, but similar to nitriding, the growth is sensitive to geometry and other factors. Masking for selective boriding is done by copper plating the areas not to be borided.

Use of only a 0.001" deep boride layer raised some concern because the original 17-4 gears were nitrided to a depth of 0.003" - 0.005". Generally, the depth of hardening must be deeper than the maximum shear stress imposed by the contact forces. It is not known whether the 0.001" deep boriding will be deep enough for the gears to meet the design requirements. The lower speed being used for the larger size borided 6B gears will result in lower contact forces, and, therefore, a shallower maximum shear stress.

Corrosion Testing

A sample of 6B was borided by MDC and used for a corrosion test to insure that its corrosion resistance would be adequate for use in the Water Processor pump. A sample of nitrided 17-4 was used as the baseline, and a sample of nitrided A-286 was also tested. The corrosion testing was performed in an aerated solution of 3.5% NaCl at room temperature. This is a much more aggressive corrosive than the "waste" water the pump is exposed to, but this was necessary to accelerate the corrosion testing.

Table 1 summarizes the accelerated corrosion testing. Figures 2 and 3 show macro-photos and cross-sections of the corrosion of the nitrided 17-4 and nitrided A-286, respectively. Significant corrosion and attack into the nitride layer were present on both samples. At the termination of the corrosion testing, the borided 6B showed no evidence

TABLE 1: CORROSION TEST RESULTS

Material	Life in "Gray" Water	Time to Significant Corrosion or Termination of NaCl Test	Expected Life in "Gray" Water
Nitrided 17-4	>1500 hours	17 hours till significant corrosion	~1500 hours
Nitrided A-286	N/A	71 hours till significant corrosion	~6000 hours
Borided 6B	N/A	213 days till test terminated (5,112 hours)	450,000 + hours (50 + years)

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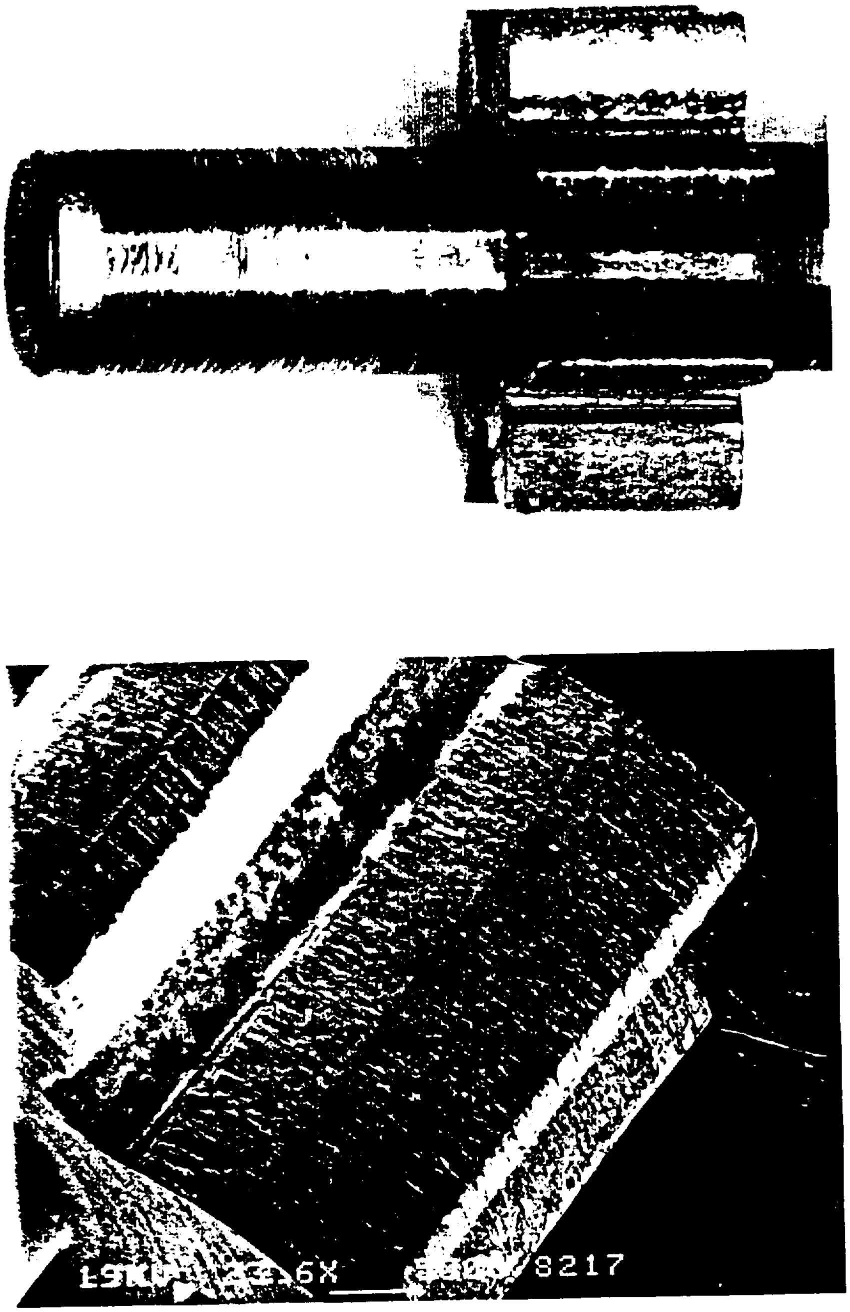

Figure 1: Top: Optical photo at 8x showing the wear present on the gear teeth of the low speed 15-5 gears following pump testing.
Bottom: SEM photo at 23.6x showing the wear present on the gear teeth of the low speed 15-5 gears following pump testing.

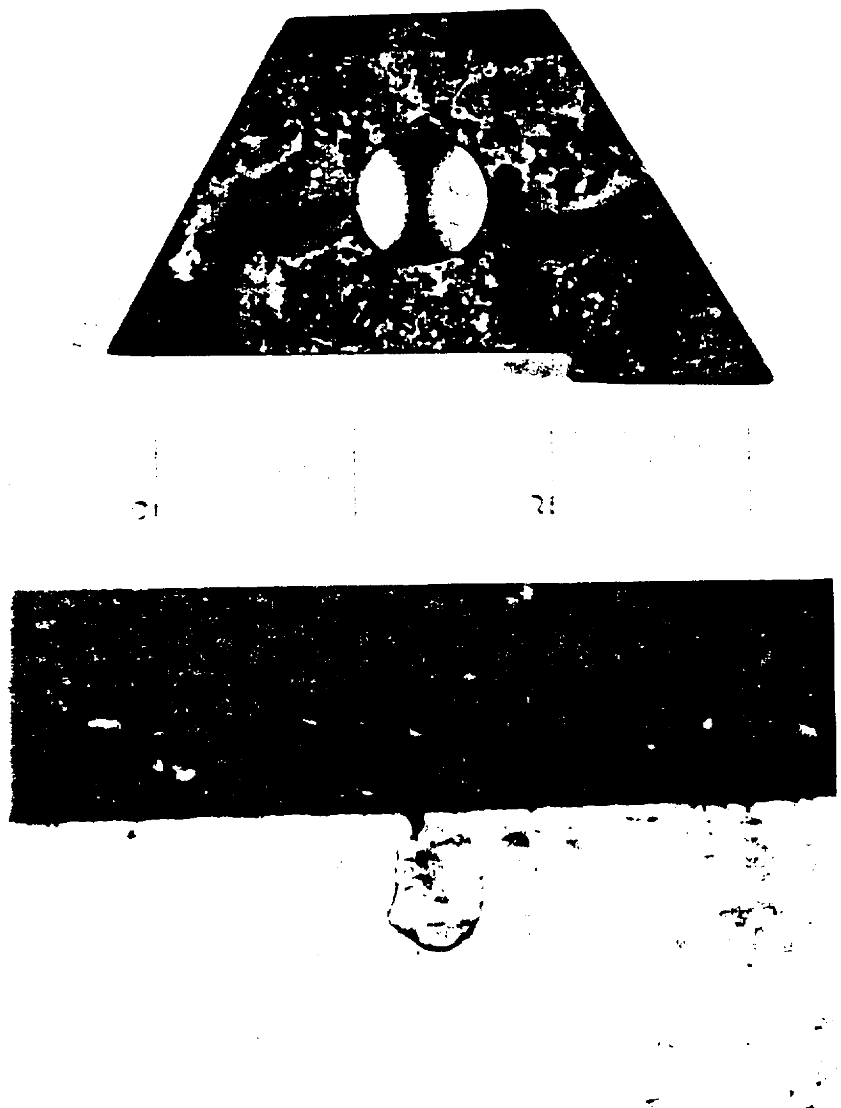

Figure 2: Top: Optical photo at 1.5x of the nitrided 17-4 sample following corrosion testing.
Bottom: Optical photo at 200x of the metallographic cross-section of the nitrided 17-4 following corrosion testing.

