Wartsila

Electrical Output Test Guidelines

LG Engines

Appendix 7A – DRAFT TEST GUIDELINES – Net Electrical Output

Electrical power and heat rate test – Plant net

Appendix 7A – DRAFT TEST GUIDELINES – Net Electrical Output

1 Objective

This document describes the performance test guidelines for the Electrical Power and the Heat Rate test on plant level for a power plant. The performance test should show the compliance of the plant with the guarantees mentioned in the guarantee sheet taking into account the adjustment of power and heat rate according to the prevailing conditions at site during the performance test. Calculations and symbols used in this document are based on ISO 15550. ISO 98-3, ISO3046-1 and ISO3046-3 standards.

2 Symbols

Symbol	Definition	Unit
P	Power	kW
c	Adjustment factor	1
E_p	Electrical energy for power test	kWh
E_{hr}	Electrical energy for heat rate test	kWh
E_{su}	High voltage transformer losses, energy	kWh
E_{hv}	Electrical energy at high voltage side of step up transformer	kWh
E_{mv}	Electrical energy at medium voltage side of step up transformer	kWh
$mf_{,net}$	Mass of net fuel consumed	Kg, lb
F_{net}	Net fuel energy consumed	kJ, Btu
LHV_{test}	Lower heating value of fuel during test	MJ/kg, Btu/lb
hr	Heat rate	kJ/kWh, Btu/kWh
tt	Time	h
f	Frequency	Hz
N	Number of periods in test	1
U_E	Uncertainty of electrical energy measurement	%
U_F	Uncertainty of fuel energy measurement	%
U_{hr}	Uncertainty of heat rate measurement	%
U_{EMU}	Tolerance of electrical energy measuring unit	%
U_{LHV}	Uncertainty of lower heating value of fuel	%
U_{mf}	Uncertainty of fuel mass metering	%
$U_{transf,I}$	Uncertainty of measuring transformer, current	%
$U_{transf,U}$	Uncertainty of measuring transformer, voltage	%
α	Adjustment factor for engine power in electrical power test	
γ	Adjustment factor for parasitic load in electrical power test	

Prefixes

Δ	Difference, Tolerance

Subscripts

x	Contractual reference conditions
y	Test day conditions
el	Electrical
hr	Heat rate
period	Measuring period
measured	Measured value
adjusted	Adjusted value
ambient	Ambient conditions

frequency	Frequency
deteroration	Deteroration
guaranteed	Guaranteed value
Min	Minimum
Max	Maximum
average	Average

3 Measurements

Symbol	Definition	Measuring point	Unit	ISO Uncertainty, max	Wärtsilä Uncertainty, max [1)]
p_y	Total barometric pressure	Fixed according to altitude	kPa	± 0.5 %	± 0.2 %
t_y	Ambient air thermodynamic temperature	At site weather station/engine air intake filter	K	± 2 K	± 1 K
t_{cy}	Charge air coolant thermodynamic temperature	At charge air cooler inlet	K	± 2 K	± 1 K
mf_{in}	Mass of fuel in to engine	Engine/Plant specific mass flow meter	kg lb	± 3 %	± 1.0 %
mf_{out}	Mass of fuel out from engine	Engine/Plant specific mass flow meter	kg lb		± 1.0 %
mf_{leak}	Mass of leak fuel	LG Engine EFB DP flow meter	kg lb		± 1.0 %
LHV	Lower heating value	at Engine/Plant specific mass flow meter	MJ/kg Btu/lb		± 0.5 %
E	Electrical energy	PMU / EMU [2)]	kWh		± 0.5 %
I	Electrical current	Engine specific measuring transformer	A		± 0.5 %
U	Voltage	Engine specific measuring transformer	V		± 0.5 %
tt	time		h		± 0.1 %

[1)] Wärtsilä recommends equipments with these accuracies, however actual uncertainties of measuring equipment used during the test(s), shall be used for calculating Electrical Power and Heat rate as per section 4.6 and 5.4 respectively.

[2)] This is the point of measurement as per agreement between the Contractor and Owner.

4 Total Plant Electrical Power test

4.1 General

Total Plant (Net) Electrical Power test shall consist of at least 6 test periods. Each test period should be at least 0.5 hour long. All EG-sets should be running at nominal load and all conditions are to be maintained within the conditions specified for the performance test during the entire test.

The measurements shall be done using on site permanently installed measuring equipment as far as possible, portable measuring equipment can be used where needed.

The Electrical Power Test is preferably done concurrently with the Heat Rate Test.

The engines shall run at the preset electrical power for at least 2 hours prior to start of test and the plant shall be at a stable operating point.

The full test period should be split into shorter test periods, due to possible major variations in the ambient conditions during the full test period. The results of the single test periods are then used to calculate the average of the full test. The actual electrical power is the average of all test periods. The guaranteed electrical power is adjusted with corresponding adjustment factor for each period and then an average is calculated, which is the actual guaranteed electrical power for the full test period. An average of the ambient conditions prevailing over the full test period should under no circumstances be used for the adjustment.

For accuracy of the test it is important that all measurement readings are taken simultaneously. The single test periods can differ somewhat without affecting the accuracy of the test. The required measurements are done on half an hour basis and the readings are recorded on a form or in the plant control system. The point of measurement depends on the agreement between the Contractor and Owner.

Only equipment required for normal operation of the plant shall be running during the test. Any redundant equipment shall be shut down. A list detailing which consumers are connected during the test is included in section 6.

Should the test be interrupted by an event not attributed to the contractor, the test shall be resumed promptly after the cause of the interruption has been removed. The test will resume when the operating levels matches that at the time prior to the trip, and shall continue for the time remaining to be completed at the time of the interruption.

Plant net energy is measured using one or several PMU's (Power Measuring Unit) or a separate EMU:s (Energy Measuring Unit) depending on the points of measurement. The power calculated from the energy for each test period is used to calculate the average power for the electrical power test, and if being done concurrently also for the heat rate test.

$P = E_p / tt$

where $E_p = E_{mv}$ or E_{hv} dependent on the agreed point of measurement.

$E_{hv} = E_{mv} – E_{su}$

4.2 Adjustment of Electrical Power for ambient conditions

Adjustment of the Electrical Power depends on the ambient conditions during the test day. If the test conditions are different than the guarantee point, adjustments are done according to the correction curve in chapter 4.2.1 that is describing the impact of different ambient conditions on the plant net electrical power.

