ELECTROMAGNETIC SHAFT CURRENT PROBLEMS A USERS VIEWPOINT

by

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ABSTRACT

This article covers a user's experience, viewpoint and resolution, with destructive stray shaft currents on a centrifugal split-case design compressor. The compressor is driven by a 33,000 HP 13-stage condensing turbine. Shaft currents have been noted by many rotating equipment users for years and had been mostly associated with wet turbine steam causing a static current. A common type grounding brush, in continuous contact with the shaft, was used to bleed off all excess currents to ground. These brushes generally proved successful where "static" conditions were present. However, at times severe currents were generated causing quick bearing deterioration. The brushes simply could not carry the current away.

Approximately ten years ago, a theory that stray currents could also be generated by high magnetic levels and fields within the equipment itself evolved. Currents generated in this manner were then termed "electromagnetic" in nature. Electromagnetic currents are definitely more destructive than static currents. The tell-tale signs are distinctive from static currents as metal can actually be removed from the shaft, definite erosion (frosting) patterns are set up (Figures 1 and 2), and frosting can and does appear at different locations throughout the machine during the magnetic destructive process. These stray currents have been present on this particular compressor since plant start-up in September of 1971.

Necessary outages, as a direct result of bearing failure, have occurred as frequently as one month and as infrequently as 1½ years. Many paths have been followed in the attempt to resolve the bearing failures prior to implementing the electromagnetic current history. Solutions ranged from installation and modification of current drain brushes, to a total radial bearing redesign by the original equipment manufacturer (OEM). The following represents Northern Petrochemical Company's (NPC) complete history and thrust into the electromagnetic theory and a final resolve.

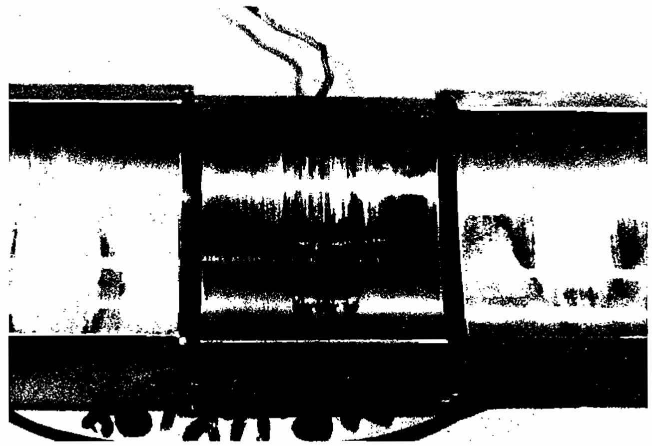


Figure 1. Erosion and Frosting Patterns on the Shaft.

Figure 2. Erosion and Frosting Patterns on the Bearings.

INTRODUCTION

Northern Petrochemical Company constructed a major polyolefins facility in Morris, Illinois and began operation in 1969. The complex consists of an ethylene plant, a low density polyethylene plant, an ethylene oxide/ethylene glycol plant, a polypropylene plant and an oxygen plant. The ethylene plant produces ethylene and propylene which are used in the polyethylene, ethylene oxide/ethylene glycol and propylene plants. The oxygen plant produces the oxygen required to manufacture ethylene oxide.

The ethylene plant began operation in September 1971 with the propylene refrigeration compressor developing bearing problems shortly after start-up with failures continuing until 1979. Although minor etching was observed on the condensing turbine, dramatic failures were experienced on both radial compressor bearings. The original compressor bearings were of the five-pad partial tilt design. One pad was positioned on bottom dead center, while the remaining four were spaced equally around the housing. No thermocouples were used in the pads and the babbitt thickness on each was 15 to 20 mils. Bearing deterioration would reoccur so quickly that shutdown criteria was revised to allow the compressor shaft to drop the total babbitt thickness on each pad. The probe gap voltage was constantly monitored and an outage scheduled after the shaft dropped 20 mils. At times the shaft would stop dropping at 15 mils as the bearing housing would act as a bearing, giving additional load carrying capacity. Runs of this nature would allow longer onstream times; however, they would cause severe shaft damage.

COMPRESSOR HISTORY

The first bearing failure occurred in November of 1971, just two months after start-up. The coupling end compressor bearing was severely damaged and dropped the shaft far enough to rub the bearing housing. Babbitt had precipitated onto the shaft and an etching on the bearing pad was noted. Destruction was so severe that little information as to the failure mode could be noted. No action was taken at this time other than replacing the bearing.

