

# Compressor Washing Instruction (Off-Line) for YAMAMA GT6 - GT9

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# 1 Introduction

## 1.1 Before reading this document

Make sure that you are familiar with the content of the following documents:

- **Maintenance Safety**  
Is dealing with the safety precautions that have to be observed while working with the Gas Turbine (GT).
- **Human-Machine Interface (HMI) Description**  
Describes the basic principles in working with the computerised control system.

## 1.2 Purpose of this document

This document describes actions necessary prior to, during and after Off-Line washing. Off-Line washing means that washing is performed when the Gas Turbine (GT) is out of operation.

## 1.3 General safety



### Warning!

**Compressor washing is to be performed only by authorised maintenance personnel.**

**Read all instructions in this document before starting the washing procedure. Do not follow the washing instructions given in the sub-supplier's documentation.**

**Misuse of the equipment may cause bodily injury and/or damage to equipment.**

**Avoid contact with and inhalation of the cleaning and anti-freeze agents.**

### Caution!

**If the ambient air temperature is, or is expected to fall within the limits 0 °C to –10 °C when washing Off-Line, anti-freeze agent must replace the water. This is because the compressor is likely to be damaged if ice is ingested. Washing at temperatures below –10 °C is not to be performed.**

**The GT has to be shut down and cooled for at least 4 hours before the Off-Line washing procedure takes place.**

**The GT should be put into operation immediately after Off-Line washing in order to dry out the fluid. If the GT can not be started, it must be purged for at least 15 minutes.**

## 1.4 Additional information

For more information regarding the washing system, refer to the following documents:

System Description: Compressor Washing, system SDB

P&I Diagram: Compressor Washing, system SDB

Description of equipment: Sub-supplier documentation, Binder 3B-3M, system SDB

## 2 General

The air pollution passing the air intake filters will develop deposits on the blades of the compressor. The fouling results in reduced flow capacity, loss of compressor efficiency and severe fouling can even cause surging. As the deposits grow they may scale off and cause clogging of the cooling channels. If they contain corrosive elements they may cause high temperature corrosion in the combustion and the turbine sections. Furthermore, heavy compressor fouling makes it more difficult to obtain a satisfactory cleaning result. For these reasons it is of great importance that the compressor is kept clean by efficient air intake filters and compressor washing as frequently as required.

The fouling of the compressor depends on the ambient air environment and the efficiency of the actual GT air intake filters. The ambient air environment varies from site to site and may also vary over the year. For this reason it is recommended to evaluate the washings during the first year of operation. This instruction suggests a number of items to be evaluated in order to build up knowledge and be able to decide:

- A suitable time between compressor washings.
- The number of washing cycles to get the compressor clean.
- The cleaning agent dilution ratio.
- The number of rinses after the last injection of washing fluid.

### 3 Washing intervals

According to chapter General, the advisable operation time between compressor washings varies from site to site. Local experience should be built up based on performance monitoring, inspections of the compressor inlet and ocular inspections of the drained fluid from the compressor<sup>1</sup> made in conjunction with the washings.

As a minimum, Off-Line compressor washing should be performed:

- If the compressor flow capacity has decreased by 3 %, or the polytropic efficiency for the compressor has decreased by 1.5 % according to the section Performance monitoring below.
- If unexplainable vibrations occur.

Furthermore, it is recommended to wash the compressor when the GT is shut down for one or another reason.

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<sup>1</sup> The drained fluid shall look clear and shall not be foamy when the washing is finished.