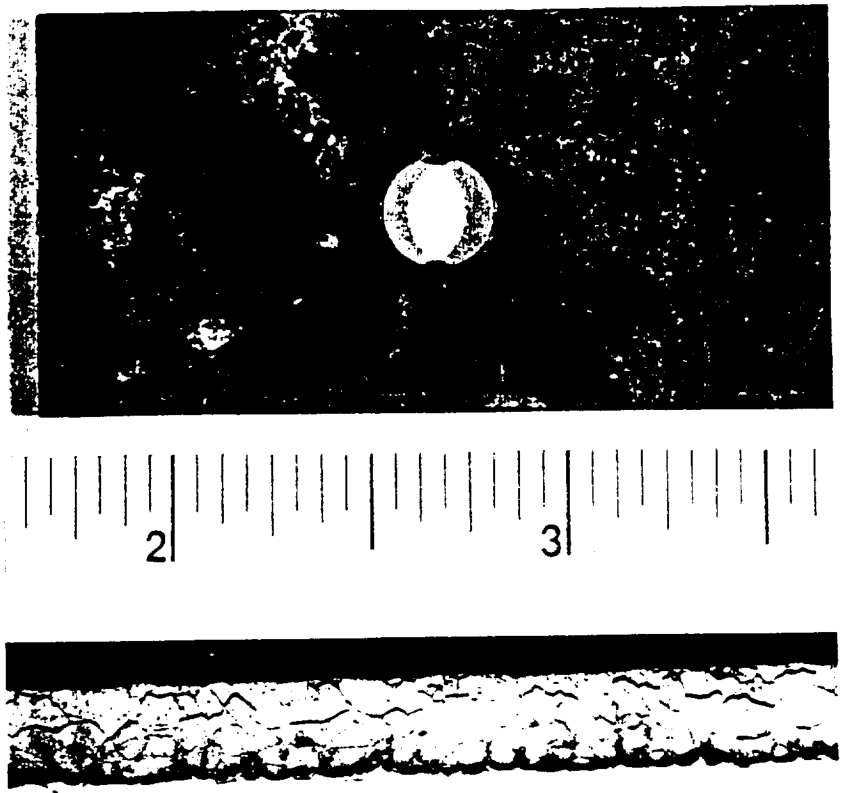

Figure 3: Top: Optical photo at 1.5x of the nitrided A-286 sample following corrosion testing.
Bottom: Optical photo at 200x of the metallographic cross-section of the nitrided A-286 following corrosion testing.

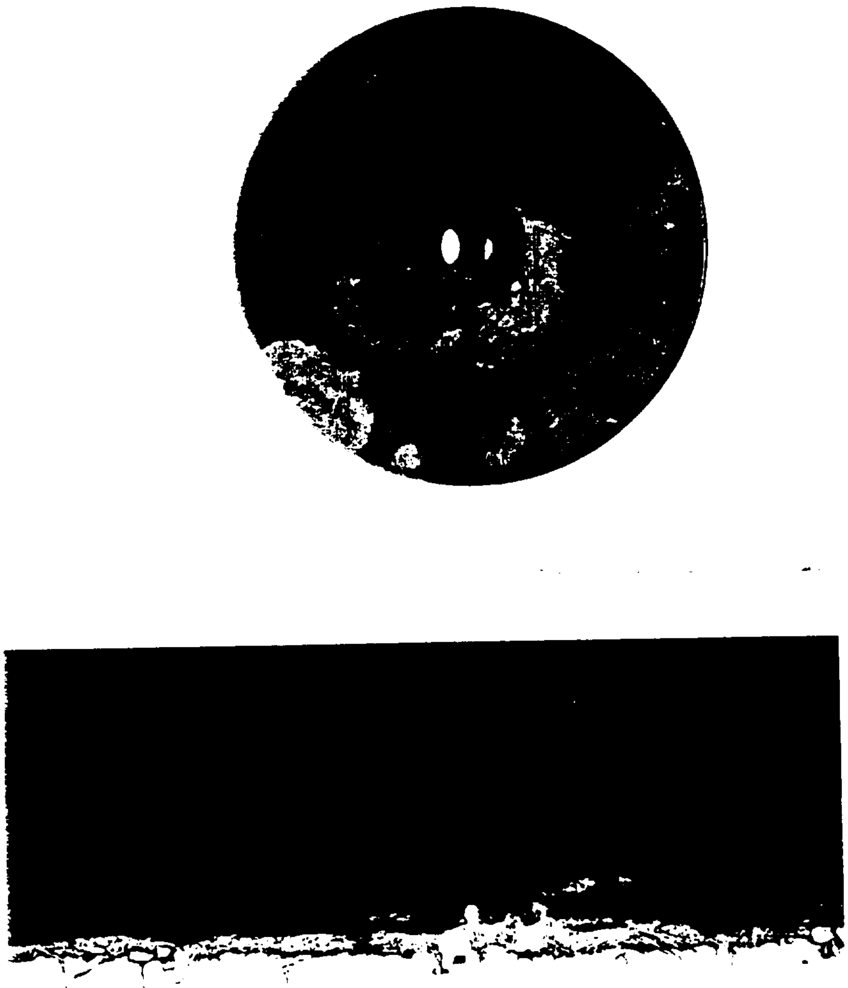

Figure 4: Top: Optical photo at 1.5x of the borided 6B sample following corrosion testing.
Bottom: Optical photo at 400x of the metallographic cross-section of the borided 6B following corrosion testing.

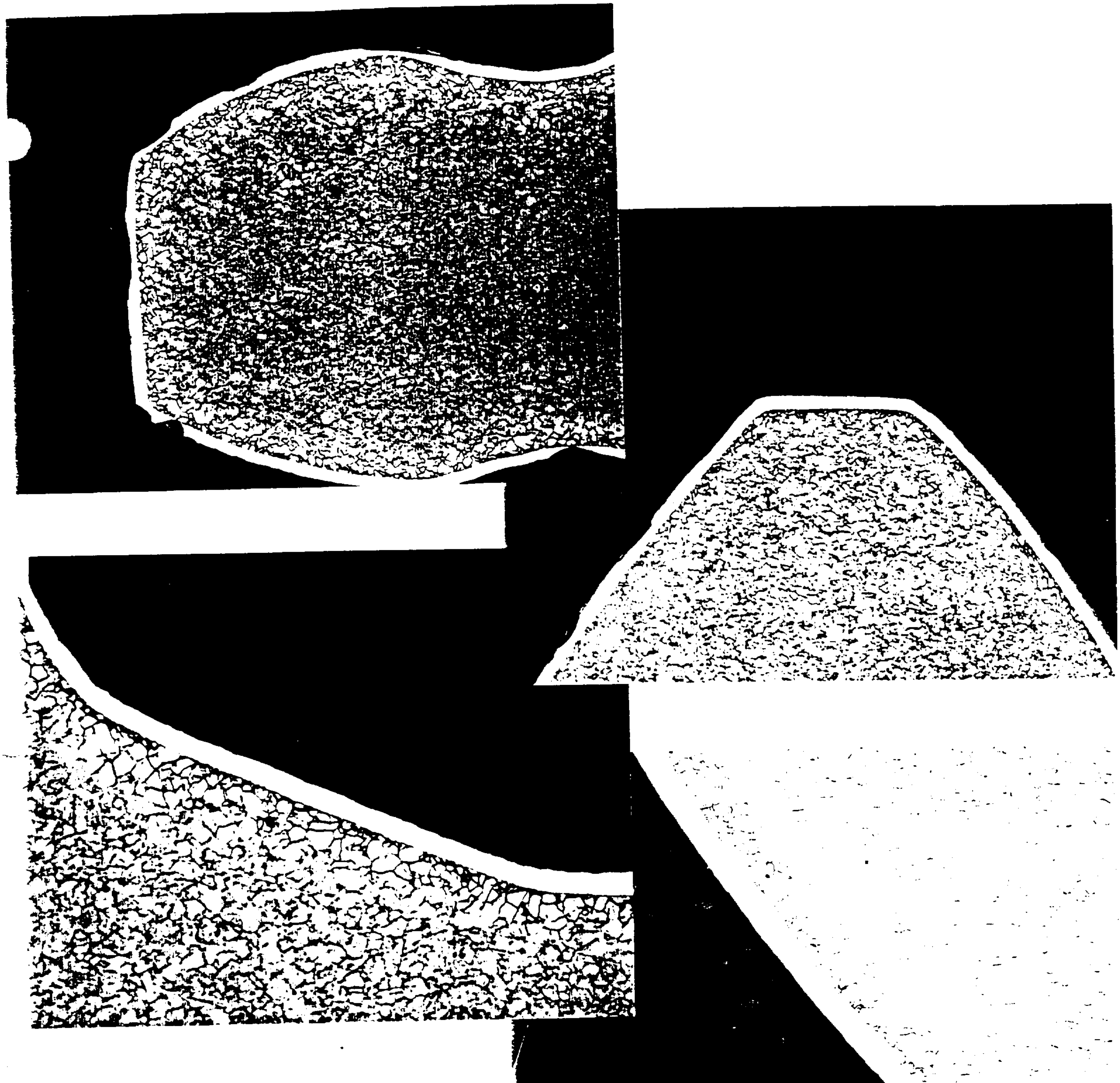

Figure 5: Optical photos at of the metallographic cross-section of the over-sized borided 718 gear. From top to bottom are areas of a spline at 100x, a gear tooth tip at 100x, a gear tooth root at 200x, and a journal diameter at 200x.