The adjustment of the guaranteed net power for each test period is calculated according to:

$P_{adjusted,\ guaranteed} = \alpha_i * P_{guaranteed}$

where:

α = net power correction factor, according to Figure 1

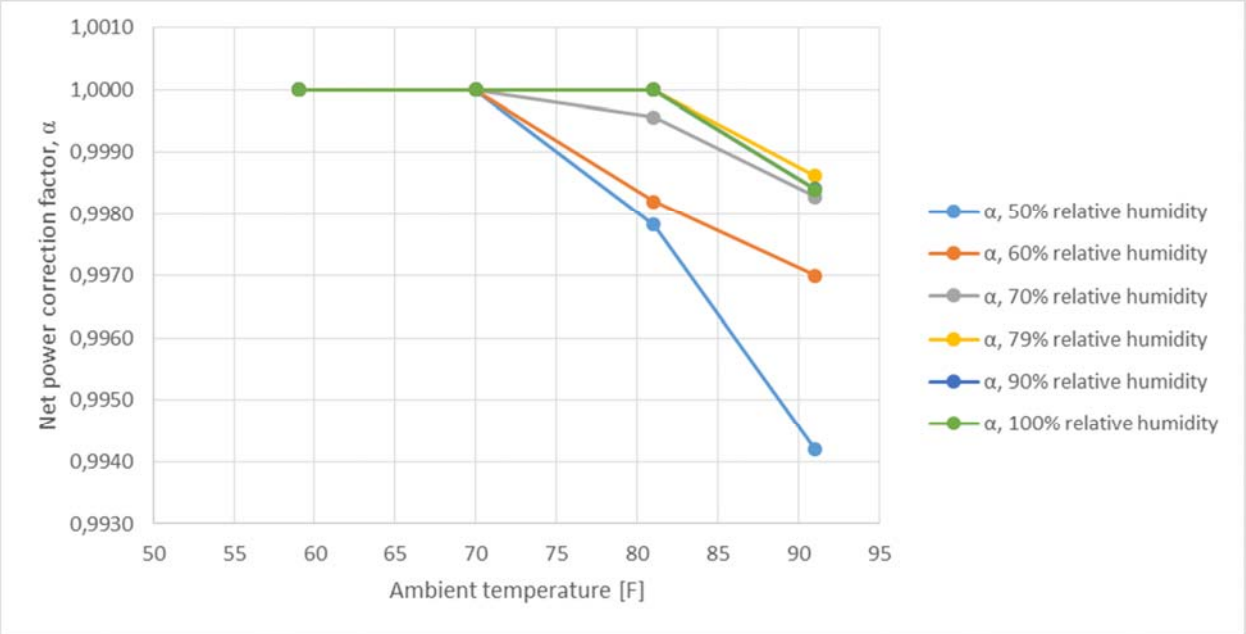
$P_{guaranteed}$ = net power at MV switch gear at guarantee conditions (refer to performance guarantees)

Index i corresponds to the individual test period.

4.2.1 Adjustment of Engine Power for ambient conditions

The plant net power shall be adjusted according to Figure 1. Linear interpolation shall be used to determine the adjusted guarantee power ($P_{adjusted, guaranteed}$) for the prevailing ambient conditions at the start of each test period.

Figure 1. Net power correction factor, α



Ambient temperature [F]	59	70	81	91
α, 50% relative humidity	1.0000	1.0000	0.9978	0.9942
α, 60% relative humidity	1.0000	1.0000	0.9982	0.9970
α, 70% relative humidity	1.0000	1.0000	0.9996	0.9983
α, 79% relative humidity	1.0000	1.0000	1.0000	0.9986
α, 90% relative humidity	1.0000	1.0000	1.0000	0.9984
α, 100% relative humidity	1.0000	1.0000	1.0000	0.9984

4.3 Grid frequency during performance test

The frequency of the grid has an impact on the output from the EG-set. The frequency should stay within 1 % of the nominal frequency during the performance test.

Larger fluctuations in frequency can be accepted in exceptional cases but should not in any case exceed 2 % of the nominal frequency.

4.4 Power factor during performance test

The power factor of the grid has an impact on the output from the EG-set.

Power factor during the performance test shall be equal to or above the reference value for guarantee conditions (typically 0.8 lagging at generator terminals). No adjustment will be made for power factors higher than the reference value.

4.5 Measurement uncertainties in electrical power test

The measurement uncertainties will cause an uncertainty in the measured electrical power. The components involved are the measuring transformers and the power measuring unit, or in some cases only the energy measuring unit. The typical uncertainty will be in the range of ± 0.3 % to 1.0 %.

Usage of uncertainties is according to VDI-2048.

$$U_E = 100 * \sqrt{(U_{EMU}/100)^2 + (\mathrm{U}_{\mathrm{transf,I}}/100)^2 + (\mathrm{U}_{\mathrm{transf,U}}/100)^2}$$

$\Delta P = P_{average} * (U_E/100)$, For definition of $P_{average}$ see chapter 4.6

4.6 Electrical Power

Average power for the electrical power test and also for the heat rate test, if being done concurrently, is according to formula below:

$$P_{average} = \frac{\sum_{i=1}^{N} P_{i,measured}}{N}$$

Where index i corresponds to each test period and N corresponds to amount of test periods during the full test period.

The guaranteed electrical power is adjusted according to the prevailing ambient conditions during each test period and the average of the adjusted guaranteed power for each period is:

$$P_{adjusted,guaranteed} = \frac{\sum_{i=1}^{N} P_{i,adjustedguaranteed}}{N}$$

The electrical power, when taking into account the uncertanties, is between:

$$P_{\max} = P_{average} + \Delta P$$

And

$$P_{\min} = P_{average} - \Delta P$$

The test is successfully passed if $P_{max} > P_{adjusted,guaranteed}$

The contractor is entitled to a possible bonus if $P_{min} > P_{adjusted, guaranteed}$. If $P_{adjusted, guaranteed}$ is between P_{min} and P_{max}, neither penalty nor bonus will apply.

5 Total plant Heat Rate test

5.1 General

Total plant net heat rate test shall consist of at least 6 test periods. Each test period should be at least 0.5 hour long. All EG-sets should be running at nominal load and all conditionsare to be maintained within the conditions specified for the performance test during the test.