## 3.1 Performance monitoring

### 3.1.1 Principle of the performance monitoring method

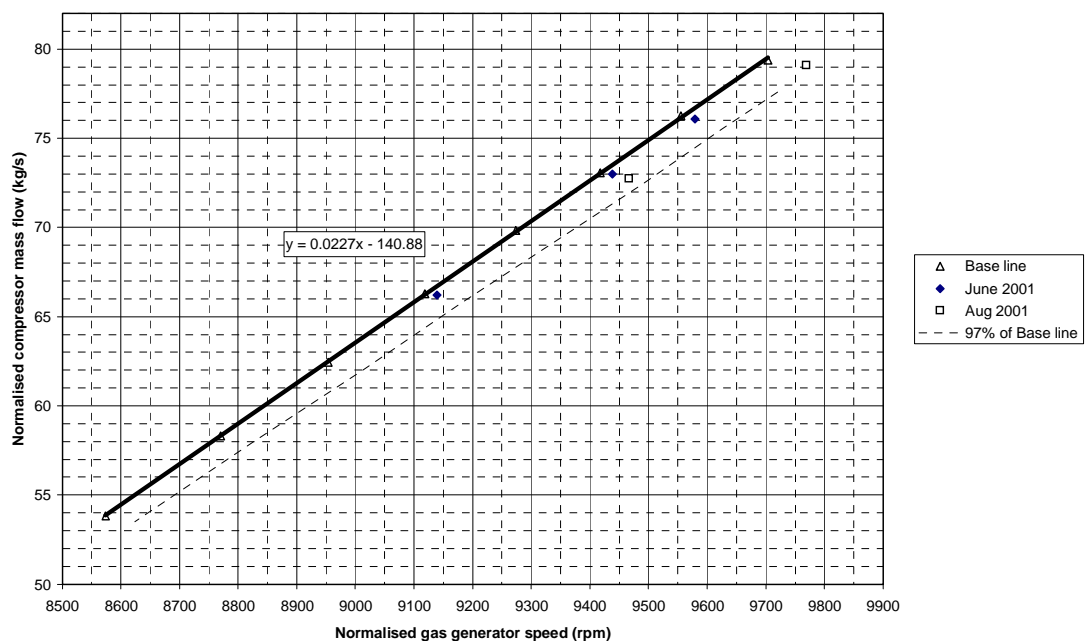
The method suggested here is to monitor the mass flow as well as the efficiency of the compressor in the following two diagrams:

- normalised<sup>2</sup> mass flow versus normalised gas generator speed
- polytropic efficiency versus pressure ratio for the compressor

The efficiency monitoring is less accurate at normalised gas generator speeds above 9900 rpm, i.e. at low ambient air temperatures.

The diagram below is an example showing "normalised mass flow versus normalised gas generator speed". The base line represents the recently cleaned compressor and is the reference when making performance checks to follow the fouling and the degradation of the compressor. There are also a number of points representing the degraded and fouled compressor in the diagram.

**Figure 3.1 Normalised mass flow versus normalised gas generator speed**



<sup>2</sup> By using normalised parameters it is possible to compare performance at different ambient conditions.

### 3.1.2 Performance monitoring procedure

The base lines and the performance checks are based on the measured data and the calculated performance parameters according to the next section.

#### 3.1.2.1 Creation of base lines

The base lines are based on readings of the measured parameters taken at start up of the GT, immediately after thorough Off-Line compressor washing. The base lines for the clean compressor may change during the lifetime of the GT due to degradation, replacement of components and fouling which is not recoverable by compressor washing.

- Take readings every 3 MW, from 8 MW up to base load.
- If there is no power output measurement, the power turbine outlet temperature,  $t_7$  may be used. Take readings every 25 °C, from  $t_7 = 390 + (2 \times t_2)$  up to base load.  
( $t_2$  = compressor inlet temperature)

#### 3.1.2.2 Intervals for Performance checks

After the creation of the base lines, performance checks should be made to measure the fouling and degradation of the compressor. It is recommended to make performance checks immediately before and after Off-Line compressor washings. In the periods between Off-Line washings, performance checks should be made once a week. Make a note about date and time for Off-Line washings!

It is recommended to use an Excel file for the monitoring. An example of the data sheet in the Excel file is shown in the enclosed Performance log sheet.

**Note!** Readings must be taken during steady state operation. Steady state is obtained after 45 minutes at the same load right after the GT start up. After a load change, steady state is obtained after 15 minutes at the same load.

