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GE Power Systems
Gas Turbine

Gas Turbine Compressor Cleaning

Liquid and Solid Compound Cleaning Recommendations For Non–DLN Gas Turbines

I. SCOPE

The scope of this document is to present the methods of compressor cleaning offered by GE. The two types of cleaning are liquid and solid compound cleaning. Two methods of liquid cleaning are employed — on line and off line. On-line cleaning is the process of injecting cleaning solution into the compressor while running at full speed and some percentage of load. Off-line cleaning is the process of injecting cleaning solution into the compressor while it is being turned at cranking speed. The advantage of on-line cleaning is that washing can be done without having to shut down the machine. On-line washing, however, is not as effective as off-line washing; therefore, on-line washing is used to supplement off-line washing, not replace it.

The second type of cleaning is solid-compound cleaning. Solid-compound cleaning is done at full speed and reduced load. Most deposits can be removed with liquid cleaning, but for those that cannot, solid-compound cleaning may be necessary. It is to be noted that some blade surface deterioration may be attributed to solid-compound cleaning.

Both types of cleaning will be discussed further in this document.

This document applies to all heavy duty gas turbine models offered by Gas Turbine Division, which do not have Dry Low Nox combustion systems. Refer to GEK 103623 for liquid washing recommendations for those units.

II. INTRODUCTION

A loss of gas turbine performance is indicated by a decrease in power output and an increase in heat rate.

Often a loss of performance is a direct result of fouling of the axial flow compressor. Fouled compressors result in reduced air flow, lower compressor efficiency and a lower compressor pressure ratio.

Compressor cleaning will remove fouling deposits and restore performance. Compressor cleaning may also slow the progress of corrosion, thereby increasing blade life and reducing the contribution of corrosion products to the formation of fouling deposits.

III. TYPES OF FOULING

The type and rate of fouling of an axial compressor depends on the environment in which it operates and the filtration present.

Experience has shown that fouling deposits consist of varying amounts of moisture, oil, soot, water-soluble constituents, insoluble dirt and corrosion products of the compressor blading material. Fouling deposits are probably held together by moisture and oil. If corrosion of the blading is occurring, the corrosion products will promote and stabilize the deposit.

It is important to minimize fouling deposits by reducing oil leaks and the ingestion of oily constituents (lube oil fumes). Good filtration may greatly reduce fouling. Moisture formation cannot be reduced in humid environments. Moisture is formed in the compressor inlet when humid air is cooled below its dew point as a result of being accelerated to about Mach = 0.5. GER 3601, “Gas Turbine Compressor Operating Environment and Material Evaluation,” discusses the factors influencing compressor fouling and corrosion.

IV. METHODS OF DETECTION

There are two basic methods for determining the cleanliness of the compressor. Visual inspection and performance monitoring are described below.

A. Visual Inspection

The best method for detecting a fouled compressor is visual inspection. This involves shutting the unit down; removing the inlet plenum inspection hatch; and visually inspecting the compressor inlet, bellmouth, inlet guide vanes and early stage blading.

If any deposits, including dust or filmy deposits, can be wiped or scraped off these areas, the compressor is fouled sufficiently to affect performance. The initial inspection also reveals whether the deposits are oily or dry. For oily deposits, a water-detergent wash is required. Location of the source of the oil and correction should be accomplished before cleaning to prevent recurrence of the fouling.

If only dry deposits are found, water alone may be sufficient.

B. Performance Monitoring

A second method for detecting a fouled compressor is performance monitoring. Performance monitoring involves obtaining gas turbine data on a routine basis, which in turn is compared to base line data to monitor trends in the performance of the gas turbine.

The performance data is obtained by running the unit at steady-state BASE load and recording output, exhaust temperature, inlet air temperature, barometric pressure, compressor discharge pressure and temperature, and fuel consumption. The data should be taken carefully with the unit warmed up.

GEK 28166, “Field Performance Testing Procedure,” can be used as a guide for assessing machine performance both before and after cleaning the compressor. The purpose of this particular document is to establish the performance of generator drive machines. The appropriate portions can, however, also be used for all machines, both generator drive and other applications, for assessing cleaning effectiveness.

Output and heat rate can be corrected to a standard condition using the turbine performance curves, and an analysis can be made of compressor pressure ratio and efficiency. The current performance levels can be compared to base line data and will aid in determining the problem area.

