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A CASE STUDY ON ROTOR DAMAGE DUE TO ELECTROMAGNETIC SHAFT CURRENTS AND SUBSEQUENT COUPLING INSTALLATION PROBLEMS FACED ON SYNTHESIS GAS COMPRESSOR OF AN AMMONIA PLANT

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Abstract

Excessive stray currents in the high-speed turbo machinery lead to catastrophic failure of the equipment. This is a fact known to the engineers long since. Unsafe conditions are generated as a result of such incidents if the actions are not taken in time. This paper describes an incident which resulted in to heavy damage to the high pressure steam turbine rotor of synthesis gas compressor of ammonia plant although the grounding brushes were installed and the plant personnel were aware of the phenomenon and all care was being taken to avoid induction of any magnetizing force during maintenance actions. Subsequent experience on the assembly trouble during coupling installation on the new rotor shaft, detailed investigation and systematic approach to rectify the discrepancies and coming out with the reliable and practical solution was the need of the time which was met by all round efforts of the plant personnel. The actions taken to overcome the typical maintenance problem faced during the assembly are also narrated in this article.

Introduction

IFFCO, Kalol unit is one of the best maintained, 28 year old Ammonia-Urea manufacturing complex with a capacity of 1100 MTPD ammonia and 1650 MTPD urea. The ammonia plant process is based on M.W.Kellogg steam reforming process. The process employs four important high speed compressor trains viz. air compressor, synthesis gas compressor, refrigeration compressor and a pair of natural gas booster compressor units. The failure was faced in the Synthesis gas compressor drive turbine, which is discussed in this paper.

Synthesis Gas Compressor Train

The synthesis gas compressor train consists of a barrel type LP and HP compressor cases driven by two turbines running in tandem, one out of which is a back pressure turbine and the other one is a condensing turbine. The machine train diagram is shown at Figure 1.

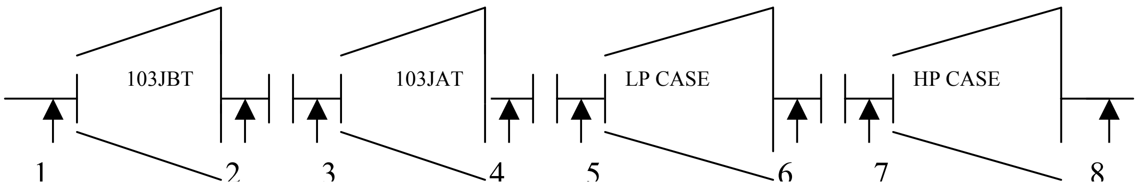

Figure 1: Machine Train Diagram

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The operating parameters, design specifications and relevant details of the back pressure drive turbine, 103JAT which suffered the damage are described below:

1. Manufacturer: Demag Delaval, USA
2. Year of commissioning: Jan, 1974
3. Number of stages:2
4. Inlet steam pressure: 105.4 Kg/cm2g
5. Exhaust steam pressure: 38.3 Kg/cm2g
6. Normal operating steam flow: 275000 Kg/h
7. Normal BHP/KW: 14800 BHP
8. Normal operating speed: 10348 RPM
9. Critical speed: 6700 RPM
10. Lubrication: light turbine oil, rust and oxidation inhibited
11. Journal bearing type: babbittlined, multiple tilting pad type
12. Thrust bearing type :Kingsbury (segmental type) thrust bearing

The turbine is equipped with a non-contact shaft vibration surveillance system series 7200 and the data analyzing software DM2K supplied by Bently Nevada, USA. The trip system is confined to the axial position of the shaft only and the radial vibration levels are not connected to the trip logic. The higher lube oil temperature conditions are also not defined for trip.

The Incident

Just before the incident, the plant was operating normally. The lubricating oil temperature for the steam exhaust end bearing at point No. 4 suddenly crossed the alarm level of 80 deg C. The normal operating lube oil temperature was 68 deg C. On observing the alarm, the oil flow to the bearing was checked by the operator through gauge glass in the field. It was found normal and action was taken to verify the temperature on the local gauge installed on the pipeline.