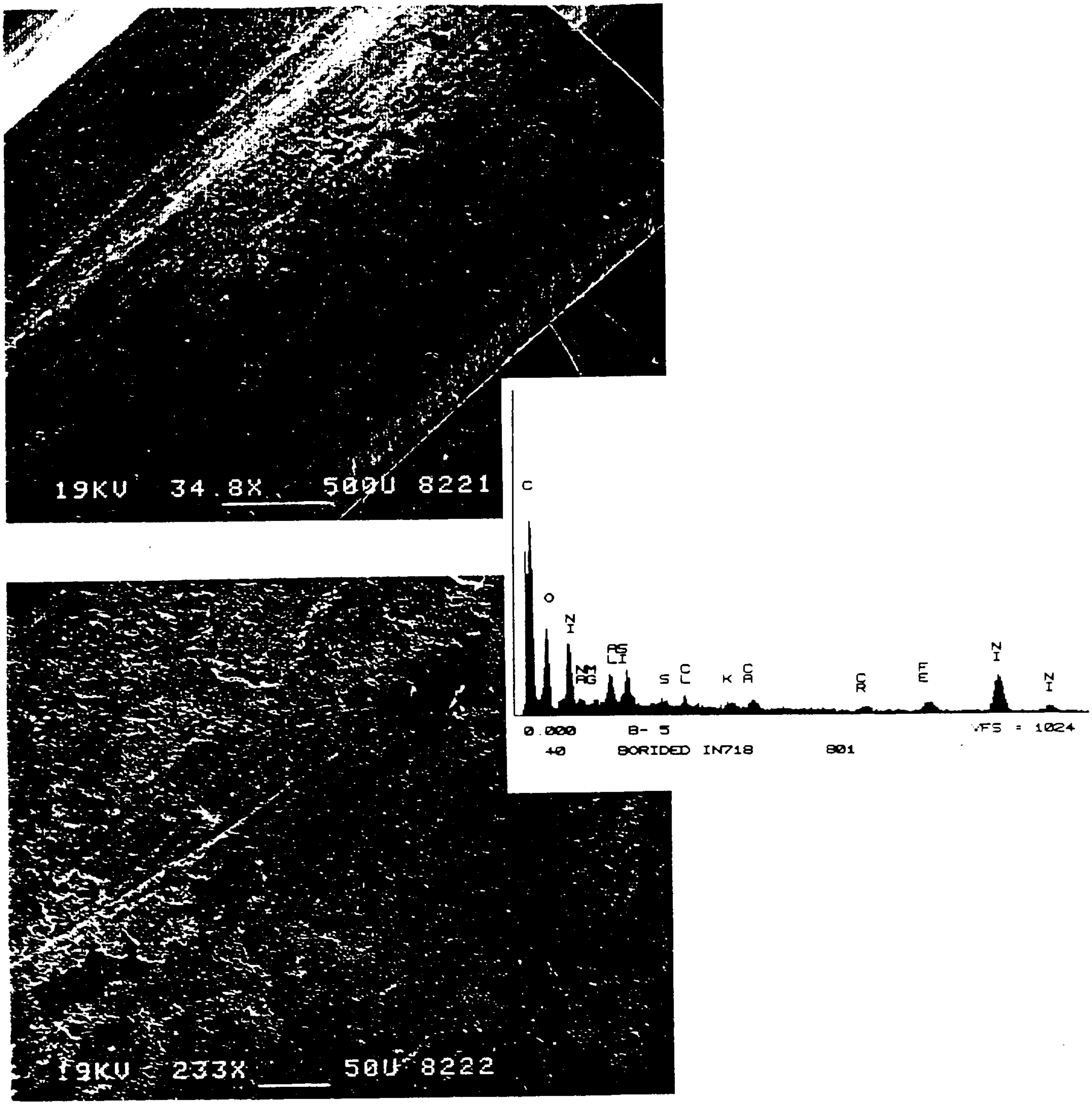

Figure 6: SEM photos at 34.8x and 233x of the surface of the over-sized borided 718 gear. An EDX analysis of the deposit material is also shown.

14. Appendix VI: Analysis of the Borided 718 and Borited 6B Gears from the WP Gear Pump, Report Number SVME3517, Dated July 14, 1995

Internal Correspondence

UNITED TECHNOLOGIES
HAMILTON STANDARD

SVME 3517
7/14/95

Memo to: Dave Parker

cc: J. Gruber, B. Bouchelle

From: Bill Schultz

Subject: Analysis of the Borided 718 and Borided 6B Gears from the Water Processor Gear Pump

References: -SVME 3346, "Examination of PDI Gear Pumps"
-SVME 2977, "Examination of Components Removed from Failed PDI Gear Pump"
-SVME 3478, "Materials Selection for Water Processor Gear Pumps"

SUMMARY

Examination of the borided 718 and borided 6B gears from two pumps revealed that the boride layers had been removed from the drive faces of the gears after 87 and 427 hours of operation, respectively. Significant wear of the base metal had also occurred. It appeared that the boride layer was too thin (only about 0.001" thick) and possibly too brittle. This allowed the highest stress due to the contact loads to occur in the softer base material, which would experience unacceptable deflections.

The company that performs the boriding, Materials Development Corporation (MDC), has stated that boriding deeper than 0.001" results in a very brittle layer which tends to spall. Therefore, boriding does not appear to be a feasible option for these gears.

Currently, no other materials are recommended for testing in these gear pumps. Analyses to determine the gear stresses and research into other materials and processes are needed before other recommendations can be made.

BACKGROUND

Borided 718 gears were manufactured for use in the previous pump (Model Number 2992). Examinations of gears run in the M/N 2992 pump are summarized in the three referenced documents. The 718 gears were conventionally hobbed. Borided 6B gears were manufactured for use in a larger, lower speed pump (M/N 2941). The 6B gear teeth

The gears were cross-sectioned perpendicular to their axis for metallographic examination. Figures 3 shows the typical cross-sectional shapes of the drive gear and the driven gear. A significant amount of material, as much as 0.005", has been removed from the drive faces of both gears, particularly near the root and tip. Higher magnification examination of the cross-sections revealed that the boride layer was removed from the working surfaces of the gear teeth. Some evidence of the boride remains near the pitch line. This is shown in Figures 4 and 5.

Detailed SEM examination revealed the presence of cracks in the boride layer adjacent to the heavily worn areas. Typical root and tip areas are shown in Figure 6. Figure 7 shows an area where the gear was clamped in a vice during cross-sectioning. The cracking present in the crushed area is indicative of the brittle nature of the boride layer.

BORIDED 6B

Figure 8 shows an optical and a SEM photo of a typical gear tooth. Significant wear has occurred on the drive faces of the gear teeth.

The gears were cross-sectioned perpendicular to their axis for metallographic examination. Figures 9 shows the typical cross-sectional shapes of the drive gear and the driven gear. A significant amount of material, as much as 0.005", has been removed from the drive faces of both gears, particularly near the root and tip. Higher magnification examination of the cross-sections revealed that the boride layer was removed from the working surfaces of the gear teeth. Some evidence of the boride remains near the pitch line. This is shown in Figure 10 and 11.

Detailed SEM examination revealed the presence of some cracks in the boride layer adjacent to the heavily worn areas, as well as what appeared to be a somewhat porous structure and possibly cracking at the boride/base metal interface. Typical root and tip areas are shown in Figure 12.

DISCUSSION

BORIDED 718

The presence of cracking in the boride layer near the heavily worn areas indicated that compressive overstressing of the boride layer occurred. It is likely that the contact loads caused plastic deformation of the base metal which led to cracking of the boride.

Once cracking initiated in the boride layer, the brittle nature of the boride layer would lead to further cracking and spalling of the boride. After loss of the boride layer, galling and adhesive wear of the 718 occurred because 718 has inherently poor galling and wear resistance. Finally severe enough galling occurred between mating teeth to cause the pump to seize. The particularly significant amounts of material removal near the roots

RECOMMENDATIONS

Based on the analyses and discussions to date, the following recommendations must be implemented before further materials recommendations can be made.

1) A detailed stress analysis of the gears should be performed. Definition of the contact stress, depth of maximum shear stress, and sliding loads are needed. It would be particularly interesting to determine if the depth of maximum shear stress is at greater than 0.001" deep (the boride thickness on the 718 and 6B) and less than 0.004" deep (the nominal nitride thickness on the 17-4).

2) A review of the available literature/information on gear pumps should be conducted.

3) Use of coatings (TiN, electroless Ni, thin dense chrome) and use of novel gear materials (ceramics, plastics, hard/soft combinations) should be researched.