It is recommended to take 3 readings of each data during 5 – 10 minutes and base the calculations on the average value.



### 3.1.3 Performance equations and measured data

The base lines and the performance checks shall be based on the following calculated and measured data.

Performance parameters to be calculated according to equations below:

$mc^*$  = Normalised compressor mass flow (kg/s)

$\eta_{p,C}$  = Polytropic compressor efficiency (%)

$\pi$  = Pressure ratio over compressor (-)

Measured data and their KKS numbers:

$mc$  = Compressor inlet mass flow (kg/s) MBT10 FF901

$N_{gg}^*$  = Normalised gas generator speed (rpm) MBT10 FS001ZE01

$p1$  = Compressor inlet pressure (bar(a)) MBT10 CP005

$p3$  = Compressor discharge pressure (bar(a)) MBT10 CP015, CP020, CP025

$t2$  = Compressor inlet temperature (°C) MBT10 CT005, CT055, CT060

$t3$  = Compressor discharge temperature (°C) MBT10 CT030, CT035, CT040

**Note!** For  $p3$ ,  $t2$  and  $t3$  the average values of the 3 measurements are used.

$$mc^* = mc \times \frac{\sqrt{\theta}}{\delta} \quad (1)$$

$$\delta = \frac{p1}{1.013} \quad (2)$$

$$\theta = \frac{t2 + 273.15}{288.15} \quad (3)$$

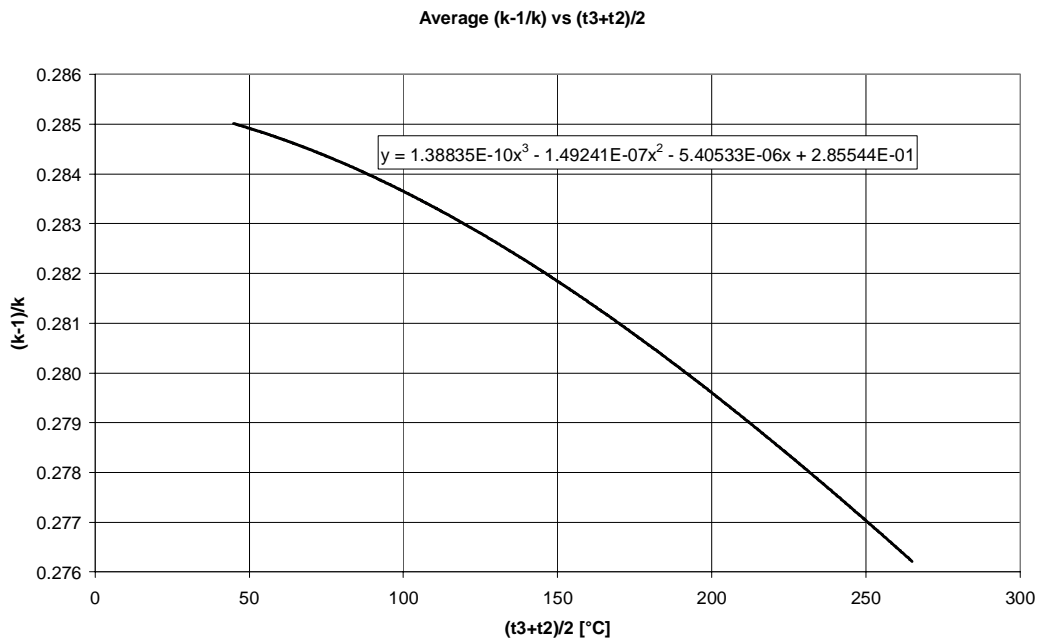
$$\eta_{p,C} \approx \frac{\left(\frac{\kappa - 1}{\kappa}\right)_{Average} \times \ln\left(\frac{p3}{p1}\right)}{\ln\left(\frac{t3 + 273.15}{t2 + 273.15}\right)} \quad (4)$$