The heat rate Test is preferably done concurrently with the electrical power test.

The engines shall run at the preset electrical power for at least 2 hours prior to start of test and the plant shall be at a stable operating point.

The full test period should be split into shorter test periods, due to possible major variations in the ambient conditions during the full test period. The actual heat rate is the average of all test periods. The guaranteed

heat rate is adjusted with corresponding adjustment factor for each period and then an average is calculated, which is the actual guaranteed heat rate for the full test period. An average of the ambient conditions prevailing over the full test period should under no circumstances be used for the adjustment.

For accuracy of the test it is important that all measurement readings are taken simultaneously. The single test periods can differ somewhat without affecting the accuracy of the test. The required measurements are done on half an hour basis and the readings are recorded on a form or in the plant control system. The point of measurement depends on the agreement between the contractor and owner.

Fuel samples are taken before and after the test. Two samples are taken at each sampling time. Both samples are to be sealed and signed, one is kept as a reference and the other is sent to an independent laboratory for analysis.

The fuel analysis should cover all the items stipulated in the fuel specification in agreement between the contractor and owner. The laboratory report shall include LHV and the tolerance on the LHV. The average LHV of the samples is used in all calculations.

The same requirements for frequency, power factor and operation of equipment apply during the Heat Rate test as during the electrical power test.

Should the test be interrupted by an event not attributed to the contractor, the test shall be resumed promptly after the cause of the interruption has been removed. The test will resume when the operating levels matches that at the time prior to the trip, and shall continue for the time remaining to be completed at the time of the interruption.

$$F_{net} = mf_{net} * LHV_{test}$$

Where, mf_{net}= fuel flow to engines measured during test duration

$$hr = F_{net} / E_{hr}$$

5.2 Adjustment of Heat Rate for ambient conditions

Adjustment of the heat rate depends on the ambient conditions during the test day. If the test conditions are different than the guarantee point, adjustments are done according to the correction curve in Figure 2 that is describing the impact of different ambient conditions on the plant net heat rate.

The adjustment of the guaranteed heat rate for each test period is calculated according to:

$hr_{adjusted,guaranteed} = \beta_i * hr_{guaranteed}$

where:

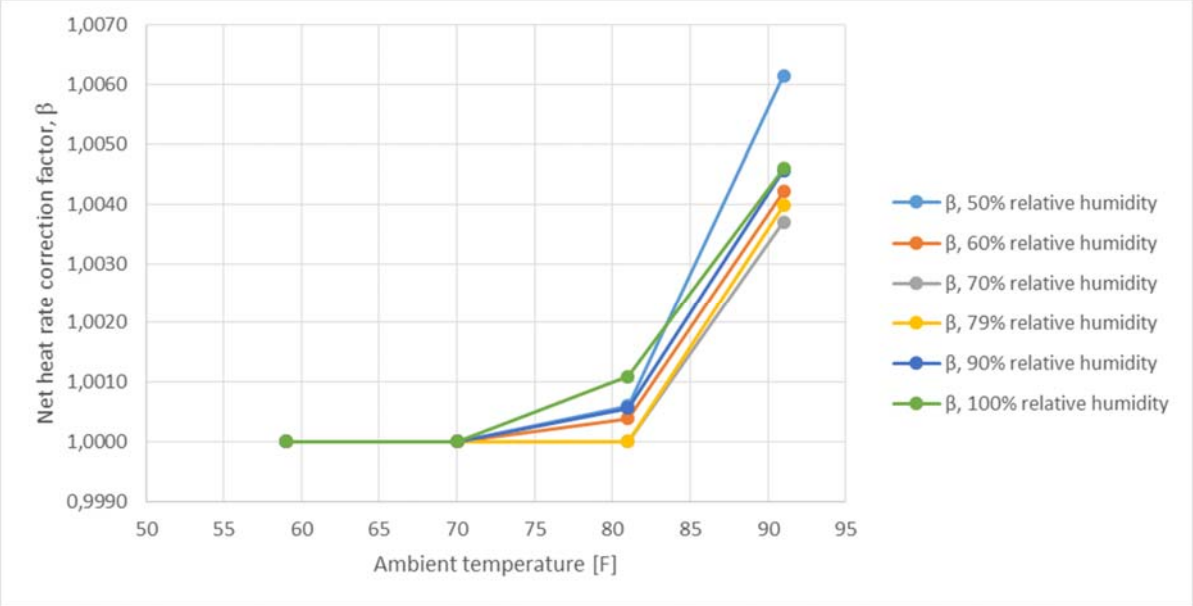
β = net heat rate correction factor for ambient conditions.

$hr_{guaranteed}$ = LHV based net heat rate at MV switch gear at guarantee conditions (refer to performance guarantees).

Index i corresponds to the individual test period.

The plant net heat rate shall be adjusted according to Figure 2. Linear interpolation shall be used to determine the adjusted guarantee heat rate ($hr_{adjusted,\ guaranteed}$) for the prevailing ambient conditions at the start of each test period.

Figure 2. Net heat rate correction factor, β



Ambient temperature [F]	59	70	81	91
β, 50% relative humidity	1.0000	1.0000	1.0006	1.0062
β, 60% relative humidity	1.0000	1.0000	1.0004	1.0042
β, 70% relative humidity	1.0000	1.0000	1.0000	1.0037
β, 79% relative humidity	1.0000	1.0000	1.0000	1.0040
β, 90% relative humidity	1.0000	1.0000	1.0006	1.0046
β, 100% relative humidity	1.0000	1.0000	1.0011	1.0046

5.3 Measurement uncertainties in Heat Rate test

The measurement uncertainties will cause an uncertainty in the measured heat rate. The components involved, in addition to the power measurement, are the fuel flow meters. For Natural Gas and Liquid Fuel consumption metering Units the uncertainty will be in the range of ± 0.3-1.0 %.

Usage of uncertainties is according to VDI-2048.

U_{mf} = uncertainty specified for the fuel flow measurement

$$U_F = 100 * \sqrt{(U_{LHV}/100)^2 + (U_{mf}/100)^2}$$

$$U_E = 100 * \sqrt{(U_{EMU}/100)^2 + (U_{transf,I}/100)^2 + (U_{transf,U}/100)^2}$$

$\Delta hr = hr_{measured} * \sqrt{(U_F/100)^2 + (U_E/100)^2}$, For definition of $hr_{average}$ see chapter 5.4

5.4 Heat Rate

The heat rate is the average of the measured heat rate for each period:

$$hr_{average} = \frac{\sum_{i=1}^{N} hr_{i,measured}}{N}$$

Where index i corresponds to each test period and $hr_{i,measured}$ is the heat rate for each individual test period.