If performance analysis indicates compressor fouling, it should be verified by a visual inspection.

V. CLEANING METHODS

There are three methods used for compressor cleaning: off-line, on-line and solid-compound cleaning.

There are two types of cleaning agents: solid compounds and liquids. Liquids are the preferred cleaning agents for reasons stated below.

A. Liquid-Compound Cleaning

It is recommended that on-line water washing be addressed in the facility’s operating air permit. Regulators may interpret this as an additional short-term emissions source, requiring an exemption similar to that provided for start-up, shutdown and transient conditions.

Liquid cleaning involves washing the compressor with water and/or detergents. This can be accomplished while the turbine is on line or off line. As the on-line washing practice has been found to be most effective when carried out daily, the specification on the liquid must be more restrictive for on-line washing than off-line washing. The water specifications for off-line and on-line cleaning are given in Table 1.

Except for the pH, the restrictions in these specifications are concerned with deposits and corrosion of the hot gas path. The pH restriction is concerned with corrosion in the water-handling system. High-purity demineralized water after contact with air will have a pH in the range of 5.0 to 6.0. Thus, allowance has been made in the pH provided this is the reason for the low pH.

If a detergent is used, additional restrictions are required to ensure no harm will result to turbine components. These are given in Appendix 1.

In general, deposits will contain some water-soluble material and oils. The latter will be more amenable to removal by detergent, but the deposit may be removable by water washing alone, depending on the amount of water-soluble material present. Hot water at 150 to 200°F (66-93°C) is generally more effective than cold water.

There are a number of detergents commercially available for this purpose, some of which, along with the deposits that have been removed, may constitute a hazardous solid waste (as defined by the US Environmental Protection Agency) when used for an off-line wash. Because of this possibility, local regulations should be considered for the storage, handling and treatment of the water wash effluent when the drain and containment system is designed.

B. Solid-Compound Cleaning

There are two types of solid compounds used: organic — nutshells and rice; and inert — catalyst supports, spent catalysts and polishing powders. Combustible compounds are preferred to inert compounds. The organics will burn up in the combustion process while the inerts will not and may cause erosion or blocked cooling holes.

A specification for these cleaners is given in Table 2.

Recent experience in the use of rice for compressor cleaning suggests that solid-compound cleaning can be detrimental to compressor blade coatings and to compressor blade surface finish. Shallow impact craters of several mils in diameter and tenths of mils in depth have been found on clean number 1 rotor blading upon inspection immediately after solid-compound cleaning. Furthermore, an increase of surface roughness from 20 microinches to 100 microinches has been observed on this blading. When one considers that the relative velocity of a particle to a number 1 rotor blade is in the range of 500 to 1,000 feet per second (152 to 305 m/s) during solid compound cleaning, such damage is not unreasonable.

In the past only solid-compound cleaning was performed at full speed; but with the advent of water washing at full speed, solid-compound cleaning no longer holds this singular advantage.

If dry, hard deposits were present, past practice was to remove them using a solid compound cleaner. However, unless deposits have dried out, they will usually contain significant moisture and water-soluble material, which can be removed using a liquid compound.

Perhaps some deposits cannot be removed except by abrasive cleaning, but it must be appreciated that some deterioration of the blade surface may accompany fouling deposit removal.

Presently, under most conditions, liquid-compound cleaning is the preferred method. Solid-compound cleaning may be necessary in certain instances. In cases where blading is corroded over time and surface roughnesses are well above OEM values (25 microinches), solid-compound cleaning should not be harmful.

VI. CLEANING AND RESTORATION OF PERFORMANCE

A. Water or Detergent Wash

1. Off-Line Compressor Wash

a. Preparation

1) Off-line washing solution must meet the requirements of both Table 1 and Appendix 1.

2) Piping to the atomizing air compressor must be opened and blocked off to prevent water from entering this area. All air-extraction lines from the compressor should be blocked off.

3) If a unit is equipped with off-base atomizing air compressor, the compressor should be deenergized during the wash and rinse cycles.

4) Open inlet guide vanes, if applicable.

5) Make sure all drains are open and diverted to suitable areas.

6) Close flame detector valves. Water will foul the flame scanners and make starting difficult.

7) When regenerators are present, the gas-side face must be covered and kept dry during compressor washing to prevent wetting regenerator deposits. These deposits may change form when wet and become extremely difficult to remove. Leave access doors open while cranking to provide an air exhaust path.