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$$\pi = \frac{p3}{p1} \tag{5}$$

$$\lambda = \left( \frac{\kappa - 1}{\kappa} \right)_{Average} = f \left( \frac{t_3 + t_1}{2} \right) \text{ According to the diagram below.}$$

**Figure 3.2 Parameter for calculation of the polytropic compressor efficiency**



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Off-Line compressor washing is recommended when any of the following conditions are fulfilled:

$$\frac{mc^*}{mc^*,baseline} \leq 0.97 \tag{6}$$

$$\frac{\eta_{p,C}}{\eta_{p,C},baseline} \leq 0.985 \tag{7}$$

where mc\*,baseline and η<sub>p,C</sub>,baseline are either read in the Excel diagrams or else calculated from polynomials made by Excel, based on the actual N<sub>gg</sub>\* and π.

## 4 Cleaning solution



**Warning!** Handle the cleaning and anti-freeze agents with care! Contact and/or inhalation can involve health hazards, like irritated skin and/or breathing difficulties. Always read the sub-supplier's product data and safety data sheets before usage.

### 4.1 Cleaning agents

The washing fluid used for Off-Line washing consists of a mixture of water and cleaning agent. Tested cleaning agents are specified in document GTI W491023E (see *Requirements in Gas Turbine Operation Instructions, 2A-3*).

As a first approach the cleaning agents are diluted according to the instructions of the sub-supplier. It is possible that the dilution ratio may be reduced since the compressor fouling is dependent on the environment of the GT and on the type of air intake filters. This may be evaluated during the first year of operation by registering the degree of foam in the drained fluid from the compressor.

### 4.2 Water quality

The water used for dilution of the cleaning agents and for rinsing must fulfil the requirements as specified in document GTI W220027E (see *Requirements in Gas Turbine Operation Instructions, 2A-3*).

### 4.3 Anti-freeze agent

Tested anti-freeze agents are specified in document GTI W491023E (see *Requirements in Gas Turbine Operation Instructions, 2A-3*).

If the ambient air temperature is, or is expected to fall within the limits 0 °C to -10 °C when washing Off-Line, anti-freeze agent must replace the water. This is because the compressor is likely to be damaged if ice is ingested. Washing at temperatures below -10 °C is not to be performed.

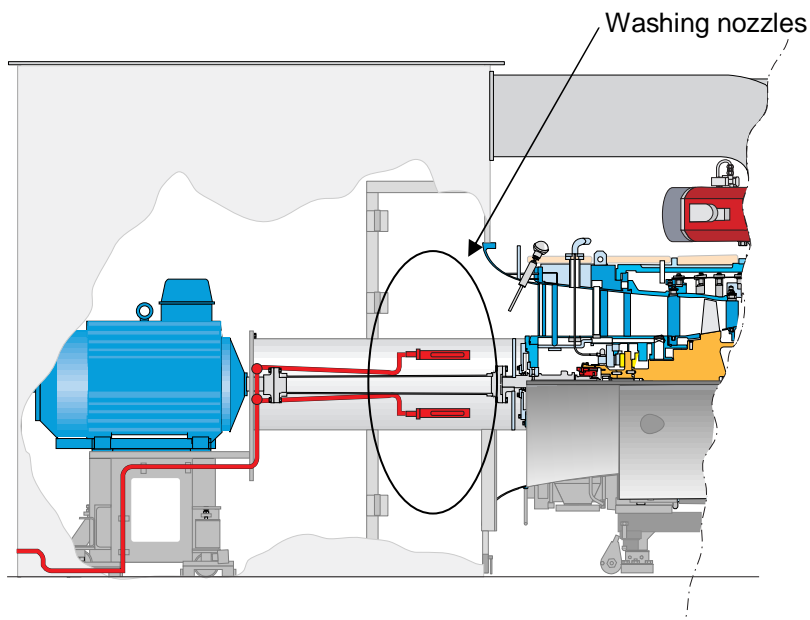
If anti-freeze agent is mixed with a solvent based product, make sure that the solution is completely mixed before use.