The field temperature gauge was also showing high temperature, which was continuously increasing. By this time the vibration levels on the non contact vibration surveillance system increased to 2.27 mils from normal level of 0.8 mils on exhaust end bearing with heavy fluctuations on the display monitor for both the journal bearings of the turbine.

The vibration levels further increased beyond 5 mils (scale limit) when the decision was taken to shutdown the unit. At that time, the temperature of the lube oil went as high as 98.2 deg C, which clearly indicated the damage to the bearings.

There was abnormal sound heard from the turbine, which supported the prediction. Just before the train was shutdown, housing vibration levels were also measured using the accelerometer and a portable vibration analyzer, which showed the peak velocity levels as high as 15 mm/sec in radial mode.

The lube oil temperature and the high radial vibration parameters were not defined for the tripping of the machine. It is worth to be mentioned that the pre-reformer section of the plant was tripped just before the incident due to which there was impact on the steam flow through the HP turbine. The lube oil temperature in the exhaust end bearing drain started increasing soon after the tripping of Pre-reformer Section.

Observations

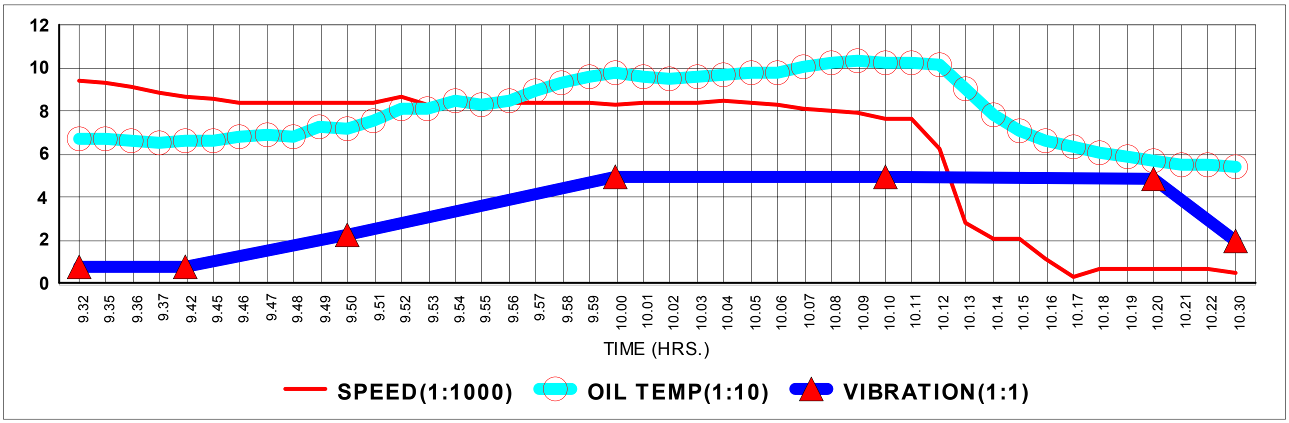
The turbine bearings were inspected immediately on shutdown. The exhaust end bearing was found badly damaged causing total loss of white metal lining. The shaft surface on the journal area was observed to have 1 mm to 1.5 mm deep scores due to heavy friction. The bearing at the other end showed little rubbing marks.

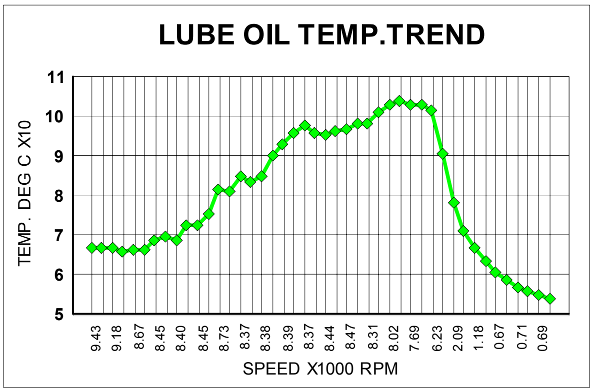
Subsequently the turbine casing was dismantled and the rotor assembly was taken out for inspection. No appreciable damage was observed to the thrust bearing located at the steam inlet end as well as on the thrust collar. However all the labyrinth seals were found badly rubbed out.