Bill Schultz

Bill Schultz
Materials Engineering

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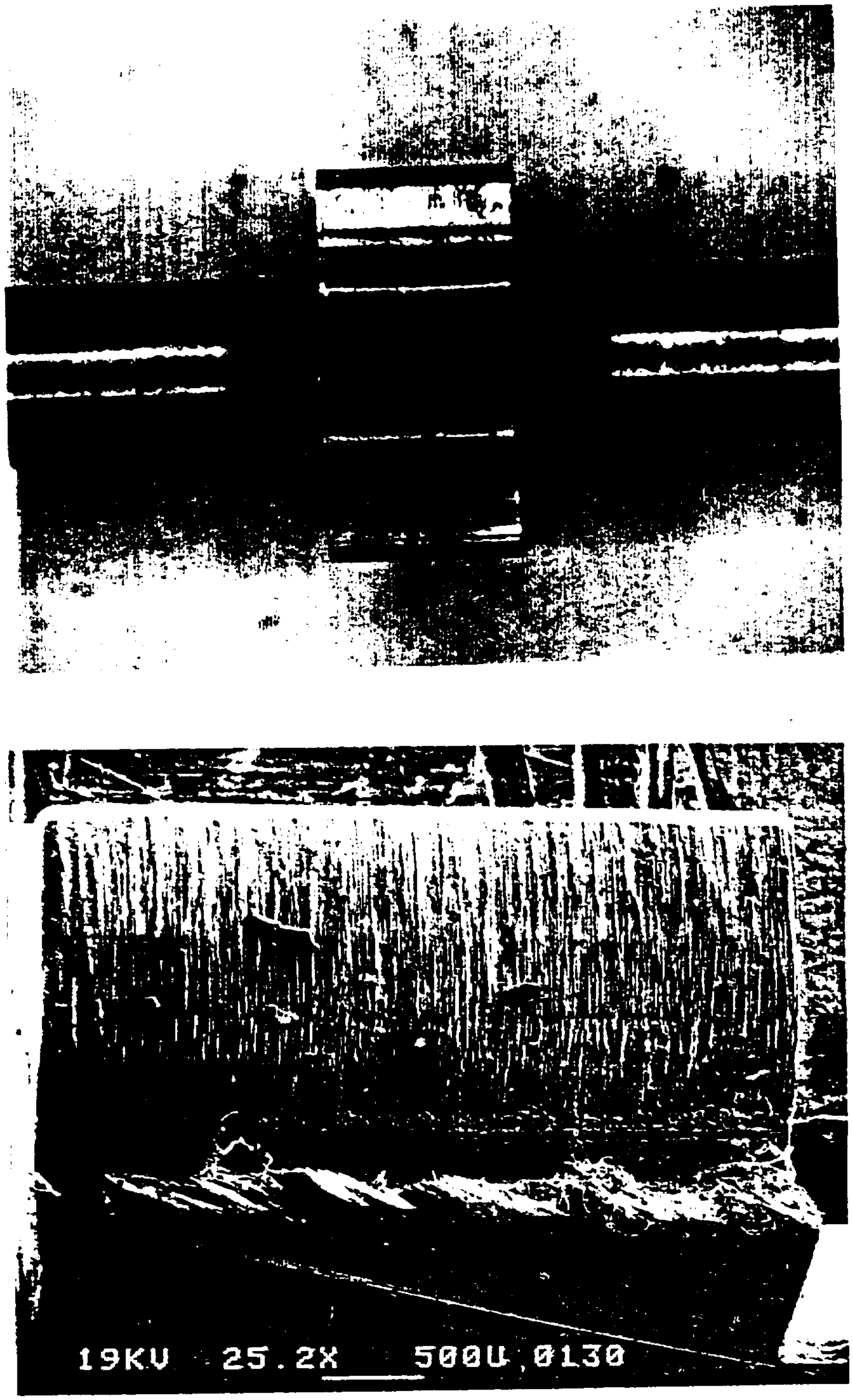
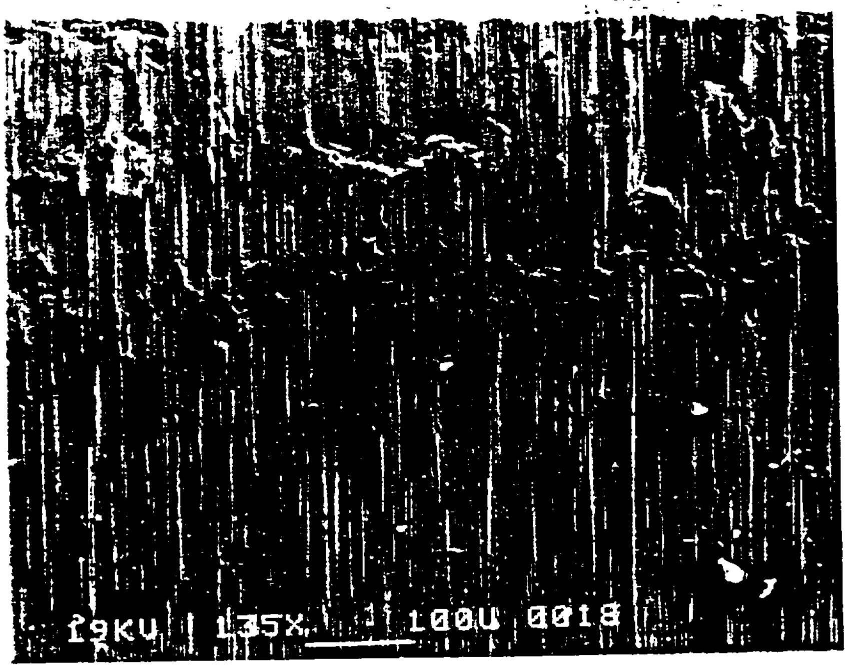
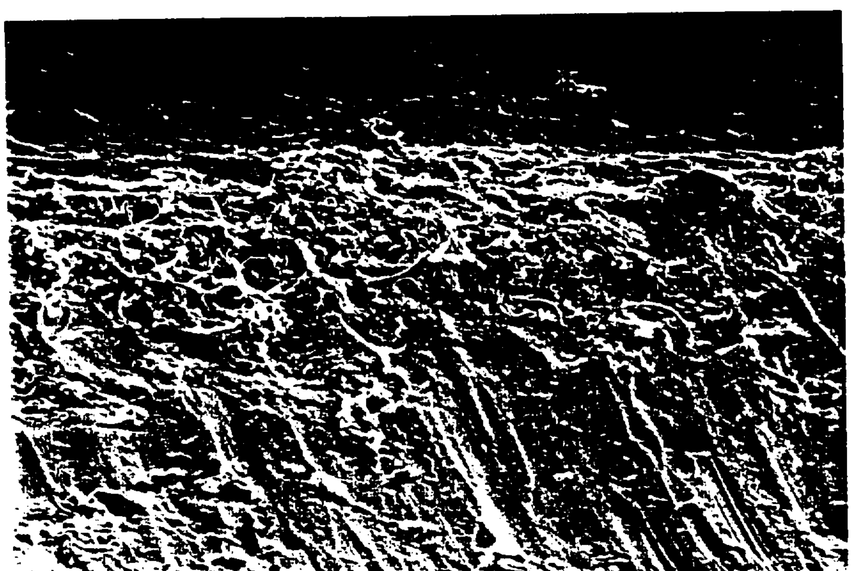


Figure 1: Typical teeth from the 718 drive gear showing significant wear of the drive faces.
TOP: Optical photo at 6x.
BOTTOM: SEM photo at 25.2x. The bottom half of the photo is the cut surface from mechanically sectioning the gear.



Tip Edge

Galled & Smeared Material on the Drive Face

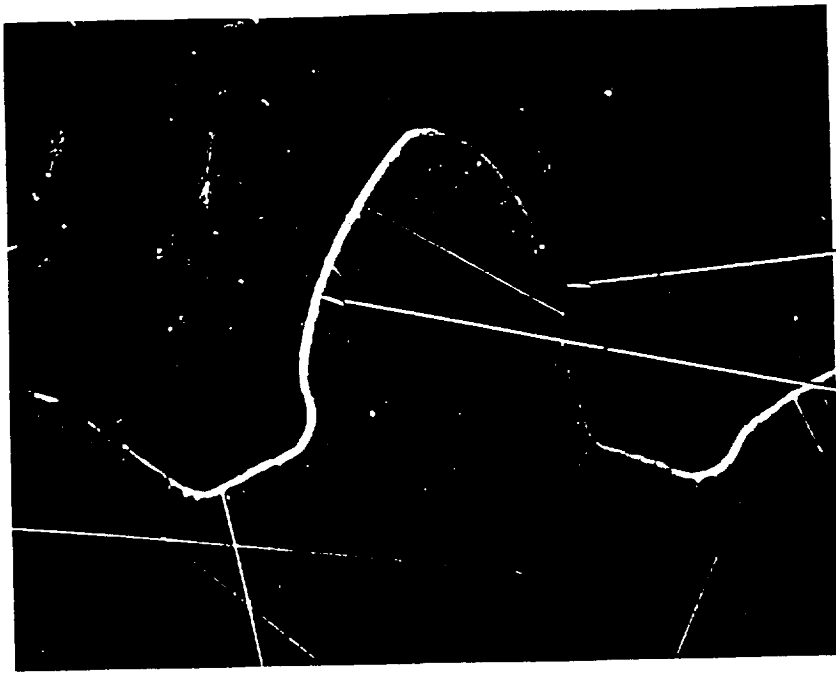


Root (as-borided surface)

Smeared Base Metal

Worn Drive Face

Figure 2: Areas of severe galling and smearing of the base metal.
TOP: SEM photo at 135x near the tip of a tooth on the 718 driven gear.
BOTTOM: SEM photo at 248x near the root of a tooth on the 718 drive gear.