The guaranteed heat rate is adjusted according to the prevailing ambient conditions for each test period and the adjusted guaranteed plant heat rate ($hr_{adjusted,guaranteed}$) for the full test period is calculated according to:

$$hr_{adjusted,guaranteed} = \frac{\sum_{i=1}^{N} hr_{i,adjusted}}{N}$$

The heat rate is between:

$$hr_{max} = hr_{average} + \Delta hr$$

$$hr_{min} = hr_{average} - \Delta hr$$

The test is successfully passed if $hr_{min} < hr_{adjusted, guaranteed}$.

The contractor is entitled to a possible bonus if $hr_{max} < hr_{adjusted, guaranteed}$. If $hr_{adjusted,guaranteed}$ is between hr_{min} and hr_{max}, neither penalty nor bonus will apply.

6 List of auxiliary equipment operational status during tests

Auto Mode: Equipment is running continuously or intermittently, governed by the plant control system

Shut down: Equipment is not running

Equipment	Auto mode	Shut down
Fuel unloading pump	x	
Main fuel feeder	x	
Engine feeder pump	x	
Pilot fuel feeder	x	
Engine hall lighting	x	
Generator side ventilation	x	
Auxiliary side ventilation	x	
Electrical building lighting	x	
Control room AC	x	
Swich gear cooling	x	
Fuel unloading station lighting	x	
Compressor room ventilation	x	
Starting air compressors *(these compressors are shared between WAPA 1 & WAPA2 – no starting of engines will be allowed for WAPA 1 during the test)*	x	
Instrument air compressors	x	
Site lighting	x	
Engine radiator fans	x	
DC system chargers, 110V	x	
Fire detection system	x	
Smoke detection system	x	
Crank case oil mist separator	x	
Vent collection compressors	x	
LG high pressure pumps	x	
LG pilot pumps	x	
Exhaust gas fans	x	
Voxidizer/RTO	x	
SCR	x	

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Heat Rate (LFO) Test Guidelines

LG Engines

Electrical Power and Heat Rate Test – Diesel engines

Contents

Appendix 7A – DRAFT TEST GUIDELINES – Heat Rate (LFO)

1 Objective

The electrical power and heat rate can be tested to show compliance with the guarantees mentioned in the guarantee sheet. This document describes the adjustment of power and heat rate according to the prevailing conditions at site during the performance test of the power plant. Calculations and symbols used in this document are based on ISO 15550, ISO 98-3, ISO3046-1 and ISO3046-3 standards.

2 Symbols

Symbol	Definition	Unit
b	Specific fuel consumption	kg/kWh, lb/kWh
k	Ratio of indicated power	1
m	Exponent of the dry air pressure ratio or total barometric pressure ratio	1
n	Exponent of the ambient air thermodynamic temperature ratio	1
p	Total barometric pressure	kPa
P	Power	kW
s	Exponent of the charge air coolant thermodynamic temperature ratio	1
t_c	Charge air coolant temperature at inlet to cooler	C
t	Ambient air temperature	C
T_c	Charge air coolant thermodynamic temperature	K
T	Ambient air thermodynamic temperature	K
α	Power adjustment factor	1
β	Fuel consumption recalculation factor	1
η	Efficiency	1
E	Electrical energy	kWh
mf	Mass of fuel	Kg, lb
F	Fuel energy	kJ,Btu
LHV	Lower heating value of fuel during test	MJ/kg, Btu/lb
hr	Heat rate	kJ/kWh, Btu/kWh
tt	Time	h
N	Number of periods in test	1
U_{EMU}	Uncertainty of electrical energy measuring unit	%
U_{LHV}	Uncertainty of lower heating value of fuel	%
U_{mf}	Uncertainty of fuel mass metering	%
$U_{transf,I}$	Uncertainty of measuring transformer, current	%
$U_{transf,U}$	Uncertainty of measuring transformer, voltage	%

Prefixes

Δ	Difference, Uncertainty

Subscripts

m	Mechanical
r	Standard reference conditions
ra	Substitute reference conditions
x	Contractual reference conditions (Site conditions)
y	Test day conditions

in	To engine
out	From engine
guaranteed	Guaranteed value
measured	Measured value
adjusted	Value adjusted according to ambient conditions
test	Test value during performance test
leak	Leak fuel
min	Minimum
max	Maximum
net	Net value
average	Average

3 Measurements

Symbol	Definition	Measuring point	Unit	ISO Tolerance, max	Wärtsilä Uncertainty, max [1)]
p_y	Total barometric pressure	Fixed according to altitude	kPa	± 0,5 %	± 0,2 %
t_y	Ambient air thermodynamic temperature	At site weather station/engine air intake filter	K	± 2 K	± 1 K
t_{cy}	Charge air coolant thermodynamic temperature	At charge air cooler inlet	K	± 2 K	± 1 K
mf_{in}	Mass of fuel in to engine	Engine/Plant specific mass flow meter	kg lb	± 3 %	± 0,5 %
mf_{out}	Mass of fuel out from engine	Engine/Plant specific mass flow meter	kg lb		± 0,5 %
mf_{leak}	Mass of leak fuel		kg lb		± 1,0 %
LHV	Lower heating value	at Engine/Plant specific mass flow meter	MJ/kg Btu/lb		± 0,5 %
E	Electrical energy	PMU / EMU [2)]	kWh		± 0,5 %
I	Electrical current	Engine specific measuring transformer	A		± 0,5 %
U	Voltage	Engine specific measuring transformer	V		± 0,5 %
tt	time	N/A	h		± 0,1 %

[1)] Wärtsilä recommends equipments with these accuracies, however actual uncertainties of measuring equipment used during the test(s), shall be used for calculating electrical power and heat rate as per section 4.6 and 5.4 respectively.

[2)] This is the point of measurement as per agreement between the contractor and owner.

For η_m (mechanical efficiency) Wärtsilä uses the value 0.9 in the heat rate and electrical power calculations.

The energy is measured using a PMU (Power Monitoring Measuring Unit) or a separate EMU (Energy Measuring Unit) depending on the point of measurement. The power is calculated from the energy for each test period.