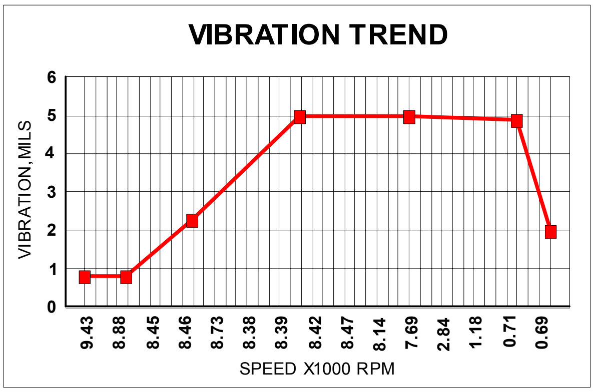
The three critical parameters viz. speed, lube oil temperature and the vibration levels on the steam exhaust end bearing, just before the incident and during the process of shutdown were recorded and these are given at the Table-1 below. Graph 1 shows the multiple variable trends for the parameters viz. Speed, vibration amplitudes and lube oil temperatures. The Graph 2 (Speed vs. Oil Temperature) and Graph 3 (Speed vs. Vibration) show the individual trends.

Table-1: Speed, vibration and lube oil temperature data.

Time	Speed RPM	Exhaust end Bearing oil, Temperature, Deg C	Vibration levels On Exhaust end Bearing, mils	Remarks
9.32	9430	67	0.81	
9.35	9320	67		
9.36	9182	66.7		Pre-reformer Section tripped Speed came down.
9.37	8884	66		
9.42	8667	66.3	0.81	Speed reduced by 500 rpm from normal.
9.45	8562	66.4		
9.46	8449	68.6		
9.47	8438	69.6		
9.48	8401	68.8		
9.49	8462	72.6		
9.50	8448	72.5	2.27	
9.51	8395	75.7		
9.52	8373	81.6		Oil temperature exceeded alarm level.
9.53	8364	81.3		
9.54	8373	85		
9.55	8381	83.4		
9.56	8375	84.8		
9.57	8378	90.2		
9.58	8385	93.2		
9.59	8389	95.9		
10.00	8367	97.8	5.0	
10.01	8421	95.9		
10.02	8442	95.5		
10.03	8416	96.6		
10.04	8467	96.9		
10.05	8441	98.2		Compressor train stopped
10.06	8307	98.4		
10.07	8135	101.2		
10.08	8018	103.1		
10.09	7930	103.9		
10.10	7693	103	5.0	
10.11	7628	103.2		
10.12	6234	101.8		
10.13	2844	90.5		
10.14	2091	78.3		
10.15	2116	71		
10.16	1180	66.9		
10.17	354	63.6		
10.18	665	60.7		
10.19	710	58.8		
10.20	714	57	4.89	
10.21	710	55.8		
10.22	690	54.9		
10.30	500	54.0	1.97	







Recent Maintenance History

The existing rotor of the turbine was in operation since January 1995. The bearings of the HP turbine were inspected during the planned turnaround about a month ago. At that time the bearing clearances were measured and the same were found within OEM recommended value for the inlet end bearing whereas there was increased clearance in case of exhaust end bearing i.e. 0.30 mm against 0.15 to 0.20mm (6 to 8 thou) recommended by OEM. Exhaust end bearing was replaced due to increased clearances.

Diagnosis of the Problem

Detailed survey of all the possible reasons for the failure was made. The failure of the bearing was not due to gradual deterioration but the catastrophic failure of the bearing was evident from the vibration data and trend shown in the Table 1 and Graph 1 respectively. Just before the incident, vibration levels were 0.8 mils on non-contact surveillance system. The rise in bearing drain oil temperature took place very rapidly. At 9.48 AM, it was normal i.e. 68.8 deg C while within the time gap of only four minutes, temperature reached 81.6 deg C i.e. there was a rise of 13 deg C in drain oil temperature. The metal temperatures are predicted to have reached very high levels beyond the melting point of white metal. The reason for keeping the turbine running for quite some time was evident from the fact that the temperature gauge on the pipeline in the field was being changed to ascertain the correctness of the reading. The time gap between 9.52 AM to 10.05 AM was long enough to show the temperature reading of 98.2 deg C. Even after stopping the compressor unit, the temperature continuously went up and reached the highest level of 103.9 deg C at 10.09 AM.