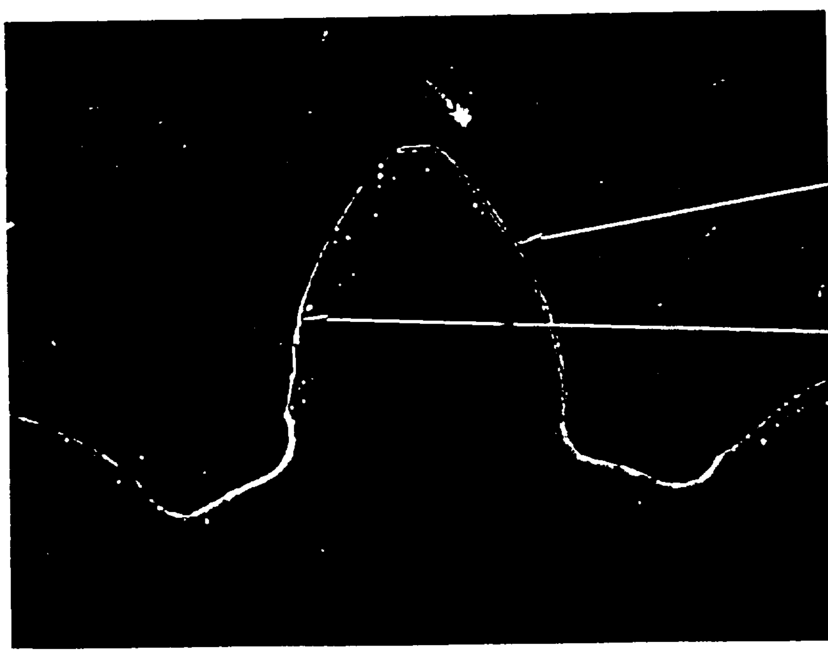
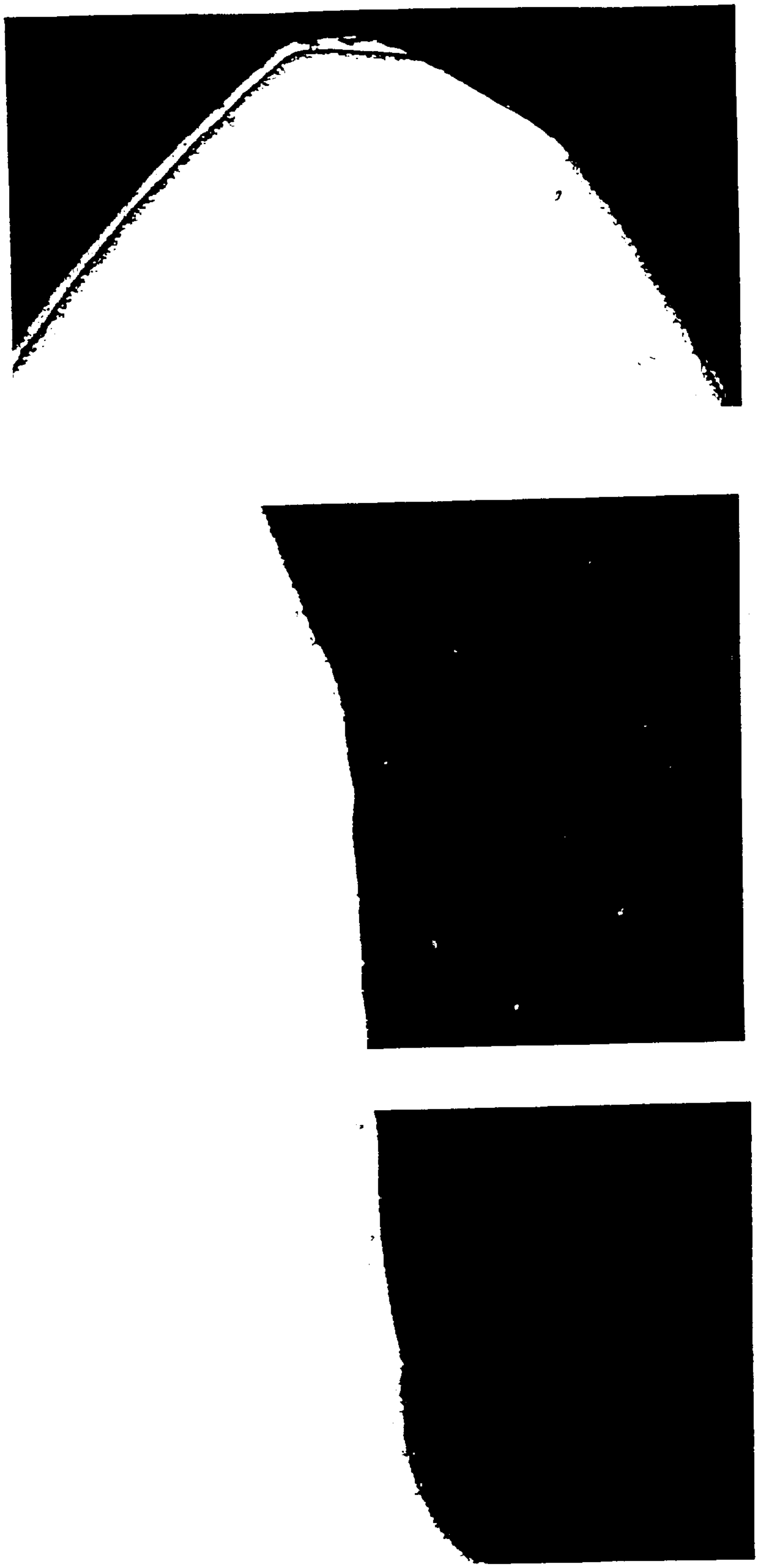


Figure 3: Optical photos at 25x of the metallographic cross-sections of the 718 gears.
TOP: Drive gear. BOTTOM: Driven gear.

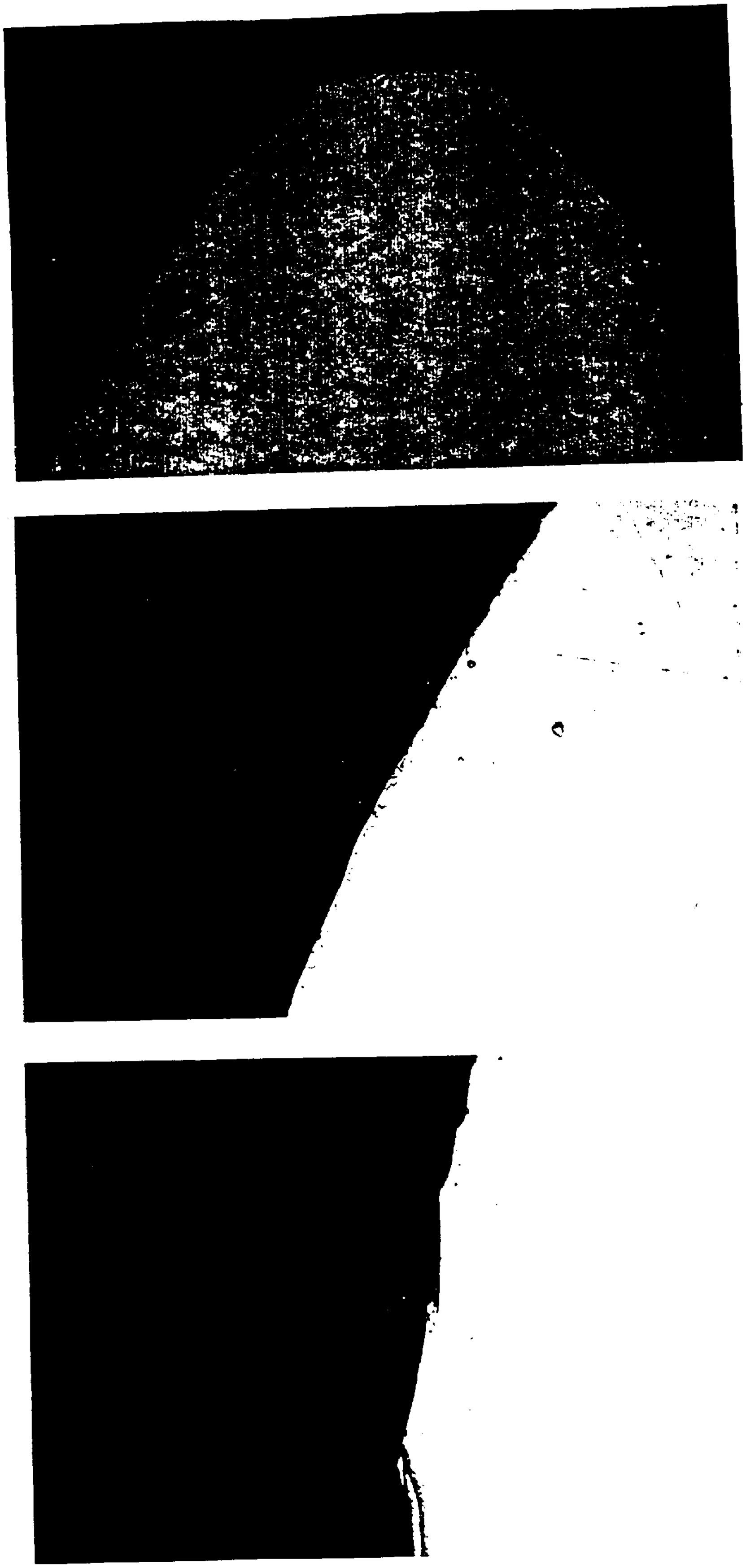


Tip (no evidence of boride on drive face)

Pitch Line (some evidence of boride diffusion zone)

Root (no evidence of boride on drive face)

Figure 4: Optical photos at 100x of the metallographic cross-section of the 718 drive gear showing the drive face of a typical tooth.



Tip (no evidence of boride on drive face)

Pitch Line (evidence of boride diffusion zone)

Root (no evidence of boride on drive face)

Figure 5: Optical photos at 100x of the metallographic cross-section of the 718 driven gear showing the drive face of a typical tooth.