A second failure occurred in April of 1972. The vibration readings steadily increased after the November 1971 start-up, reaching a 10 mil peak-to-peak displacement. The compressor was shutdown and both bearing pads were severely wiped, as well as the shaft journals; thus, the rotor and bearings were replaced. A special note must be mentioned at this time. Both compressor rotors experienced rubs while initial compressor test runs were conducted at the OEM. (The electromagnetic theory revolves around the alignment of magnetic fields caused by the rub or "wipe".)

The third bearing failure occurred in May of 1972, just one month later. Once again, inspection of this failure showed the compressor coupling end bearing severely wiped and the outboard journal bearing pitted. Also, babbitt was transplanted onto the compressor shaft. The turbine bearings were also inspected and for the first time showed an electroprecipitation with only slight damage. During this outage, a grounding brush system was installed on each outboard end of both the compressor and turbine. The brush was of the spark plug variety and designed to carry the shaft currents to ground. An ammeter was also installed to measure the current. Finally, the oil supply holes were enlarged to allow additional oil supply into the housing. Once again the failures were so severe that an actual failure mode could not be established.

The ethylene plant was shutdown in November of 1972. Other plant related repairs were necessary; however, the compressor bearings were inspected and no damage was found. The machine began to show a continual slow drop on the compressor coupling end shaft shortly after November of 1972. The shaft dropped 16 mils; however, actual peak-to-peak vibration, as indicated by vibration monitors, had steadily decreased. The additional bearing surface actually helped stabilize the rotor. However, the 16 mil drop prompted another shutdown in November of 1973 and the resultant inspection revealed the following:

1. The bottom center compressor bearing pad was wiped severely.
2. Both side pads were also wiped and electroprecipitation was observed since these pads did not see severe damage.
3. The two upper half bearing pads, although never touching, showed strong signs of electroprecipitation on the trailing edge.
4. Strong evidence of electroprecipitation was noted on approximately 1/3 of each active thrust pad. The electrical effect caused the bearing surface to appear like 600 grit emery cloth and dark gray in color. All trailing edges of these pads showed electroprecipitation.
5. The turbine radial bearings were in good condition; however, the active and inactive thrust bearing pads showed minor signs of electroprecipitation (frosting).

Shutdowns similar to those described above were required throughout 1976 with all failure characteristics being similar. The program, now set forth by NPC, would attack the problem in two directions:

1. Redesign an improved grounding system.
2. Redesign the compressor bearing.

These efforts were directed at the OEM, by outside consultants, and by our own personnel. However, the end results did not change.

REDEFINING THE PROBLEM

A bearing redesign, one which could give additional load carrying capacity, constantly reappeared as our best possible solution. In October of 1977 another bearing manufacturer was contacted to supply a different bearing. The manufacturer designed a bearing with 30% additional load carrying capacity and added misalignment capabilities by the way of a total movement pad. The off-set pivot ball and socket design, with five pads, was used. Also, a babbit thickness of only five mils was used which was much different from our past experiences. Thermocouples were also made available on the bottom pad, which were also not previously used.

The first bearing of this design was installed on the compressor coupling end in November of 1977 and ran exceptionally well and was inspected in May of 1978. A scheduled outage had occurred allowing a complete inspection. No damage was noted except for a "shiner" on the bottom pad. A "shiner" is caused by a too slow turning gear speed, resulting in a minor wipe. During this outage, the outboard bearing (combination thrust and journal) was also installed. This redesigned bearing, with only five miles of babbitt, had obviously changed our shutdown criteria. The voltage was continously very closely monitored and signs of bearing wear were looked for. More importantly, bearing temperatures were also carefully monitored and were found to remain stable, ranging from 120°F to 130°F. Ambient effects on the monitor proximeters had to be adjusted since only small probe voltage changes (indicating shaft drop) could be tolerated with a one volt deviation necessitating an outage. Graphs were generated showing temperature effects on the proximeter and how they were related to voltage swings.