$P = E / tt$

4 Electrical Power Test

4.1 General

The electrical power test is preferably done concurrently with the heat rate test.

The engines involved in the test shall run for 2 (two) hours at full load prior to the start of the test in order to achieve stable conditions in all engine components and external systems.

Because there can be major variations in the ambient conditions during the full test period, it is important to split the full test into shorter test periods. These single test periods are then used to calculate the average of the full test. Please note that under no circumstances should an average of the ambient conditions prevailing over the full test be used for the adjustment. Each single test period should be at least 0.5 hour long and the full test should consist of at least 4 test periods.

The required measurements are done on half an hour basis and the readings are recorded on a form or in the plant control system. For accuracy of the test it is important that all measurement readings are taken simultaneously. The period can differ somewhat from 0,5 hour without affecting the accuracy of the test.

The electrical power is calculated from the produced electrical energy during each test period. The actual electrical power and actual fuel consumed is naturally the sum of all test periods.

The measured electrical power and heat rate for each single test period is adjusted for the ambient conditions prevailing and measured at the start of each test period.

The final measured power and heat rate during the full test is the average of the adjusted powers and the average of the adjusteded heat rates, which are calculated separately for each half an hour test period.

The point of measurement depends on the agreement between the Contractor and Owner.

Should the test be interrupted by an event not attributed to the Contractor, the test shall be resumed promptly after the cause of the interruption has been removed. The test will resume when the operating levels matches that at the time prior to the trip, and shall continue for the time remaining to be completed at the time of the interruption.

The substitute reference conditions are described in the Power Plants performance figures sheet.

4.2 Adjustment of Electrical Power for ambient conditions

The ISO 15550 and ISO 3046 standards give a uniformed way to adjust performance from one condition to another. The adjustment is always done via reference conditions that can be either the standard reference conditions as stipulated in ISO 15550:2002 clause 5 or the substitute reference conditions declared by the engine manufacturer.

The formulas below are according to ISO 3046. The exponent values have been defined by the engine manufacturer according to ISO 3046-1:2002.

Exponent values are: m = **0.7** n = **3.0** s = **2.5**

Test day conditions							
t_y		ºC		ºF	T_y		K
t_{cy}		ºC		ºF	T_{cy}		K
p_y		kPa					
η_m							
P_y		kW					

$$k = \left(p_y / p_{ra}\right)^m * \left(T_{ra} / T_y\right)^n * \left(T_{cra} / T_{cy}\right)^s$$ ISO 3046-1:2002(E), (5)

where

$(p_y / p_{ra})^m \leq 1$

$(T_{ra} / T_y)^n \leq 1$

$(T_{cra} / T_{cy})^s \leq 1$

$$\alpha = k - 0.7 * (1 - k) * (1 / \eta_m - 1)$$ ISO 3046-1:2002(E), (2)

$$P_{ra} = P_y / \alpha$$ ISO 3046-1:2002(E), (1)

Substitute reference conditions							
t_{ra}	45	ºC	113	ºF	T_{ra}	318.15	K
t_{cra}	55	ºC	131	ºF	T_{cra}	328.15	K
p_{ra}	100	kPa					
η_m	0.9						
P_{ra}	9000	kW					

$$k = \left(p_x / p_{ra}\right)^m * \left(T_{ra} / T_x\right)^n * \left(T_{cra} / T_{cx}\right)^s$$ ISO 3046-1:2002(E), (5)

where

$(p_x / p_{ra})^m \leq 1$

$(T_{ra} / T_x)^n \leq 1$

$(T_{cra} / T_{cx})^s \leq 1$

$$\alpha = k - 0.7 * (1 - k) * (1 / \eta_m - 1)$$ ISO 3046-1:2002(E), (2)

$$P_x = \alpha * P_{ra}$$ ISO 3046-1:2002(E), (1)

Contractual Reference Conditions (Site conditions)							
t_x	27,2	ºC	81	ºF	T_x	300.35	K
t_{cx}	53	ºC	127.4	ºF	T_{cx}	326.15	K
p_x	100	kPa					

η_m	0.9						
P_x	9000	kW					

Humidity of the intake air may condense and form liquid water in the charge air cooler (CAC), when the ambient humidity is high. Wärtsilä diesel engines use dew point control to limit condensation in the CAC. When the dew point control is active, it may increase the charge air coolant temperature set point at CAC inlet. In such a situation the charge air coolant temperature derating break point (substitute reference condition Tcra) will be adjusted according to the calculated CAC dew point temperature and override the nominal derating break point.

4.3 Grid frequency during performance test

The frequency of the grid has an impact on the output from the EG-set. The frequency should stay within 1 % of the nominal frequency during the performance test.

Larger fluctuations in frequency can be accepted in exceptional cases but should not in any case exceed 2 % of the nominal frequency.

4.4 Power factor during performance test

The power factor of the grid has an impact on the output from the EG-set.

Power factor during the performance test shall be equal to or above the reference value for guarantee conditions (typically 0,8 lagging at generator terminals). No adjustment will be made for power factors higher than the reference value.

4.5 Measurement uncertainties during electrical power test

The measurement uncertainties will cause an uncertainty in the measured electrical power. The components involved are the measuring transformers and the power measuring unit, and in some cases only the energy measuring unit. The typical uncertainty will be in the range of ± 0.3 % to 1.0 %.

Usage of uncertainties is according to VDI-2048.

$$U_E = 100 * \sqrt{(U_{EMU}/100)^2 + (U_{transf,I}/100)^2 + (U_{transf,U}/100)^2}$$

$\Delta P = P_{average} * (U_E/100)$, for definition of $P_{average}$ see 4.6.

4.6 Calculation of Electrical Power

Average measured and adjusted power for the electrical power test is according to below formula:

$$P_{average} = \frac{\sum_{i=1}^{N} P_{i,adjusted}}{N}$$

The Electrical Power, when taking into account the uncertainties, is between

$$P_{\max} = P_{average} + \Delta P$$

And

$$P_{\min} = P_{average} - \Delta P$$

The test is successfully passed if $P_{max} > P_{guaranteed}$

The contractor is entitled to a possible bonus if $P_{min} > P_{guaranteed}$. If $P_{guaranteed}$ is between P_{min} and P_{max}, neither penalty nor bonus will apply.