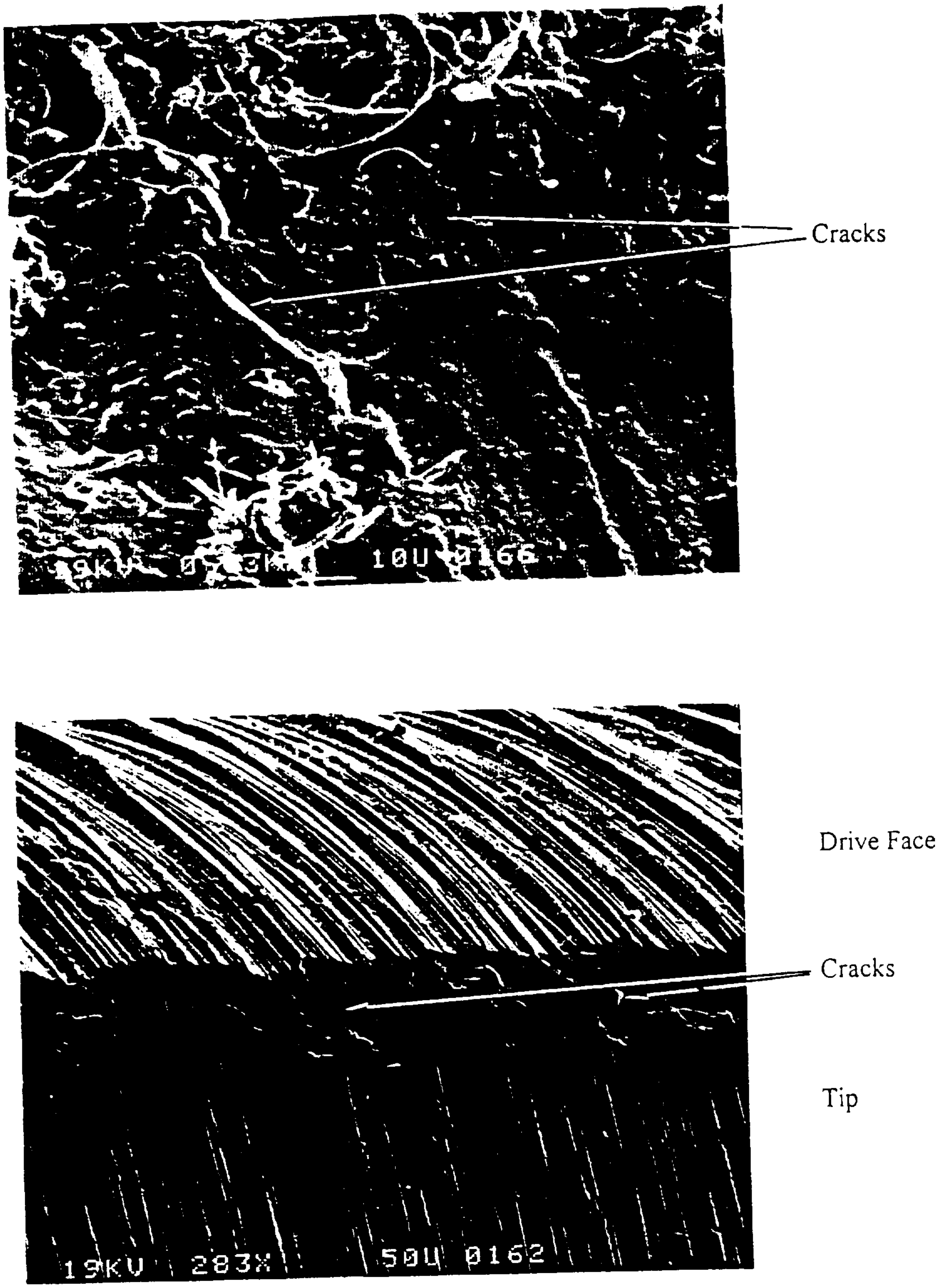


Figure 6: SEM photos showing cracking of the boride layers adjacent to the worn areas on the 718 drive gear.
TOP: 830x near the root of a typical tooth.
BOTTOM: 283x at the tip of a typical tooth.

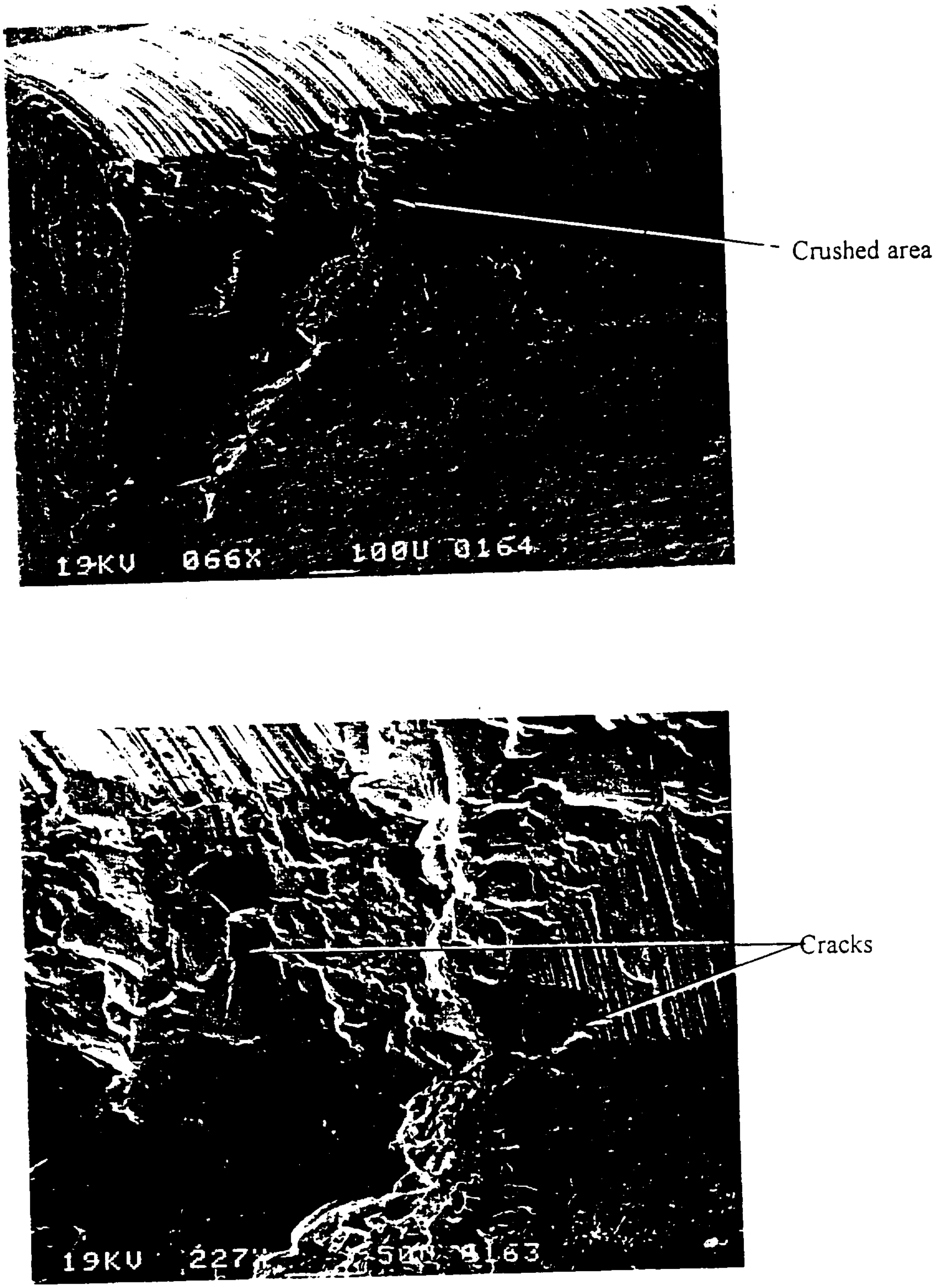


Figure 7: SEM photos at 66x and 227x of an area of the 718 drive gear that was crushed by a vice during sectioning. The cracking present is indicative of the brittle nature of the boride layer.