The study of the data revealed that the failure of the bearing was spontaneous. The reasons that can be attributed to such spontaneous failure could be

(a) Sudden loss of lubrication

(b) Failure of the white metal lining of the journal bearing pads

(c) High electromagnetic shaft currents causing arcing and loss of lubricating film inside the bearing.

Out of the above referred three reasons, the first one is ruled out as there was no sign of any choking/restriction to the lube oil flow path in the lube oil inlet piping, oil distributing holes in the bearing casing and the drain pipe line when they were examined after dismantling the bearings. The filter elements in the lube oil supply line were found free from any deposits and the elements were in good condition.

The failure of the white metal lined bearing pads under load cannot be explained as the plant has the well set inspection procedure of the incoming materials including the bearings. The bearing pads were examined for the white metal lining bond using the Hoyt bondmeter and ultrasonic examination. The spares used for the replacement were procured from the OEM and had undergone all kind of rigorous testing before being despatched to the customers. Spontaneous failure of the bearing after the operation for about one month can not be attributed to the bearing metal failure when the machine was in steady state condition after successful startup.

Subsequently the third prediction was critically examined for the evidence. The following points supported the predictions of exorbitantly high shaft currents.

1. The residual magnetism levels were checked on the failed shaft journal on the exhaust end. The magnetic field strength of 25 Gauss max. was recorded on the journal after disassembly of the rotor. The photograph below shows the measured readings on the rotor at different areas. This level is very high as compared to the normally permissible levels of 3 to 4 gauss on the shaft journals, which is a close clearance zone of the high speed turbine shaft.

Photograph 1 Damaged Shaft Journal

2. On the damaged white metal lined bearing pads (from where white metal lining was badly rubbed out and barely any amount of white metal could be visible on them) , max. strength of the magnetic field density was 15 gauss. The photograph below shows the readings.

Photograph 2 Damaged Bearing Pads

3. The casing, on which the bearing shell was fitted, was also checked for the residual magnetism levels. The levels were recorded as high as 24 Gauss. Photograph 3 shows the readings.

Photograph-3 Journal Bearing Shell Casing

4. The grounding brush provided on the shaft was inspected and found badly worn out resulting in loss of contact with the shaft. The space available for the installation of the brush was a limitation and it did not allow for the suitable arrangement to measure the developed voltages and current.

All the above symptoms lead to the conclusion that the failure was a result of excessive magnetically induced currents. It is worth mentioning that the level of magnetism was found to be concentrated on only the exhaust end bearing journal/casing and there was no sign of appreciable amount of residual magnetism on the other parts of the rotor as well as casing.