5 Heat Rate Test

5.1 General

The heat rate test is preferably done concurrently with the electrical power test.

The engines involved in the test shall run for 2 (two) hours at full load prior to the start of the test in order to achieve stable conditions in all engine components and external systems.

The required measurements are done on half an hour basis and the readings recorded on a form or in the plant control system. For accuracy of the test it is important that all measurement readings are taken simultaneously. The period can differ somewhat from half an hour without affecting the accuracy of the test. Each single test period should be at least 0.5 hour long and the full test should consist of at least 4 test periods.

The electrical power is calculated from the produced electrical energy during each test period, see chapter 4. The measured electrical power and heat rate for a single test period is adjusted for the ambient conditions prevailing and measured at the start of each single test period.

The final measured power and heat rate during the full test is the average of the adjusted powers and the average of the adjusted heat rates, which are calculated separately for single test period.

The point of measurement depends on the agreement between the contractor and owner.

Fuel samples are taken before and after the test. If samples are taken during the test, then the amount of samples and spillage is to be deducted from the measured fuel consumption. Two samples are taken at each sampling time. Both samples are sealed and signed, one is kept as a reference and the other is sent to an independent laboratory for analysis.

The analysis should cover all the items stipulated in the fuel specification in agreement between the contractor and owner. The laboratory report shall include LHV and the uncertainty of the LHV measurement. The average LHV of the samples is used in all calculations.

Unless stated otherwise, all heat rate figures in this document are LHV based.

Same requirements for frequency, power factor and operation of equipment apply during the heat rate test as during the electrical power test.

Should the test be interrupted by an event not attributed to the Contractor, the test shall be resumed promptly after the cause of the interruption has been removed. The test will resume when the operating levels matches that at the time prior to the trip, and shall continue for the time remaining to be completed at the time of the interruption.

5.2 Adjustment of Heat Rate for ambient conditions

The ISO 15550 and ISO 3046 standards give a uniformed way to adjust performance from one condition to another. The adjustment is always done via reference conditions as stipulated in ISO 15550:2002 clause 5.

The formulas below are according to ISO 3046. The exponent values have been defined by the engine manufacturer for according to ISO 3046-1:2002.

Exponent values are: m = **0.7** n = **0.78** s = **1**

Test day conditions							
t_y		ºC		°F	T_y		K
t_{cy}		ºC		°F	T_{cy}		K
p_y		kPa			η_m		
hr_y		kJ/kWh		Btu/kWh			

$$k = \left(p_y / p_r\right)^m * \left(T_r / T_y\right)^n * \left(T_{cr} / T_{cy}\right)^s$$ ISO 3046-1:2002(E), (5)

$$\alpha = k - 0.7 * (1 - k) * (1/\eta_m - 1)$$ ISO 3046-1:2002(E), (2)

$$\beta = k / \alpha$$ ISO 3046-1:2002(E), (8)

$$b_r = b_y / \beta$$ ISO 3046-1:2002(E), (7)

or

$hr_r = hr_y / \beta$

Standard reference conditions							
t_r	25	ºC	77	°F	T_r	298,15	K
t_{cr}	38	ºC	100,4	°F	T_{cr}	311,15	K
p_r	100	kPa			η_m		
hr_r		kJ/kWh		Btu/kWh	hr_r		

$$k = \left(p_x / p_r\right)^m * \left(T_r / T_x\right)^n * \left(T_{cr} / T_{cx}\right)^s$$ ISO 3046-1:2002(E), (5)

$$\alpha = k - 0.7 * (1 - k) * (1/\eta_m - 1)$$ ISO 3046-1:2002(E), (2)

$$\beta = k/\alpha$$ ISO 3046-1:2002(E), (8)

$$b_x = \beta * b_r$$ ISO 3046-1:2002(E), (7)

or

$$hr_x = \beta * hr_r$$

Contractual Reference Conditions (Site conditions)							
t_x	27,2	ºC	81	ºF	T_x	300,35	K
t_{cx}	53	ºC	127,4	ºF	T_{cx}	326,15	K
p_x	100	kPa			η_m	0,9	
hr_x	8479	kJ/kWh	8037	Btu/kWh			

The heat rate figures in the tables above are all LHV based. The corresponding HHV based heat rate at contractual reference conditions is 9258 kJ/kWh or 8775 Btu/kWh when assuming an HHV/LHV ratio of 1,08618. For a different HHV/LHV ratio, the HHV based heat rate at contractual reference conditions shall be adjusted as follows:

*Adjusted heat rate guarantee (HHV) = Heat rate guarantee (HHV) * HHV/LHV ratio / 1,08618*

The fuel flow is measured according to agreed point of measurement(s) and calculated for each test period separately.

$$mf_{measured} = mf_{in} - mf_{out}$$

mf_{in} = fuel flow to engine measured for the test duration

mf_{out} = fuel flow return from engine measured for the test duration

$$mf_{net} = mf_{measured} - mf_{storage} - mf_{leak}$$

$mf_{storage}$ = fuel stored during the test duration

mf_{leak} = leak fuel flow for the test duration

$$F_{net} = mf_{net} * LHV_{test}$$

$$hr_{measured} = F_{net} / E_{measured}$$

$E_{measured}$ = Measured electrical energy during Heat Rate test

The measured heat rate for each period is adjusted according to prevailing conditions for the period.

5.3 Measuring uncertainties in Heat Rate test

Usage of uncertainties is according to VDI-2048.

$$U_{mf} = 100 * \sqrt{\left(U_{mf,in}/100\right)^2 + \left(\mathrm{U_{mf,out}}/100\right)^2}$$

$$U_F = 100 * \sqrt{\left(U_{LHV}/100\right)^2 + \left(\mathrm{U_{mf}}/100\right)^2}$$

$$U_E = 100 * \sqrt{\left(U_{EMU}/100\right)^2 + \left(\mathrm{U_{transf,I}}/100\right)^2 + \left(\mathrm{U_{transf,U}}/100\right)^2}$$

$\Delta hr = hr_{average} * \sqrt{\left(U_E/100\right)^2 + \left(\mathrm{U_F}/100\right)^2}$, for definition af $hr_{average}$ see 5.4

5.4 Calculation of Heat Rate

Average measured and adjusted heat rate for the heat rate test is according to below formula:

$$hr_{average} = \frac{\sum_{i=1}^{N} hr_{i,adjusted}}{N}$$

The heat rate is between

$$hr_{\max} = hr_{average} + \Delta hr$$

$$hr_{\min} = hr_{average} - \Delta hr$$

The test is successfully passed if $hr_{min} < hr_{guaranteed}$.