A momentary oil loss occurred to the compressor in November of 1978. Thrust temperatures increased to 200°F to 210°F, indicating a bearing wipe. The compressor was, once again, shutdown; however, only the thrust bearing active pads showed any damage. Only these pads were replaced and the machine was quickly placed back on-line. The thrust disc, although not damaged, had obviously experienced some rubbing action. Although the thrust failure occurred, it was unrelated to the previous problems. It was felt that the original problem may be gone. One month later, in December of 1978, the suction end bearing voltage reading indicated a drop of four mils. The decision was made to shutdown and replace both journal bearings. When manually tripped, the compressor bearing temperature instantly climbed to 360°F. Table 1 details the inspection results. Strong evidence of electroprecipi-

TABLE 1. COMPRESSOR BEARING APPEARANCE — 12/30/78 FAILURE

SUCTION END (FIGURE 1)

1. Bottom Pad
   - A. Bronze was exposed on the pad from the middle of the pad to the trailing edge.
   - B. There was a melt/wipe in the center of the pad starting ¼ in. from the leading edge to the center of the pad. It was 1 in. wide.
   - C. There was some babbitt in the center of the pad in the wiped bronze area. It was smeared in a 1 in. by 1 in. area.
   - D. The babbitt was smoothly worn and tapered into the exposed bronze area.
2. Trailing Side Pad
   - A. There was a melt/wipe starting 1 in. in from the leading edge all the way to the trailing edge of the pad. It was 1 in. wide and centered in the middle of the pad.
   - B. The trailing edge of the pad was pitted.
3. Trailing — Top Pad
   - A. The pad was pitted on both sides. It was ⅜ in. wide starting at the leading edge and tapered to ⅛ in. at the trailing edge.
   - B. There was pitting in the socket.
4. Leading — Top Pad
   - A. The pad was pitted on both sides. It was ¼ in. wide starting at the leading edge of the pad and increased to ½ at the trailing edge.
5. Leading Side Pad
   - A. Bronze was exposed on the pad from the middle of the pad to the trailing edge all across the pad.
   - B. The babbitt was pitted. It was smoothly worn and tapered into the exposed bronze area.
   - C. There was a babbit smear ½ in. wide and 1 in. long starting at the center of the pad and going toward the trailing edge.

DISCHARGE END

1. Bottom Pad
   - A. Bronze was exposed on the pad from the middle of the pad to the trailing edge all across the pad.
   - B. The babbitt was pitted.
   - C. The babbitt area was smoothly worn and tapered into the exposed bronze area.It started to taper ¼ in. in from the leading edge.
2. Trailing Side Pad
   - A. No wiping on the pad.
   - B. Pitting was all across the pad from the trailing edge forward ¾ in.
3. Trailing Top Pad
   - A. No wiping on the pad.
   - B. Pitting was all across the pad from the trailing edge forward 1 in.
4. Leading Top Pad
   - A. Good condition.
5. Leading Side Pad
   - B. There was slight pitting across the pad from the trailing edge forward ⅜ in.

tation was once again noted and the compressor shaft showed the identical signs. One month later, January of 1979, the exact situation reappeared. Table 2 details the inspection during this outage. The grounding system obviously was not adequate.

The previous year's experience with the redesigned bearings proved successful. However, due to the rapid deterioration, the bearing manufacturer was called in to assist in troubleshooting. The following potential causes were discussed.

Bearing Lube Oil Loss

The high bearing temperature could have been due to a loss of lube oil. For the December 30, 1978 failure, when the suction end bearing reached 360°F, the lube oil pressure would have had to fall to 3 to 5 psig. During the December 30, 1978 and January 29, 1979 failures, no low lube oil pressure alarms occurred and the auxiliary lube oil pump did not start. This would indicate that the lube oil pressure did not fall, so there should have been sufficient oil pressure at the bearings.

Abnormally High Bearing Load

The high bearing temperature could have been due to an abnormally high downward bearing load on shutdown. The bearing on the coupling end did not indicate this problem. (See Table 3 for a description of its condition.) A process modification was made, but was eliminated as a potential source since the first bearing ran from November 1977 until September 1978 and underwent several shutdowns with no problems. The newer bearings, installed in September 1978, ran until November 1978 and also underwent several shutdowns with no problems.