## 5 Washing equipment

### 5.1 Washing nozzles

The GT is equipped with 4 nozzles for compressor washing. The nozzles are mounted on the shaft cover between the GT start motor and the compressor. On the connection between the nozzles and the washing unit, there is a filter.

**Figure 5.1 Placement of washing nozzles**



### 5.2 Washing unit

Main data:

There are two tanks.

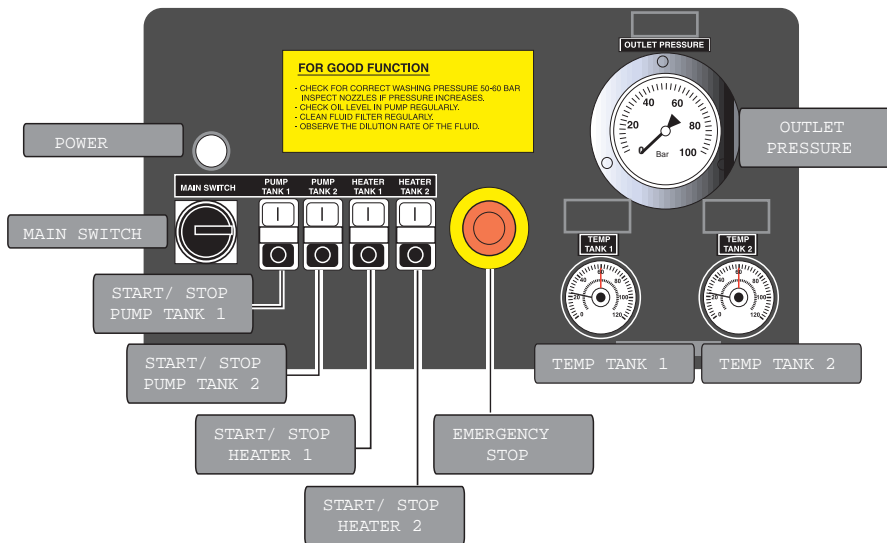
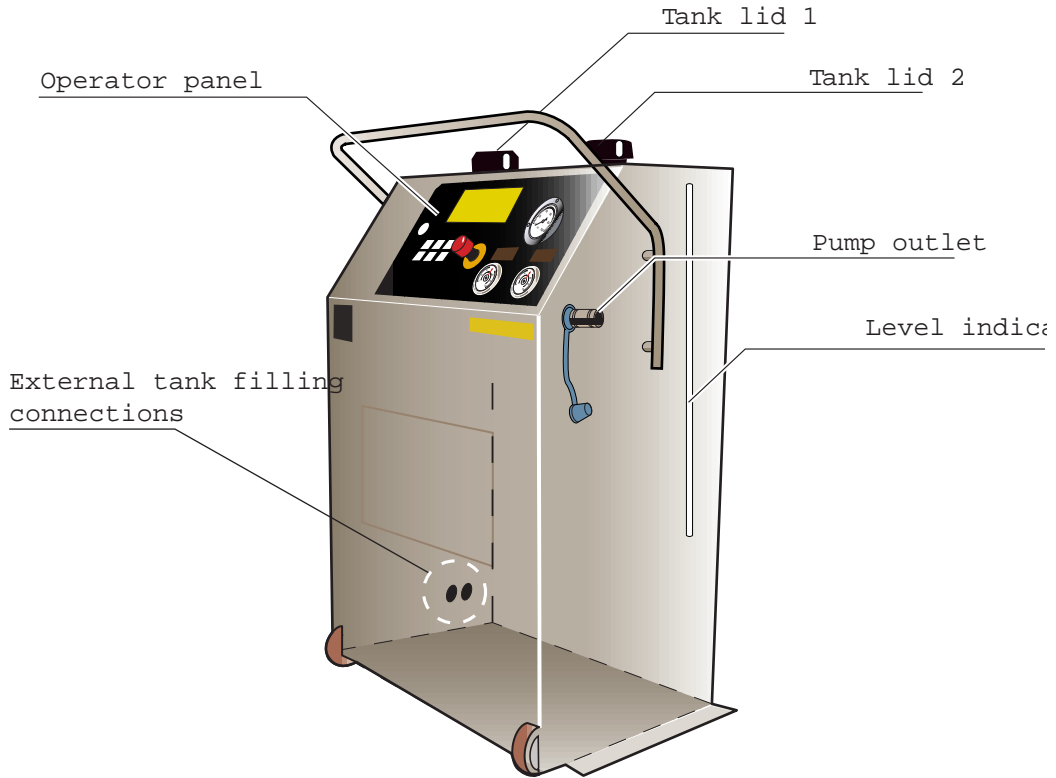
The volume of each tank is 80 l.