8) For off-line water wash the operator must take appropriate precautions to prevent freezing in the compressor inlet, gas turbine, exhaust and drain system. Off-line water washing should not be done at compressor inlet temperatures,CTIM, less than 40°F (4°C), measured while cranking..

b. Washing Procedure

Washing can be accomplished using a permanent system (a series of nozzles or a spray ring mounted in the inlet plenum) or with a manual system (a hand-held hose and spray nozzle). With either system, take care to cover the full circumference of the bellmouth. The inlet plenum and bellmouth should be cleaned first to prevent these deposits from being washed into the compressor during the cleaning.

Washing with water or detergent should be done at crank speed or slower. This provides more effective washing near the hub of the rotor. Flow rates are given in Table 3.

CAUTION

> To prevent thermal shock, wheelspace temperature must be no more than 120°F (49°C) greater than the wash water temperature. If cool water is used [60°F (16°C)], the wheelspace temperature must not exceed 180°F (82°C). If hot water [180°F (82°C)] is used, the wheelspace temperature must not exceed 300°F (149°C).

Utilize the detergent wash procedures which follow:

1) Apply solution at the rate specified in Table 3.

2) Apply the solution at crank speed for three to five minutes, shut unit down, continue spraying during coastdown until the solution is no longer drawn into the compressor inlet. Crank speed is considered to be approximately 350 rpm for the MS-7001; 300 rpm for the MS-9001; 600 rpm for the MS-3002, 5001, 5002 and 6001.

3) Allow the detergent to soak for 20 minutes and rinse with water at crank speed for 15 to 20 minutes following the recommended flow rates of Table 3.

c. Rinsing Procedure

The effectiveness of the wash and the rinse can most easily be evaluated by observing the runoff from the drains during the rinse and visual inspection of the compressor inlet at the end of a wash cycle.

1) The compressor should be rinsed until the drain water appears clean.

2) The runoff water may also be checked for the amount of impurities it contains by measuring its electrolytic conductivity. The conductivity value will decrease as washing continues and the runoff water contains fewer dissolved impurities.

3) Another method of testing is to use an atomic absorption spectrometer if one is available for checking the level of trace metals.

Note: The detergent wash may need to be repeated depending on the amount of fouling and detergent effectiveness.

d. Restoration

1) After final rinse, crank for 20 minutes to remove all water.

2) After final drying cycle,

   a) Reassemble extraction and atomizing air piping.

   b) Open flame scanner valves.

   c) Close all drain valves.

   d) If applicable, close inlet guide vanes.

   e) If applicable, reenergize off-base atomizing air compressor and remove regenerator cover.

2. On-Line Compressor Wash

The intent of on-line washing is to keep the gas turbine compressor clean through frequent washings of short duration. When the compressor is suspected of being heavily fouled, an off-line wash should be performed.

Adding water for wash will increase the compressor pressure ratio and thus reduce the surge margin. Under normal circumstances, there is ample surge margin to allow for washing and steam or water injection for NO_x control or power augmentation. However, the following steps are recommended prior to performing an on-line wash.

a. Preparation

1) On-line washing solution must meet the requirements of both Table 1 and Appendix 1.

2) Turbine must be running at full speed and not in the process of shutting down.

3) Compressor inlet temperature,CTIM from the Speedtronic panel, must be greater than 50°F (10°C).

4) Set the inlet guide vanes to 81° or greater.

5) Reduce load by 5% if operating at base load.

b. Washing Procedure

1) Apply solution at the rate specified in Table 3.

2) Continue to apply solution for 20 minutes.

3) On-line wash should be done on a regular basis.

3. Solid-Compound Cleaning

Solid-compound cleaning is not recommended for reasons previously stated.

a. Preparation

1) Solid-compound cleaning is done at full speed and reduced load. This keeps internal temperatures down and eliminates possible damage by cleaning material due to hot corrosion in the turbine section. Nutshells are recommended over rice and both over the inerts.

2) Make sure turbine has been running for at least 30 minutes before solid-compound cleaning to ensure dryness.

3) Make sure solid-compound injection is done at an even rate.

4) Evaporative coolers must be shut down one half-hour before solid-compound cleaning to make sure surfaces are dry.