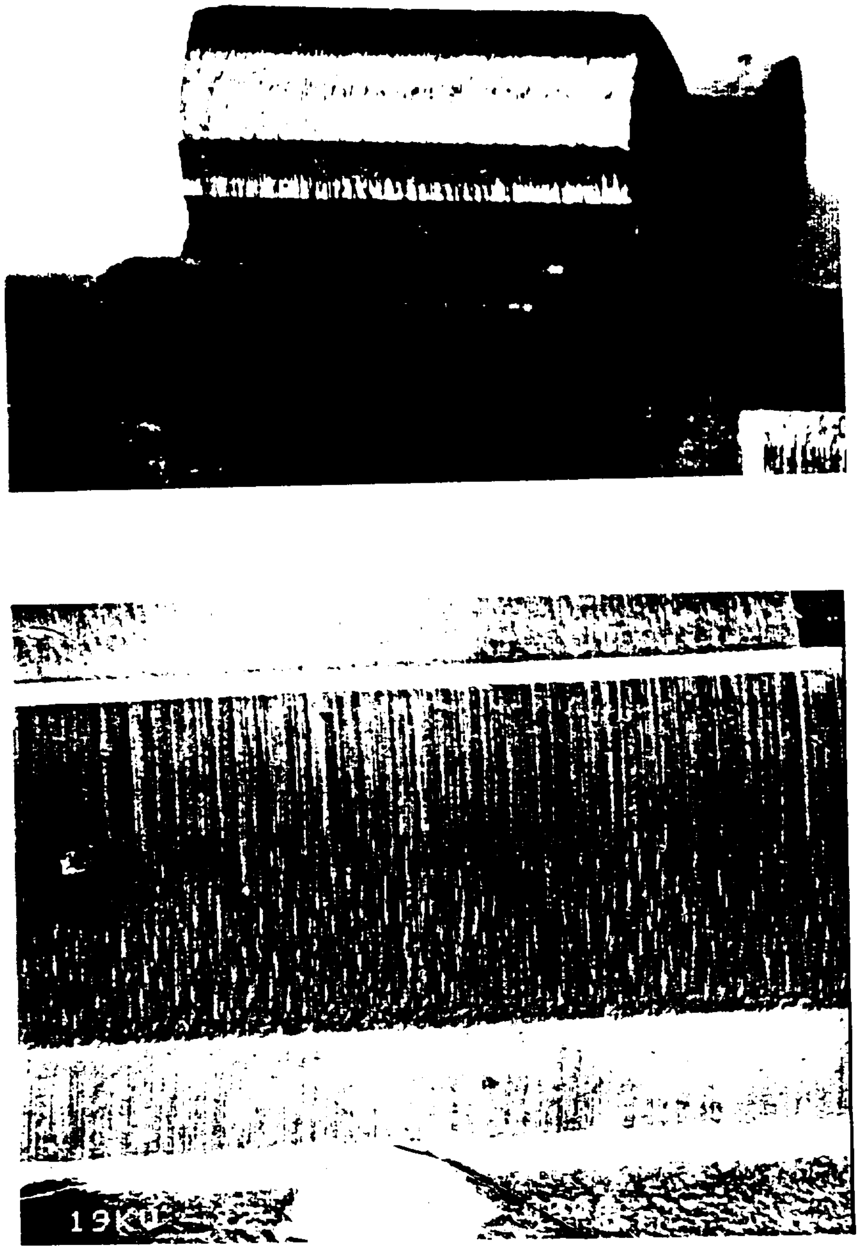


Figure 8: Typical teeth from the 6B drive gear showing significant wear of the drive faces.
TOP: Optical photo at 10x.
BOTTOM: SEM photo at 22.5x.

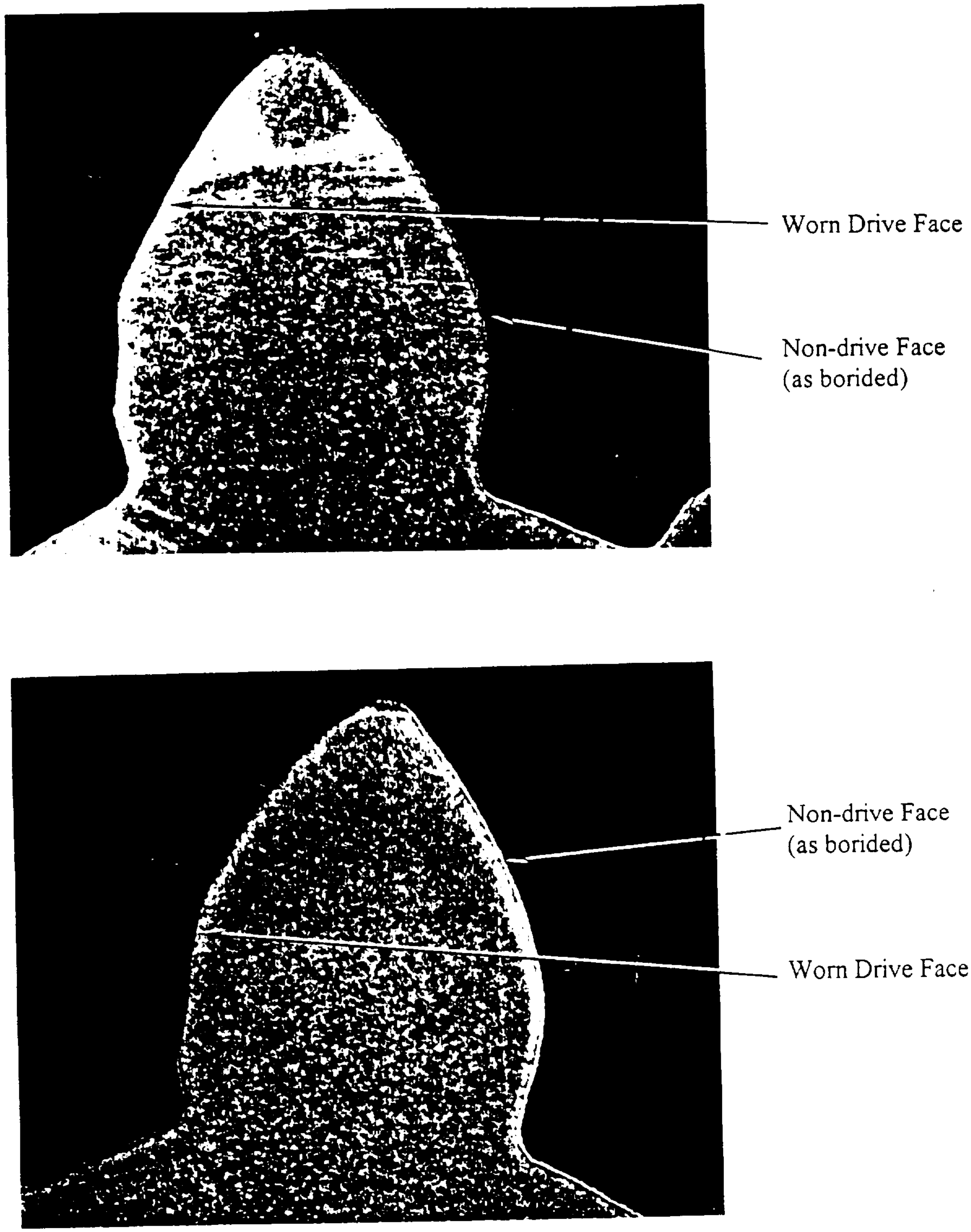
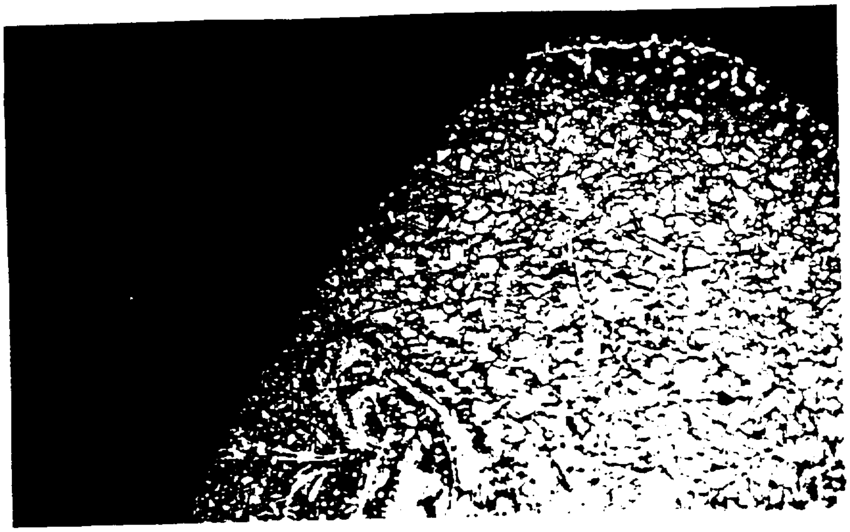
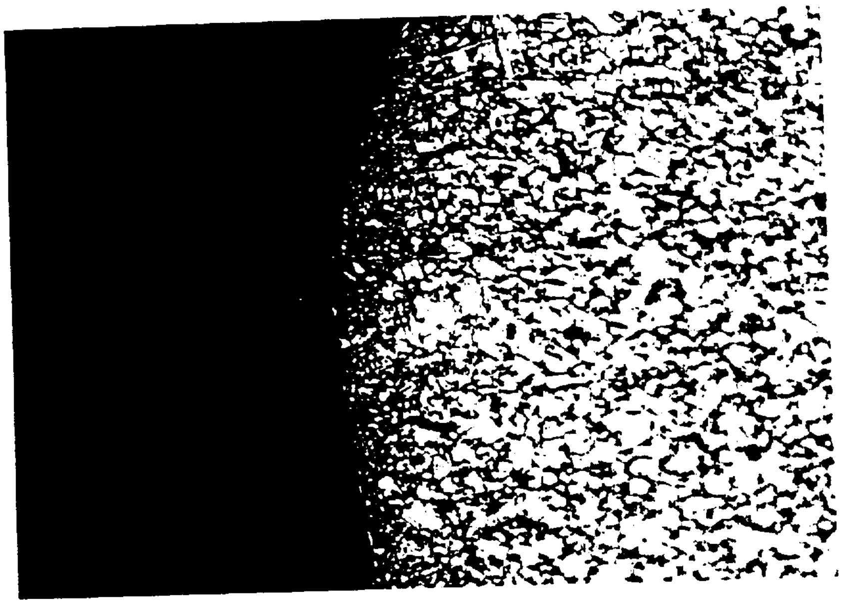


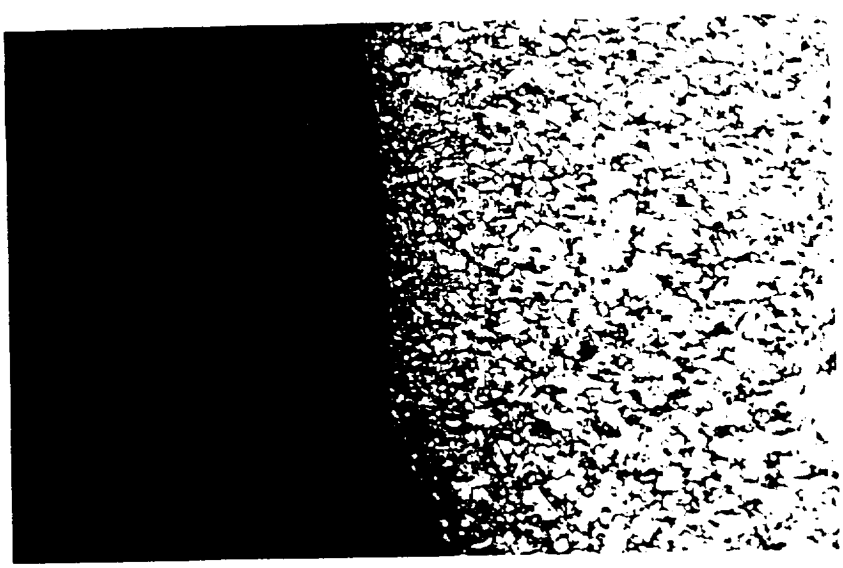
Figure 9: Optical photos at 25x of the metallographic cross-sections of the 6B gears.
TOP: Drive gear. BOTTOM: Driven gear.