The fluids may be heated to maximum 60 °C.

The working pressure of the fluids is 50-60 bar(g).

For a more detailed description of the equipment, refer to Sub-Supplier's Documentation.  
See binder 3B-3M SDB.

**Figure 5.2 Washing unit and control panel**



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### 5.3 Storage of equipment at freezing temperatures

The washing equipment must not be exposed to freezing temperatures. If Off-Line compressor washing was last performed with anti-freeze agent (replacing water), the washing equipment is already prepared for freezing temperatures. If that is not the case, the washing equipment must be prepared as described below.

It is recommended to perform this preparation in conjunction with Off-Line compressor washing during that part of the year when freezing temperatures may occur, since the GT must be stopped and cooled in accordance with chapter Preparations prior to washing.

Preparation of the washing equipment if exposed to freezing temperatures:

1. Stop and cool the GT according to chapter Preparations prior to washing.
2. If the preparation is performed when the GT is rotating, the drain valves SDB50-AA210, AA215, AA220, AA225 and AA230 on the GT have to be opened.
3. Connect the high-pressure hose from the washing nozzles to the pump outlet of the washing unit (SDB10 AA050).
4. Fill each tank with approximately 2 litres of anti-freeze agent.
5. Start 'pump tank 1'.
6. The pump will stop automatically when tank 1 is empty.
7. Start 'pump tank 2'.
8. The pump will stop automatically when tank 2 is empty.
9. Remove the high-pressure hose from the washing unit and connect it to the purging air pipe instead. Blow purge air for at least 30 seconds in order to empty the anti-freeze agent in the nozzles, pipes and hoses.
10. Close the drain valves SDB50- AA210, AA215, AA220, AA225 and AA230 on the GT.
11. Purge the GT for 15 minutes.

### 5.4 Service and maintenance of equipment

The service and maintenance instructions according to the Sub-Suppliers Documentation in binder 3B-3M SDB should be followed.

## 6 Preparations prior to washing

**Caution!** Be careful not to get foreign particles into the washing system. Dirt in the compressor washing system can clog the washing nozzles.

### 6.1 General

1. Make notes according to the enclosed log sheets.
2. Shut down the GT.
3. Let the GT cool during barring for at least 4 hours. During the cooling of the GT, it is recommended to fill the tanks and heat the fluids as described below.
4. Open the drain valves SDB50- AA210, AA215, AA220, AA225 and AA230 on the GT.
5. Check the pump oil level of the washing unit according to the Sub-supplier's Documentation – binder 3B-3M SDB.
6. Connect the high-pressure hose from the washing nozzles to the pump outlet of the washing unit (SDB10 AA050).

### 6.2 Filling of tanks

Use only the recommended cleaning and anti-freeze agents and the specified water quality according to chapter Cleaning solution. Filling of the tanks may be performed either via the tank lids on the top of each tank or else via the external filling connections. See figure in chapter Washing equipment.