Vibration Data

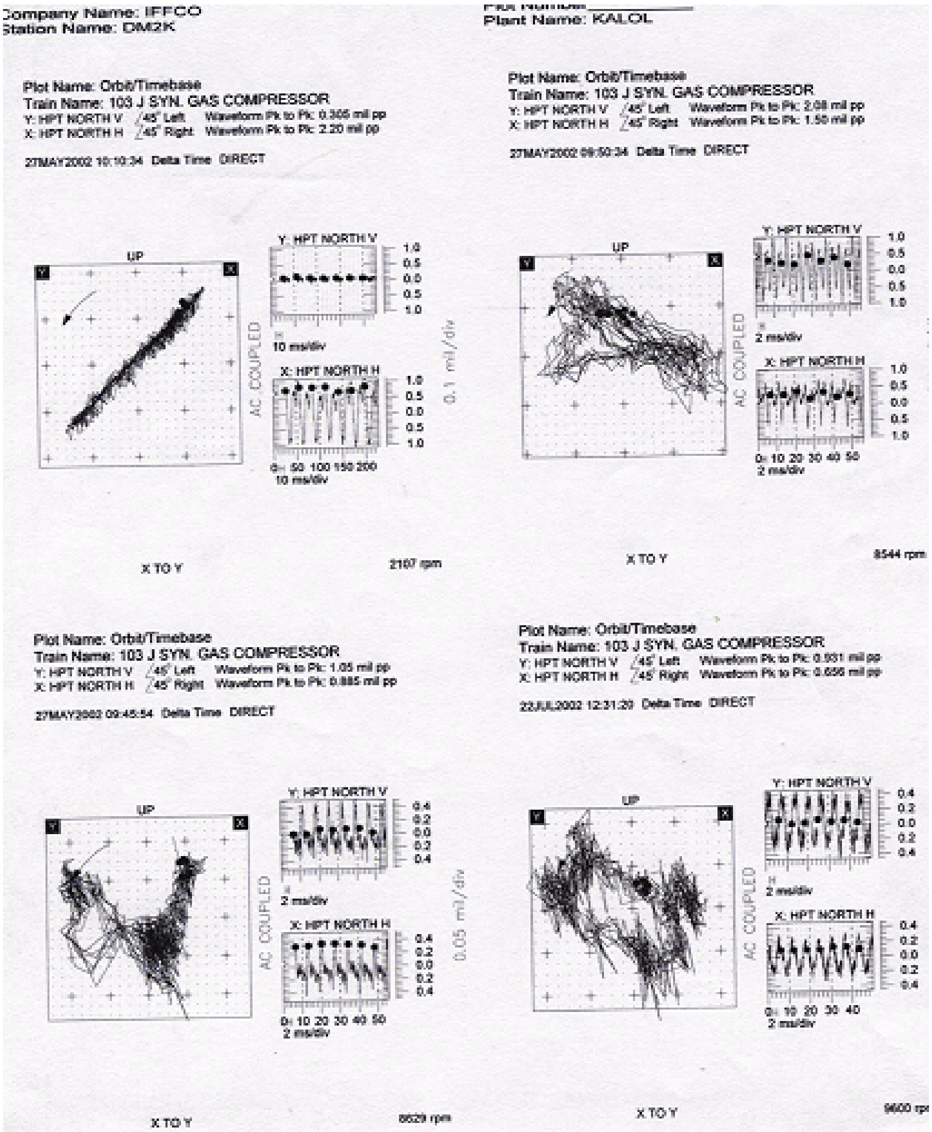
The machine is connected to the data Manager 2000 vibration analyzing software which draws the vibration data from the 7200 series non-contact vibration monitoring system supplied by Bently Nevada.

The trend of the vibration levels is shown at Graph 1. It is revealed from the data that the shaft vibration levels were just 0.8 mil till 9.42 am which increased to 2.27 mils at 09.50 am. After two minutes, at 9.52 am, bearing drain oil temperature crossed the alarm levels and shot up to 81.6 deg C from a normal level of 66.3 deg C recorded at 9.42 am i.e. rise in drain oil temperature by 15.3 deg C within a span of 10 minutes.

This confirms spontaneous failure of the bearing, which is a common phenomenon for the failure due to high magnetism levels in turbo machinery. Also there were spikes seen on the time wave form as well as on the unfiltered orbit as if there was the presence of the electrical run out just before the incident which are indicative of the flow of magnetic currents through the shaft near the probe area.

Figure 2 shows the unfiltered orbit and wave form shapes at different speeds of the unit during the failure (27.5.2002) and during the normal plant operation (22.7.2002).

Figure 2 Vibration data viz. Orbit and waveform plots prior to, during and after failure



Demagnetisation

It was a challenging task to undertake degaussing of the bearing housing which was the part of the huge casing. Portable demagnetizing equipment was used to undertake the degaussing. The magnetized surface was scanned with electromagnetic yoke (normally used for the purpose of magnetic particle inspection) while keeping the demagnetizing current 'ON'. The instrument got the facility to perform demagnetizing with AC currents producing reversing fields. Since the direction of the magnetic field was of complex nature showing irregular distribution of the field polarity, about six scans were required to be performed to bring down the level from 25 Gauss to 5.8 Gauss. Permissible magnetism levels are given at Table-2 below for reference.

Table 2: Permissible magnetism levels on different machine components

Machine Components	Maximum Permissible level of magnetism
Close clearance components viz. bearings and shaft journals, pad retainers, seals and gears as well as teeth of gear coupling	**3 Gauss**
Bearing Housings accommodating the pad retainer assembly, diaphragms, impellers etc	**6 Gauss**
Casings, pipe lines closely connected to the machine, other areas of the machine	**10 Gauss**

Actions Proposed to be Taken

1. The online voltage/current monitoring instruments are available in the market. It has been decided to install the suitable instrument, which will continuously display the values, which are to be considered as a critical parameter for the operation of the compressor train.