5) Make sure that any separators that are installed on compressor air extraction lines (i.e., cooling and bearing sealing air lines) are functioning, and that any blowdown valves installed on these separators are open.

b. Cleaning Procedure

1) The solid compound can be applied to the compressor either through an injection ring permanently installed in the bellmouth for that purpose or by a manual method.

2) When the solid compound is injected manually, a location should be used to allow time for good dispersion in the airstream. There is no mixing within the compressor; therefore, if the solid compound is not dispersed when it enters the compressor, only portions will be cleaned. A hopper or other device may be helpful in establishing an even injection rate.

CAUTION

Solid compound injection may cause fouling of flame scanners and a possible trip. Following the injection rates in Table 3 will help prevent this.

It has been determined that the accumulation of combustible material in regenerator tubes can cause burning and serious damage to the regenerator. Both nutshell and rice fall into this category; therefore, extreme caution should be exercised to control the flow rate of nutshells or rice. The flow rate of the solid compounds should be carefully and consistently maintained at or below the flow rates given in Table 3 for different size machines.

Note: Use only inert cleaning compound for units equipped with GARRET regenerators.

CAUTION

Too rapid injection of solids may lead to an accumulation of solids in the cooling and sealing air lines and the No. 2 bearing housing. The even injection rates shown in Table 3 should be followed.

3) To determine the effectiveness of solid compound cleaning, set load to 20% and make note of the exhaust temperature and compressor discharge pressure.

a) Inject solid compound and maintain constant load. Use 20-pound (9-kg) increments of solid compound at the proper rates. If the cleaning is effective, the exhaust temperature will drop and the compressor discharge pressure will increase.

b) Inject solid compound until no further effect is seen. At this point, solid-compound cleaning is finished.

4) Make final inspection of inlet to determine cleaning effectiveness.

c. Restoration

If applicable, return the evaporative coolers to normal service. Normal operation may be resumed.

B. Results of Cleaning

After cleaning, there should be a noticeable increase in performance. Increase in performance is a function of how fouled the compressor was initially. An increase in BASE load power of 10% is not uncommon following an off-line wash. This can be confirmed by comparing restored performance data to levels of performance before cleaning, utilizing the procedure in GEK 28166 for generator drive machines and the appropriate procedure for other applications as previously described under Performance Monitoring. It should be noted that full power may not always be regained once significant fouling occurs. Regular compressor cleaning will help maintain performance. Specific intervals must be determined based on customer performance.

TABLE 1

QUALITY SPECIFICATION*

OFF-LINE WASHING	
TOTAL SOLIDS (dissolved and undissolved)	100 ppm
TOTAL ALKALI METAL	25 ppm
OTHER METALS WHICH MAY PROMOTE HOT CORROSION (i.e. lead, vanadium)	1.0 ppm
pH (determined by glass electrode)	6.5 to 7.5
ON-LINE WASHING	
TOTAL SOLIDS (dissolved and undissolved)	5 ppm
TOTAL ALKALI AND OTHER METALS WHICH MAY PROMOTE HOT CORROSION	0.5 ppm
pH (determined by glass electrode)	6.5 to7.5

See Table A1 in Appendix 1 for chemical specifications.

TABLE 2

SOLID CLEANING COMPOUND

Particle Size	40 to 200 microns
Stone Content	10 ppm (weight parts) max

*Applies to water or water and detergent solution

TABLE 3

INJECTION RATES

Machine	Solid Compound[1] flow rate lb/min	Off Line[2]			On Line[2]		
		Press (psig)	Temp (°F)	Flow (GPM)	Press (psig)	Temp (°F)	Flow (GPM)
MS3001, 3002	0.72	115	150-180	15	100	50-180	3.5
MS5001, 5002	1.75	85	150-180	35	100	50-180	8
MS6001	2.3	85	150-180	42	100	50-180	10
MS7001EA	3.5	85	150-180	50	100	50-180	18
MS7001F/FA	5.0	85	150-180	81	100	50-180	26
MS9001E	5.0	85	150-180	72	100	50-180	26
MS9001F/FA	7.2	85	150-180	117	100	50-180	38

[1] Dispensed at a uniform rate over the cleaning period. The rate should not be higher than that shown above.

[2] Mixed at manufacturer's suggested mix ratio.