1. Fill tank 1 with 80 l of washing fluid. Fill water (or anti-freeze agent) first and then the cleaning agent in order to avoid priming the system with undiluted cleaning agent and to minimise the generation of foam.
2. Fill tank 2 with 80 l of rinse fluid, i.e. water or anti-freeze agent.

### 6.3 Heating the fluids

1. Ensure that both tanks are filled to the correct level.
2. Ensure that the green power indicator lamp is on.
3. Ensure that the thermostats are set to 60 °C.
4. Press the start buttons 'heater tank 1' and 'heater tank 2'. Green indication lamps are turned on.
5. The heaters will be switched off automatically when the set temperature is reached. Heating time depends on the filled volume, the initial temperature of the fluid and the ambient temperature. The heating time for a full tank is normally 60 to 90 minutes.

**Note!**            **Fluids refilled during the washing procedure do not require heating to a temperature of 60 °C.**



## 7 Washing procedure



### Warning!

If the skin is hit by cleaning or anti-freeze agent, follow the recommendations in the sub-supplier's product data and safety data sheets.

Never operate the washing unit if there are any leaks from fittings, pipes or hoses.

Always disconnect the washing unit from electrical supply when performing any installation or maintenance action to the washing system. Always ensure that no pressure is present when removing or adjusting any part.

Before entering the air inlet plenum to inspect the compressor inlet, to wash the compressor bellmouth and inlet guide vanes by hand or to clean up fluid that is possibly left after the washing, inform the GT control room personnel about the activity to be performed. Never put your hands in the compressor inlet unless the start motor has stopped and its main breaker is switched off and locked in off-position. Not obeying this warning may lead to severe injuries.

Before leaving the plenum make sure that no tools, rags or dirt etc. are left, as they can cause severe damage to the compressor.

### 7.1 Off-Line washing sequence overview

Figure 7.1 Off-Line compressor washing

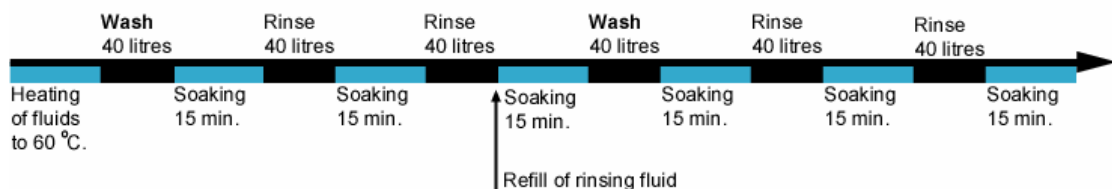
**Conditions:**

GT shut down and cooled prior to washing.

Washing and rinsing fluid pressure 50-60 bar (g).

GT running on 2300 rpm (purge) when injecting washing or rinsing fluid.

GT running on 215 rpm (barring) when soaking.



The time consumption, excluding the cooling down time ~ 1h 45 min.

## 7.2 General notes

1. The GT has to be cooled before the washing procedure can take place, see chapter Preparations prior to washing.
2. The water must be replaced by anti-freeze agent at ambient air temperatures of 0 °C and below. See chapter Cleaning solution.
3. If the 10 hours cooling down period (at barring) after GT shut down will end before or during the washing procedure, 'Lube oil FG' and 'Barring FG' have to be activated manually.
4. The washing unit pump can only be started when both heaters are switched off.
5. The washing and rinse fluid pressure should be 50-60 bar(g). A change in the pressure indicates that the nozzles and/or any of the washing system filters are clogged.
6. Check the temperatures of the fluids each time the pump is stopped during the washing procedure and switch on the heaters if necessary during the soaking periods.
7. The soaking period is specified for 15 minutes. This might have to be shortened in warm and dry climates to avoid drying out, which results in dirt and cleaning agent getting stuck to the compressor. The duration of the soaking period must be based on local experience.
8. With reference to chapter General, it is recommended to evaluate the washing during the first year of operation. The washing interval, the number of washing cycles needed to get the compressor clean, the cleaning agent dilution ratio and the number of rinses after the last injection of washing fluid is then evaluated. This evaluation may be based on samples of drained fluid from the compressor<sup>3</sup>, performance analyses, inspections of the compressor inlet and/or borescope inspection of the compressor. The warning at the beginning of this chapter must be strictly followed.