Tip (no evidence of boride on drive face)

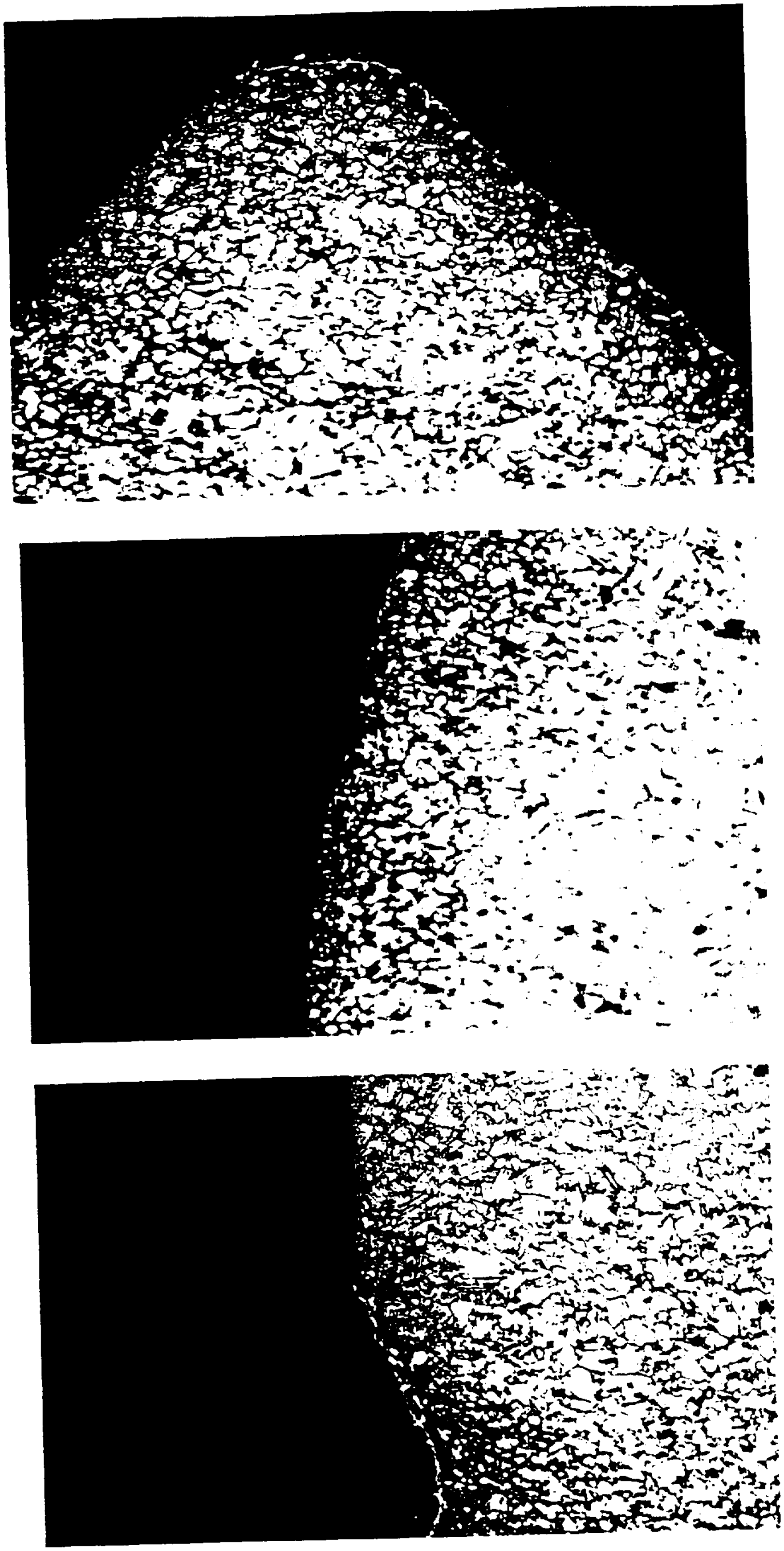


Pitch Line (evidence of boride diffusion zone)



Root (no evidence of boride on drive face)

Figure 10: Optical photos at 100x of the metallographic cross-section of the 6B drive gear showing the drive face of a typical tooth.



Tip (no evidence of boride on drive face)

Pitch Line (evidence of boride diffusion zone)

Root (no evidence of boride on drive face)

Figure 11: Optical photos at 100x of the metallographic cross-section of the 6B driven gear showing the drive face of a typical tooth.

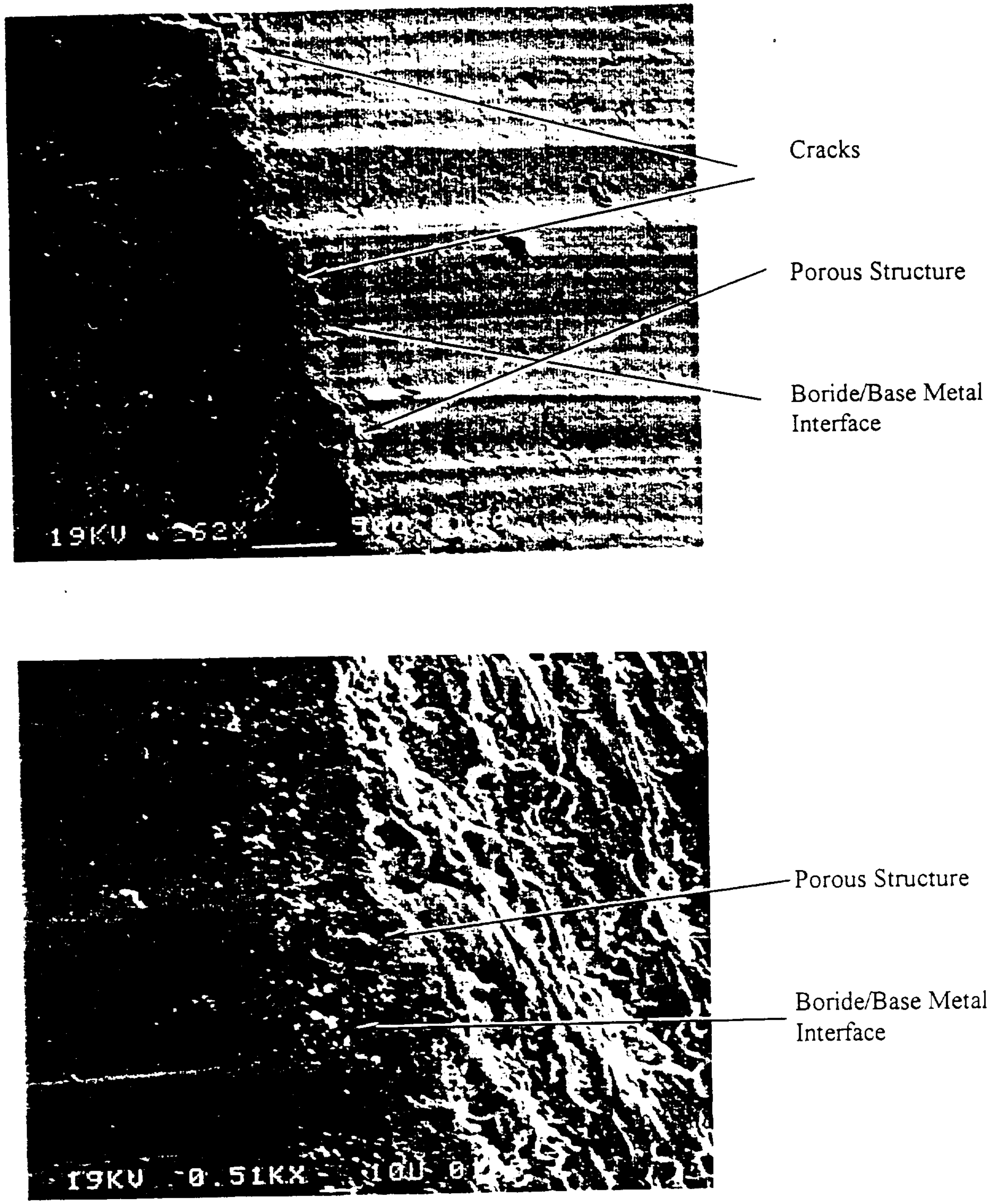


Figure 12: SEM photos of the boride layer adjacent to the worn areas on the 6B drive gear showing cracking, what appears to be a porous structure, and porosity/cracking at the boride/base metal interface.
TOP: 262x near the tip of a typical tooth.
BOTTOM: 510x at the root of a typical tooth.