APPENDIX 1

COMPRESSOR CLEANING-COMPOUND SPECIFICATION

1.0 Scope

1.1 This specification is for cleaning compounds for use in compressor washing. It is required that these compounds will not cause harm to gas turbine components. Thus, their purity and composition must be such that they do not cause aqueous corrosion or stress corrosion of compressor materials. Also, it is required that they do not cause hot corrosion in the turbine. Furthermore, they must not lead to compressor fouling. With regard to the cleaning agents themselves, they must be chemically stable in themselves and in their mixtures with water. Also, they must not form combustible mixtures and they should satisfy all local codes relative to health and safety requirements. Compliance with this specification does not imply a cleaning compound improves the cleaning of a compressor over and above what can be obtained from water alone.

2.0 Requirements

2.1 The cleaning compound when mixed with water in the manufacturer's prescribed concentration shall satisfy the water washing specifications for on-line and off-line water quality given in Table 1. In the pure state it shall satisfy the specification given in Table A1.

2.2 The residue or ash content of the cleaning compound shall not exceed 0.01%. See test 4.1.

2.3 The storage stability of the cleaning compound shall show no marked color change, shall not separate and shall not corrode or stain the steel specimen when tested as specified in test 4.5.16 of MIL-C-85704A. This test is given in 4.2.

2.4 The cleaner and its mixtures with water shall not form gums under compressor conditions.

2.5 The Pensky-Martens flash point of the cleaning compound shall be above 140°F (60°C) (ASTM D93).

3.0 Material Compatibility

3.1 Use of the cleaning compound shall not have adverse effects on engine system materials such as compressor or turbine materials.

4.0 Tests

4.1 Ash content: preparation of test samples

Approximately 10 g of cleaning compound shall be weighed to the nearest 0.1 mg in a tared porcelain crucible. The crucible shall be heated at 221° ± 2°F (105° ± 1°C) for 24 hours, then heated at 464° ± 4°F (240° ± 2°C) for the next 24 hours. Following this, the crucible and its contents shall be carefully ignited over a Bunsen-type gas burner. The crucible shall then be placed in a muffle furnace at 1,900°F (1,040°C) for 2 hours. The crucible shall be transferred to a desiccator, cooled and weighed until constant weight. The ash content shall be calculated as the percentage of the initial weight of cleaning compound.

4.2 Accelerated storage stability (from MIL-C-85704A)

Preparation of test sample. A 150-ml portion of a well-shaken cleaning compound shall be poured into each of two chemically clean 250-ml pressure-resistant clear glass bottles which shall be approximately 9.5 inches

(24.1 cm) in height and 2.5 inches (6.4 cm) in outside diameter. **One bottle** shall be capped and stored in the dark for at least six days at room temperature. A strip of steel 6 by 0.5 by 0.02 inches (15.2 x 1.3 x 0.05 cm) conforming to MIL-S-7952 shall be polished to remove surface contamination and then cleaned by boiling for one minute in chemically pure isopropyl alcohol and one minute in mineral spirits. The steel strip shall be placed in the **other test bottle** and the bottle shall be capped. The capped bottle containing the steel strip shall be thoroughly shaken for one minute.

Procedure. The capped bottle containing the steel strip shall be placed in a water bath and heated at a uniform rate to a temperature of 140° ± 4°F (60° ± 2°C) over a period of five hours. It shall be held at this temperature for three hours. No heat shall be applied to the bath overnight. The above heating procedure shall be repeated each day for five days. (This test need not necessarily be attended if an interval time is used to regulate the temperature automatically. The test may be started on a Wednesday, Thursday or Friday and still have the pressure bottle removed on a normal workday.) On the morning of the sixth day, the bottle shall be removed from the bath, uncapped, examined for separation and the steel strip carefully withdrawn from the cleaning compound. Separation into layers shall be cause for rejection. The portion of the steel strip which had been immersed in the compound shall be examined for evidence of pitting, corrosion and uneven darkening. The open bottle shall be capped and the two bottles shall be thoroughly shaken for one minute, then allowed to remain undisturbed for one hour at room temperature and then examined. Any marked change in the color and uniformity of the aged sample shall be considered as showing unsatisfactory stability properties.

TABLE A1

CHEMICAL CONTENT OF CLEANING COMPOUND

Total alkali metals	25 ppm max
Magnesium + calcium	5 ppm max
Vanadium	0.1 ppm max
Lead	0.1 ppm max
Tin + copper	10 ppm max
Sulfur	50 ppm max
Chlorine	40 ppm max

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