The contractor is entitled to a possible bonus if $hr_{max} < hr_{guaranteed}$. If $hr_{guaranteed}$ is between hr_{min} and hr_{max}, neither penalty nor bonus will apply.

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Heat Rate (LG) Test Guidelines

LG Engines

Contents

1 Objective

The Electrical Power and Heat Rate can be tested to show compliance with the guarantees mentioned in the guarantee sheet. This document describes the adjustment of power and heat rate according to the prevailing conditions at site during the performance test of the power plant. Calculations and symbols used in this document are based on ISO 15550, ISO 98-3, ISO3046-1 and ISO3046-3 standards.

The Electrical Power test and Heat Rate test for Liquid Gas (LG) engines should be done according to the Electrical Power test and Heat Rate test for the applicable main fuel/alternate fuel: C_3 – C_{20} mixes/diesel, pilot fuel: diesel.

2 Symbols

Symbol	Definition	Unit
C_x	Carbon number, e.g. C_1, C_2, C_3 = methane, ethane, propane	
E	Electrical energy	kWh
EFB	Engine fuel booster	
F	Fuel energy	kJ, Btu
mf	Mass of fuel	Kg, lb
LHV	Lower heating value of fuel	MJ/kg, Btu/lb
hr	Heat rate	kJ/kWh, Btu/kWh
U_{EMU}	Uncertainty of electrical energy measuring unit	%
U_E	Uncertainty of electrical energy measurement	%
U_F	Uncertainty of fuel energy measurement	%
U_{LHV}	Uncertainty of lower heating value of fuel	%
U_{mf}	Uncertainty of fuel mass metering	%
$U_{transf,I}$	Uncertainty of measuring transformer, current	%
$U_{transf,U}$	Uncertainty of measuring transformer, voltage	%

Prefixes

Δ	Difference, Tolerance

Subscripts

test	Test value
main	Main fuel: (C_3 – C_{20}) OR Alternate fuel: diesel
pilot	Pilot fuel
total	Sum of main and pilot fuel
start	Beginning of test
stop	End of test
hr	Heat rate
measured	Measured value during test

3 Electrical Power test

The Electrical Power test should be done according to the Electrical Power test for the main fuel/alternate fuel: C_3 – C_{20} mixes/diesel, pilot fuel: diesel.

4 Heat Rate test

The Heat Rate test should be done according to the Heat Rate test for the main fuel/alternate fuel: C_3 – C_{20} mixes/diesel, pilot fuel: diesel.

4.1 Pilot fuel in Heat Rate Test

The Pilot fuel consumption has to be added to the main fuel consumption in heat rate calculations. The measuring tolerances for the pilot fuel measurement should be added to the tolerances for the total fuel flow measurements.

Engine fuel booster module has two diesel/gas separators. Diesel liquid is returned inside EFB fuel supply line to engine as fuel. To avoid diesel liquid accumulation term in EFB, liquid levels should be set to Low level before start of test and before end of test. Gas phase flows out of the EFB are measured and reconditioned to $C_3 - C_{20}$ liquid phase and returned in plant common supply line.

$$mf_{pilot,measured} = mf_{pilot,stop} - mf_{pilot,start}$$

$mf_{\text{pilot,measured}}$ = pilot fuel consumption measured for the engine during the test duration

$$F_{pilot,measured} = mf_{pilot,measured} * LHV_{pilot,test}$$

$$F_{main,measured} = mf_{main,measured} * LHV_{main,test}$$

$$F_{total,measured} = F_{main,measured} + F_{pilot,measured}$$

$$hr_{total,measured} = F_{total,measured} / E_{hr}$$

4.2 Measurement tolerances in Heat Rate test

The measurement uncertanties will cause an uncertainty in the measured electrical power. The components involved are the measuring transformers, the power measuring unit (or only the energy measuring unit), the fuel flow meter and fuel heating value analysis. The typical uncertanties will be in the range of ± 0,5 % to 1,0 %.

Usage of uncertainties is according to VDI-2048.

Engine specific fuel mass flow measurement:

$$U_{mf} = 100 * \sqrt{(F_{main} / F_{total}) * (U_{main,mf} / 100)^2 + (F_{pilot} / F_{total}) * (U_{\text{pilot,mf}} / 100)^2}$$

$U_{main,\text{mf}}$ = Uncertainty of the main fuel mass flow measurement

$U_{pilot,\text{mf}}$ = Uncertainty of the pilot fuel mass flow measurement

$$U_F = 100 * \sqrt{(F_{main} / F_{total}) * (U_{main,LHV} / 100)^2 + (F_{pilot} / F_{total}) * (U_{\text{pilot, LHV}} / 100)^2 + (U_{mf} / 100)^2}$$

$$U_E = 100 * \sqrt{(U_{EMU} / 100)^2 + (U_{\text{transf,I}} / 100)^2 + (U_{\text{transf,U}} / 100)^2}$$

Uncertainty of the heat rate measurement

$$\Delta hr = hr_{measured} * \sqrt{(U_E/100)^2 + (U_F/100)^2}$$

4.3 Calculation of Heat Rate

The heat rate is calculated as described in the performance test guideline for the main fuel.

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Noise Level Test Guidelines

LG Engines

Appendix 7A - Noise level test guidelines

Appendix 7A – DRAFT TEST GUIDELINES – Noise Level

1 Objective

The objective of this test is to determine the noise level of the power plant facility or plant component as measured in accordance with the procedures described hereafter. Compliance of the measured noise level of the Facility or Component with the set noise level limit or guarantee will be demonstrated during plant commissioning or performance test. All noise level measurements will be arranged by the Owner in accordance with Limits and Obligations of the Contract or the Environmental Licence.

2 Measurement Equipment

The measurement instrument shall be an integrating sound level meter, which directly calculates the A-weighted equivalent continuous sound pressure level $L_{Aeq,\,T}$ where T indicates the sampling time.

The sound level meter should comply with international standard IEC 61672-1:2002 or ANSI S1.4 requirements for "class 1" instrument. If an older instrument is used, it shall comply with requirements set in IEC 60804 for "type 1" integrating sound level meter.