TABLE 2
COMPRESSOR BEARING APPEARANCE — 1/29/79 FAILURE

SUCTION END

1. Bottom Pad
   A. Bronze was exposed on the pad from the middle of the pad to the trailing edge all across the pad.
   B. There was pitting on the sides.
   C. The babbitt was smoothly worn and tapered to the bronze area.
   D. There was a wipe.
2. Trailing Side Pad
   A. The last half of the pad from the middle of the pad to the trailing edge was pitted.
   B. The babitt in the center was smeared across the bearing 1 in. wide.
3. Trailing Top Pad
   A. There was slight pitting on trailing edge of the bearing 1 in. forward.
4. Leading Top Pad
   A. There was slight pitting on the trailing edge of the bearing 1½ in. forward.
5. Leading Side Pad
   A. There was severe pitting on the last half of the pad from the center to the trailing edge.
   B. There was a babbitt smear on the last half of the pad across the bearing.

DISCHARGE END

1. Bottom Pad
   A. Bronze was exposed on the pad from the middle of the pad to the trailing edge all across the pad.
   B. Slight pitting was present ½ in. in from the leading edge to the center.
   C. The babbitt was smoothly worn and tapered to the bronze area.
2. Trailing Side Pad
   A. Slightly pitted.
   B. Slightly shiny at trailing edge.
3. Trailing Top Pad
   A. Slightly pitted.
   B. Slightly shiny at trailing edge.
4. Leading Top Pad
   A. One scratch ½ in. in from side — no bronze was exposed.
   B. Slightly pitted.
   C. Slightly shiny at trailng edge.
5. Leading Side Pad
   A. Slightly pitted.
   B. Some small shiny spots.

TABLE 3
COMPRESSOR BEARING APPEARANCE

DISCHARGE END — NOVEMBER 1977 TO MAY 1978

1. Bottom End
   A. Shiny spot in the center 1 in. wide x 1½ in. long.

Turning Gear

The turning gear rotates at 10 RPM. According to the bearing OEM calculations, the following oil film thickness for the compressor should occur at these respective speeds:

Speed (RPM)	Oil Film Thickness (mils)
4000	1.4
3000	1.2
2000	0.9
1000	6.0
500	0.45
10	0.001

It was felt that the 10 RPM speed did not permit a sufficient oil film to be built up to protect the bearing. The bearing, with a slow turning gear, should have a shiny spot in the center of the pad. The bearing coupling end that ran from November 1977 to September 1978 was run using the turning gear for start-up and shutdown. It exhibited this "shiny" spot in the center of the pad (Table 3). However, it did not wipe to expose any of the bronze, and the bottom bearing pad temperature did not spike upward on any shutdown. This does not appear to be the cause of the two recent failures. A minimum of 25 RPM and a preferred 30 to 40 RPM was recommended.

Electrostatic/Electromagnetic Current Generation

When the bearings were removed in the December 30th failure, pitting on the bearing surface was seen. This was thought to be due to electrostatic precipitation of the babbitt on the shaft, since the grounding brushes were not worn or were not in contact with the shaft. This situation was corrected at that time. When the bearings were removed after the January 29th failure, pitting on the bearing surface was observed again. The grounding brushes were worn, which indicated that they were in good contact with the shaft. After observing this, the bearing manufacturer representatives recommended a consultant be contacted on shaft current generation. After describing over the phone the bearing appearances and circumstances, the consultant indicated the pitting seen appeared to be a classical case of electromagnetic precipitation. This was caused by a portion of the rotor being magnetized due to a rub, grinding, or some other similar cause, and it generated an AC current rather than the DC current of electrostatic currents. It could not be effectively eliminated by grounding brushes. The thrust bearing failure (November 1978) could have been the source.

Bearing Pad Arc Change

If there is a loss of babbitt material on-line due to electromagnetic precipitation, the babbitt removed first would be that closest to the shaft or the trailing edge of the bottom pad. It would start at the bottom pad at the trailing edge and remove babbitt uniformly across the bearing and gradually work its way to the leading edge of the bearing (Figure 1). As it progresses along, it will change the arc of the bearing pad because it is removing babbitt material at the trailing edge but not the leading edge. This can lead to at least three bad situations:

Change in Bearing Pad Effective Surface Area

As the babbitt is removed and the arc of the pad changes, the effective bearing surface area can decrease. This is because the portion of the bearing pad on the leading edge, that is not pitted yet, may not have a compatible radius to carry any of the load. Since there appeared to be a loading problem on the OEM bearings prior to the newer bearings, it may not take much bearing rea reduction to cause problems.

Change in Pivot Off-set

As the babbitt is removed and the arc of the pad changes, the pivot off-set can change. This can lead to a negative preload characteristic in which the loading edge of the bearing is trying to dig into the shaft rather than lean away. This can prevent a proper oil film from building up on the bearing and lead to a failure.