2. The temperature measurement of the drain oil is a very poor monitoring practice to know the condition of the bearing. It has been decided to install the suitable RTD on the journal bearings of the complete train to display the bearing metal temperature.

3. Measurement of the magnetism levels on all the components of the high-speed turbo machinery will be performed during each overhaul/inspection without fail.

4. 7200 Series vibration monitoring system is to be replaced by advanced vibration surveillance system, 3300 Series of Bently Nevada and the shaft vibration levels will be included in the trip logic to safeguard the machine against high radial vibrations.

Good Maintenance Practices to Avoid Catastrophic Failures due to Shaft Currents

Offstream practices

1. During all inspection opportunities, it should be made a practice to inspect the bearings, journals and other accessible components for the residual magnetism levels. If these levels are found beyond the above referred maximum permissible levels, it is highly recommended to perform degaussing using the suitable instrumentation and expertise.

2. During shutdown, the inspection of the bearings shall be performed to identify if there is any sign of spark erosion on the bearings or journal. The maintenance technician shall be made aware of the patterns of spark erosion of the bearings. This would help in diagnosing the impeding trouble in advance and the measurements of the magnetism levels can be performed with great care.
3. The tools and tackles used for the assembling/disassembling the high-speed equipment during maintenance shall be inspected for not having excessive magnetism levels which may otherwise get transferred to the machine components during use.
4. Any repairs are done using the welding techniques, it must be ensured that the earthing cable is connected to the part as close as possible to the area where weld deposits are to be made. The current flowing through the welding cables can introduce magnetism in the machine if it is wrapped or kept in close contact with the machine surface. The current between the welding electrode and the earthing electrode can also cause the induction of magnetism in the closeby components.
5. The grounding brushes shall be inspected and repairs shall be performed if required. The suitable reliable instrumentation shall be installed to avoid failure of the current draining system.

Onstream practices

1. Regular measurement of shaft currents and voltage (preferably once in fortnight) is advisable. Online measurement systems are available which may be studied and suitable protective equipment shall be installed for proper monitoring of the shaft current and voltage levels.
2. Inspection of the grounding brush shall be done, if possible at regular intervals otherwise at least whenever high currents/voltage levels are observed.

Coupling Assembly Problems

The synthesis gas back pressure turbine 103 jat lets down the 105.4 Kg/sq.cm steam to 38.3 Kg/sq.cm and uses this power to drive the synthesis gas compressor unit consisting of two barrels via continuous lubricated gear coupling. The technical data of the turbine are given on Page 1. The coupling details are given below:

1. Manufacturer: Kop-Flex Inc. USA
2. Coupling Type: Keyless hydraulically fitted gear type coupling
3. Hub Bore taper diameter, Inch: 3.8188 to 3.9115
4. Hub material: AISI 4140 Low Alloy Steel
5. Recommended Mounting and Dismounting Pressure, PSI: 20,000
6. Max. allowable assembly pressure, PSI: 26,600
7. Interference required: 0.002"/inch diameter of shaft