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<sup>3</sup> The drained fluid shall look clear and shall not be foamy when the washing is finished.

### 7.3 Off-Line washing step by step

OS = Operator Station, WU = Washing Unit

General notes below refer to section General notes above.

1. OS - Activate 'Washing FG', bleed valves will close and compressor inlet guide vanes will open.
2. OS - Activate 'FG Purging', the start motor accelerates the gas generator to purging speed.
3. WU - Switch off the tank heaters.
4. WU - Press the start button 'pump tank1' (general note 4). Washing fluid is injected.
5. WU - Note the fluid pressure in the Compressor washing log sheet (general note 5).
6. WU - Stop the pump when 40 l is injected (general note 6).
7. OS - Stop 'FG Purging'.
8. Let the washing fluid injected in the compressor soak and drain for approximately 15 minutes while the GT is barring (general note 7).
9. OS - Activate 'FG Purging', the start motor accelerates the gas generator to purging speed.
10. WU - Press the start button 'pump tank2' (general note 4). Rinse fluid is injected.
11. WU - Stop the pump when 40 l is injected (general note 6).
12. OS - Stop 'FG Purging'.
13. Let the rinse fluid injected in the compressor soak and drain for approximately 15 minutes while the GT is barring (general note 7).
14. OS - Activate 'FG Purging', the start motor accelerates the gas generator to purging speed.
15. WU - Press the start button 'pump tank2' (general note 4). Rinse fluid is injected.
16. WU - The pump will stop automatically when tank 2 is empty (general note 6).
17. OS - Stop 'FG Purging'.
18. WU - Fill tank 2 with 80 l of rinse fluid and switch on the 'heater tank2' as soon as possible. It is not necessary to wait for the temperature to reach 60 °C.
19. Let the rinse fluid injected in the compressor soak and drain for approximately 15 minutes while the GT is barring (general note 7, 8).
20. Repeat items 2 to 17 (general note 8).

## 7.4 Actions after Off-Line washing

### At the WU:

1. Remove the high-pressure hose from the washing unit and connect it to the purging air pipe instead. Blow purge air for at least 30 seconds in order to empty the fluid in the nozzles, pipes and hoses.

### At the GT:

2. To obtain an optimal Off-Line washing result, it may be necessary to enter the air inlet plenum and wash the compressor bellmouth and the inlet guide vanes by hand. Then the warnings in the beginning of this chapter must be strictly followed.
3. Close the drain valves SDB50- AA210, AA215, AA220, AA225 and AA230 on the GT.
4. If there is fluid left on the floor of the air inlet plenum and if there is a risk for ambient air temperatures of 0 °C and below during the following period of operation, the fluid has to be cleaned up. This is because the compressor is likely to be damaged if ice is ingested. When eliminating fluid the warning at the beginning of this chapter must be followed.

### At the OS:

5. Switch of 'Washing FG'.
6. Set in position 'AUTOMATIC':
  - 'FG Purging'
  - 'FG Barring' (if in manual position)
  - 'FG Lube Oil' (if in manual position)
7. Check that the GT is ready for start
8. The GT should be put into operation immediately after the washing in order to dry out the fluid. If the GT can not be started, it must be purged for at least 15 minutes. In conjunction with this it is recommended to check the GT ignition system as follows:
  - Activate 'FG Purging'. The gas generator accelerates to purging speed.
  - Wait until the purging time has elapsed.
  - Activate 'Pilot ignition FG'. Repeat until a stable flame indication is received.
9. Make a note in the Logbook that washing has been performed.
10. Make notes according to the enclosed Performance log sheet as soon as possible.

## 8 Appendices

1. Compressor Washing Log Sheet
2. Performance Log Sheet