Similar Bearing and Shaft Radius

As the babbitt is removed and the arc of the pad changes, the radius of the bearing can approach the radius of the shaft. This would be due to uniform babbitt removal at equal distances from the shaft. If this occurs, it can prevent a proper oil film from building up on the bearing pad and lead to a failure.

It has also been shown that a sudden bearing failure can occur when sufficient electromagnetic damage has been done. A progressive failure, as was experienced, will increase the temperature until a certain amount of damage has occurred, at which time a drastic failure could occur. Also, noncontacting probes have had erroneous readings due to electromagnetic precipitation.

CORRECTIVE ACTION PLAN

Northern Petrochemical set out with the following corrective action plans.

1. Get the electromagnetic current consultant to help diagnose and verify the problem.
2. Recheck the effect on compressor loading from recent process revisions.
3. Calculate the babbitt removal and pad arc change necessary to cause bearing problems.
4. Add more thermocouples on the compressor bearings:
   a. between bottom pads
   b. one each in two side pads
5. Hook-up a pressure recorder on the lube oil supply at the low pressure lube oil switch.
6. Modify procedures to use the turning gear on a very limited basis and investigate speeding up the turning gear to 25 RPM.

A time table of six months was set up to implement this program since a major scheduled ethylene plant outage was set for September of 1979.

Although the direction had been set and the main concentration would focus on the electromagnetic theory, the practical approach was far from being realized. Many ideas and approaches had previously circulated, but actual results throughout the industry were limited.

The consultants visited the Morris Complex to inspect the machine and the failed bearings. It was stated that the area of electromagnetically generated currents in rotating equipment is an art just beginning to evolve. Actions could be recommended, but the results could not be predicted. The following recommendations were made:

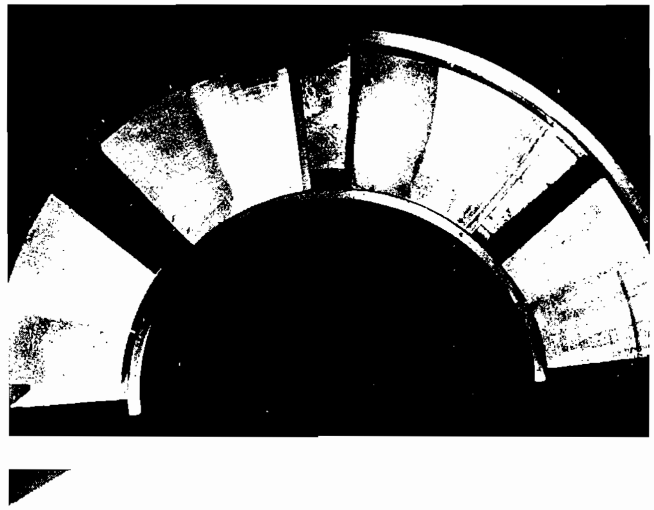
1. The initial rubs on both rotors during testing at the OEM could have initiated the action.
2. Residual magnetism had continued to increase over the life of the compressor.
3. Damage had been minimized, but not halted, by the first addition of shaft brushes.
4. Electromagnetic effects were reduced again by the insertion of non-magnetic bearing pads.
5. The overpowering buildup of the magnetic field continued despite these measures.
6. Surge of mechanical shocks (rubs) to the system had occurred causing damage. Inspection of the thrust disc that was in service during the thrust bearing failure on November 1978 showed high levels of magnetism (12 gauss). All gauss levels should be three or below.
7. It was recommended that the unit be thoroughly demagnetized and/or improved design grounding brushes be added next to each journal bearing.
8. Continually monitor brush currents even after demagnetizing had occurred.

9. Demagnetize the entire unit (case and rotor) in segments.
10. Contact other users to share experiences and possible solutions.

Immediate steps were taken to purchase grounding brushes and finalize plans to demagnetize the rotor.

ACTUAL MEASUREMENT AND DEGAUSSING PROCEDURE

The unit was entirely disassembled in September of 1979. Magnetic levels were measured prior to any degaussing on both turbine and compressor cases and component parts. Levels ranged from 3 to 36 gauss, with the compressor showing consistently higher readings. Also, all component parts were inspected for electromagnetic current damage. Figures 3 to 6 reveal similar damage patterns as experienced previously; however, they were not to the point where failure was imminent since the damage had also spread to the turbine.