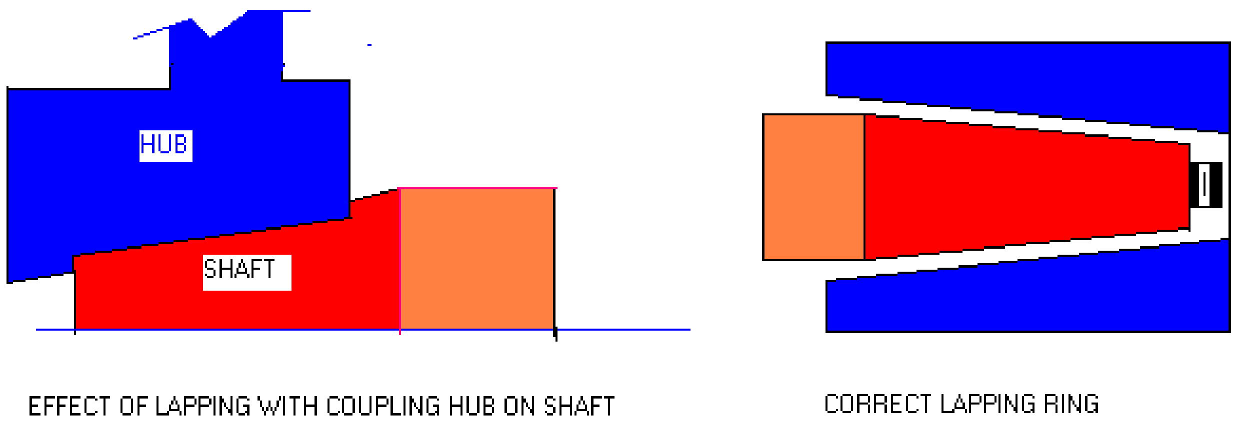
Subsequent to the damage to the rotor, it was decided to replace the same with the spare rotor available as an insurance spare. The installation of the coupling on both the ends of the new rotor shaft was an important activity as the mounting of the gear coupling sometimes lead to the damage to the shaft if proper procedures are not followed or if there are incorrect dimensions/surface finish either on the shaft or on the coupling hub bore.

During the installation of the coupling hub on opposite thrust end (exhaust end) of the turbine rotor shaft, it was experienced that the drive required for the coupling was not achieved even after raising the pressure to 26000 PSI on the hydraulic coupling installation unit. In order to transmit the torque from one shaft to the other through friction, the hub must grip the shaft tightly which can only be accomplished by advancing the hub on the tapered shaft by a specific amount called, 'drive' (0.400 inch in this case). The lapping of the coupling was performed prior to installing the coupling hub on the shaft, as required blue match was not available. Prior to lapping, approx. 45 to 55 % contact was available when checked using Prussian Blue. In absence of the ready made lapping gauges, the coupling hub itself was used to clear the minor high spots observed on the shaft during the blue match. A little lapping on the shaft using the coupling hub itself helped to improve the contact area to appx. 90 %.

After lapping operation and achieving the better contact area, the coupling hub was again taken up for installation. The drive required after expansion, using the hydraulic coupling installation device, was still not available. As against 0.400 inch drive required, only negligible drive could be achieved even with very high installation pressures on the hydraulic tool. It was concluded that the reason for the difficulty in the installation of the coupling hub was the improper lapping practice.

Figure 3 below shows the condition when the coupling hub itself was used to lap the taper surface on the shaft for removal of minor high spots. The localized steps created on the shaft as well as on the hub bore prevented the hub to get the required drive. Even micro step cut during lapping by coupling was so deep that the pressure exerted by the hydraulic installation device was insufficient to drive the coupling hub on the shaft with specified interference fit.

Figure 3 Result of lapping the shaft with the coupling hub



In order to remove the steps created by lapping with the coupling itself, suitable lapping tools (ring and plug tools) of cast iron were prepared to lap and match the taper of the shaft and the hub. These lapping tools were checked for the perfect match and then were used to lap the tapered surface of the coupling seat area on the shaft as well as for lapping the tapered surface of the coupling hub bore. It was ensured that the tool length covers the entire tapered length of the hub and shaft so that no step shall be cutting during the process of lapping. This procedure resulted in the successful installation of the coupling.

Conclusion

Knowledge gained out of the experience on failures of high speed machinery in the past has been greatly utilized to protect the equipment by installing suitable instruments/gazettes on old generation high speed turbomachinery (which were not provided with voltage-current monitoring system by the OEM) for avoiding high electrostatic and electromagnetic currents in operation. Reliability assessment and regular maintenance of the shaft grounding installations is a very critical activity and no efforts shall be spared to ensure the effectiveness of such system.

The use of instrumentation for monitoring the critical parameters viz. shaft vibration level, lubricating oil temperature, etc., shall be made more effective by designing suitable and practically feasible interlocking trip logic. This can help to avoid serious machinery damages and add safety to the operation. The spare turbine rotor and coupling hub could be utilized by creative approach and technical skills of the plant personnel in exhibiting the work capabilities demanded by the situation. The quality checking of the insurance spares and components shall be meticulously done to avoid occurrence of any emergency when these are required in service.