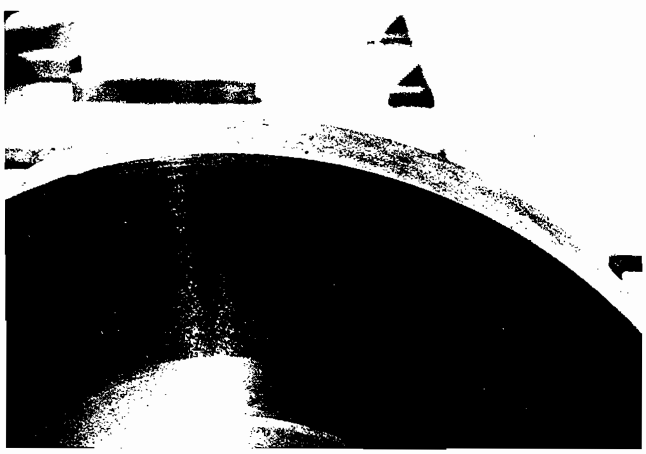


Figure 3. Turbine Thrust Disc Showing Typical Frosting.

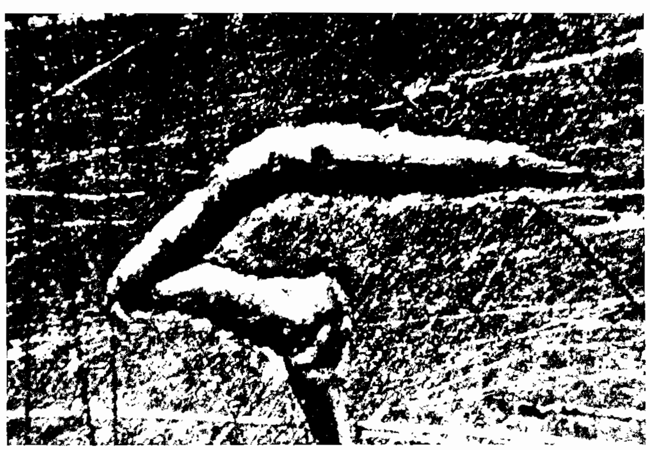


Figure 4. A Bearing Pad 100X Showing a Typical Spark Track.

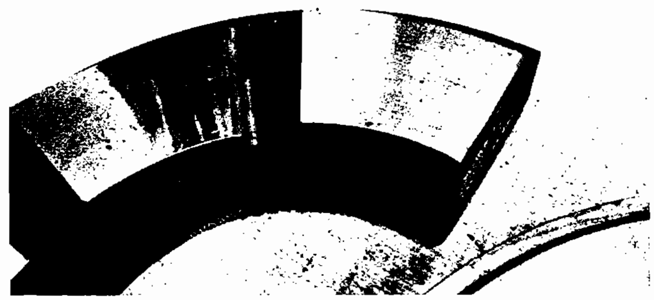


Figure 5. Turbine Thrust Pads Showing Frosting on ½ of All Pads. Pad babbitt deterioration begins on the trailing edge.

Demagnetizing the unit was accomplished in two days and done in parts, with parts being separated into the smallest component. The procedure used to demagnetize the unit was to measure the magnetism at each point on the unit and then reduce it by an opposing magnetic field. The magnetic survey was done by means of a gaussmeter probe, thus locating spots of high magnetic levels. Efforts were made to reduce magnetic levels as low as two gauss, especially in parts adjacent to the rotor bearings and seal surfaces. The actual magnetic levels were reduced to two gauss or less on rotor and bearing areas. The bearing housings, interstage components and diaphragms were demagnetized to less than five gauss (usually less than three gauss, while casings and piping were degaussed to less than 15, and usually 6, gauss. All units were reassembled and the grounding brushes were installed. Voltage readings on each brush (Figure 7) would be taken bi-monthly so any trends could easily be observed.

RESULTS

The propylene compressor and turbine resumed operation in late September 1979. Continual monitoring of the amperage off the brushes ranged from 0.03 to 0.8 amps. Since start-up, no bearing failures have occurred and the bearing temperatures have all remained stable (120°F to 130°F), with no drop in the shaft being noted. Two years of running have elapsed and a major plant outage is scheduled in September of 1981, during which detailed inspections shall be made. Plans

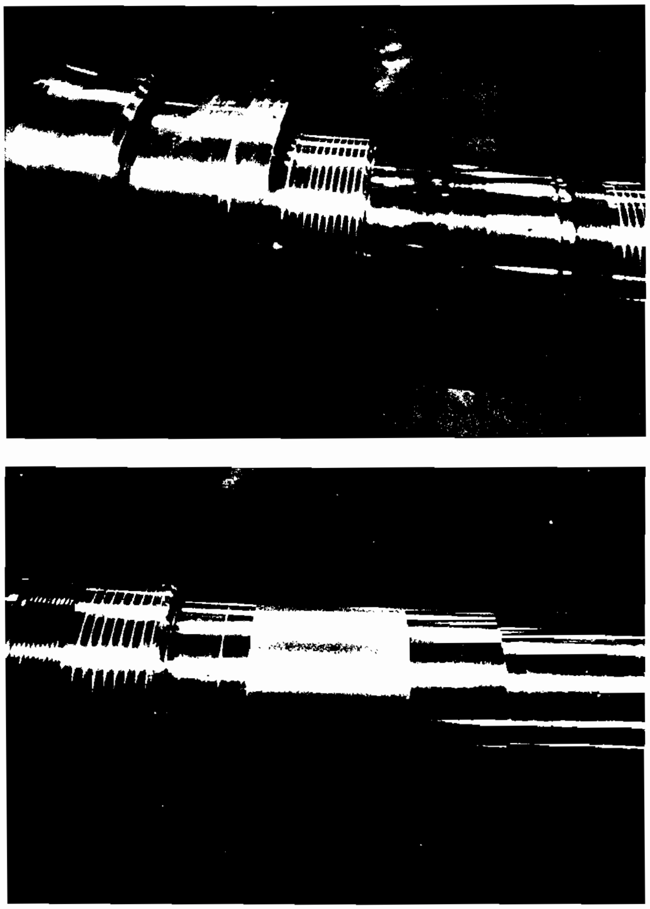


Figure 6. Typical Frosting on the Shaft.

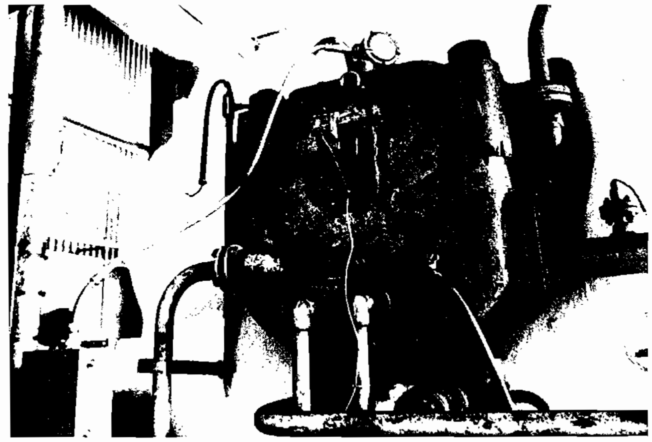


Figure 7. Voltage Measurement on Brushes.

are to resurvey the machine's magnetic levels, and depending upon the findings, the decision will be made whether or not to degauss. All rotating spare parts have been checked and degaussed to levels below two gauss.

CONCLUSIONS

NPC had experienced severe damage and short compressor run length since operation began. The problem is felt to be directly related to electromagnetic currents which are much stronger than the sister static currents. Damage was much more severe and quicker. It was felt that the proper approach was a total degauss and were very skeptical of partial degaussing methods due to other users' experiences. The problem which once caused outages every other month has been arrested and the results are a two-year run period without failure. Plans are to resurvey the magnetic levels each time the compressor is open and at that time decide whether additional degaussing is needed. Since experience is limited, it is felt that the problem could easily reoccur and will be guarded against in future actions.

It is quite critical that preventive maintenance programs be set up to measure and compare magnetic levels on all equipment. Magnetic levels could easily build, causing downstream problems. Parts which have experienced rubs should especially be suspect and magnetic levels checked.

ACKNOWLEDGEMENTS

Although I feel privileged to present this paper, many Northern Petrochemical Company plant personnel contributed greatly to initial plans and actual implementation. Success was realized through total commitment and a team atmosphere. We are also indebted to Mr. John Sohre, Mr. Paul Nippes and Centritech Corporation for their ideas, consulting and recommendations. We feel this assistance has led to a final resolve of our continual compressor bearing failures.

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