The performance of the measurement equipment shall be field-checked by using an external, traceably calibrated sound level calibrator or a pistonphone in conforming IEC 60942:2003 or ANSI standard S1.40 in accordance with good measurement practice. The sound level meter calibration level shall be checked immediately before and after each measurement session.

3 Measurement Procedure

3.1 Plant Environmental Noise

3.1.1 Standard Measurement Procedures

The noise measurements shall be conducted in accordance with the following standards (or relevant later editions of the relevant standard):

- ISO 1996/1 Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures. 2016
- ISO 1996/2 Acoustics - Description, measurement and assessment of environmental noise. Part 2: Determination of environmental noise levels. 2015

Practical comments and recommendations for the application of above-mentioned standards on the plant environmental noise measurement are given in the following chapters 3.1.2, 3.1.3, 3.1.4, 3.1.5. In case the practical recommendations are in conflict with the standard, the standard shall be applied.

3.1.2 Measurement Positions

Prior to commencing noise measurements the Contractor and the Owner shall carry out a joint survey of the measurement positions. The Owner, or if so deemed necessary, the Independent Consultant, shall measure the noise at these mutually defined measurement positions.

The measurements shall be made where possible in open environment. The environment is defined as open if there are no vertical surfaces, which would reflect sound (e.g. building walls) within 10 meters from the measurement position or the sound source.

If in practical measurement situation there are vertical reflective surfaces in existence close to any of the measurement positions, compensation to measurement result(s) shall be made according to ISO 1996-2:2007 Annex B Microphone positions relative to reflecting surfaces. Placing microphone near a reflecting surface results to 3...6 dB (L_{refl}) increase in measurement results due to reflection from the vertical reflective surface(s). In case of reflections the test item is defined to comply with set noise performance guarantee level, if the test result L_{test} from which the relevant L_{refl} is subtracted, is less than or equal to the guarantee level L_{gtd}, or

$$L_{\text{test}} \leq L_{\text{gtd}} + \text{L}_{\text{refl}}$$

The microphone height shall be 1.5 meters above the ground level.

All reasonable precautions shall be taken to minimise the influence on the readings from sources of interference, such as inclement weather conditions and electrical interference. The microphones should have and effective windshield fitted during noise measurements to minimise the effects of wind turbulence

3.1.3 Sampling Time

The duration of a measurement at one measurement position shall be 180 seconds to ensure that the measured values are representative of the sound level emitted. At each measurement position, 3 separate measurements shall be performed, in order to make the duration of the whole measurement at one position at least 9 minutes excluding weather events.

If significant background noise level variance exists at a specific measurement location measurement time shall be increased in order to minimize background noise fluctuation effects to the measurement results.

If any individual measurement result differs remarkably from other measurement results considering the relevant noise levels, it is to be ignored. **The final measured result is the arithmetic average of all relevant measured results at current location.**

3.1.4 Weather Conditions

Noise measurements shall not be conducted during periods of rain or in windy conditions due to the potential negative impact on noise measurements during such conditions. Wind conditions below 5 m/s as measured at a minimum height of 2 meters above ground shall be considered acceptable. The wind direction and speed shall be measured with an anemometer or referenced to a close by weather station.

3.1.5 Background Noise Correction

On completion of the tests, the measured values will be corrected for the measured background noise. The resulting noise impact from the Facility, at each measurement position, shall be compared with the noise level guarantee or noise level limits set in the environmental license.

The procedure for measuring the noise impact of a power plant under conditions of background noise shall be the following:

- The background noise level (L_N) shall be measured when the Facility is shut down.
- The total noise level (L_{S+N}) will be measured when the Facility is running at full load.
- The difference between those two readings ($L_{S+N} - L_N$) shall be calculated.
    - If the difference is less than 3 dB(A), the background noise level is too high for an accurate measurement and the Facility is deemed to have met the Noise Level Guarantee.
    - If the difference is between 3 and 10 dB(A), a correction ΔL_N will be required (see Figure 1 below).
    - If the difference is greater than 10 dB(A), no correction ΔL_N will be required.
- The chart presented below shall be used for corrections. The x-axis describes the difference value ($L_{S+N} - L_N$) obtained by the procedure described above. The intersection of the x-value and the curve is used to get the correction from the y-axis.
- The background noise measurements and the total noise level measurements shall be taken at approximately the same time of day (but not necessary on the same day) to ensure the accuracy of the results.

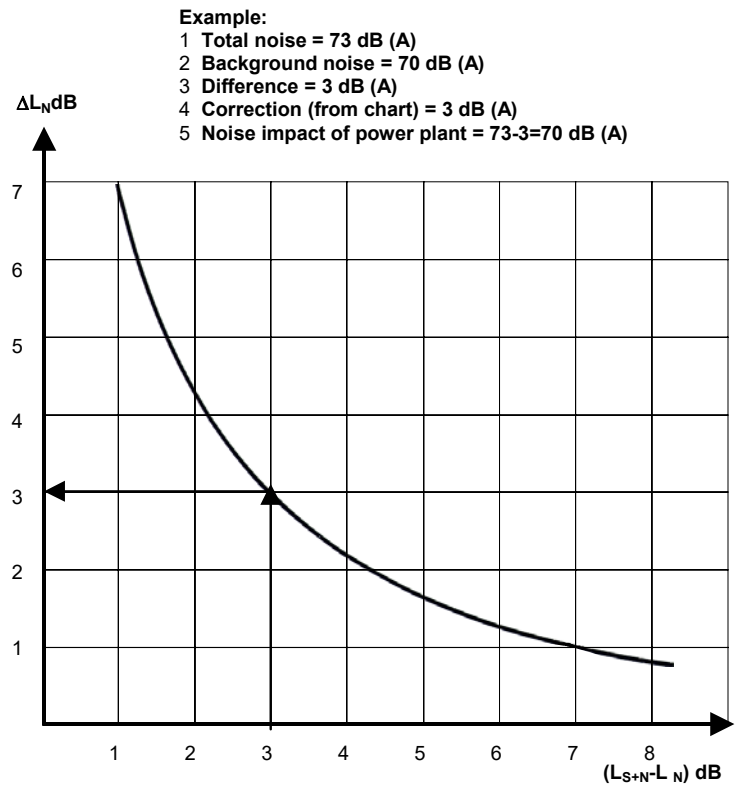

Figure 1: Correction for background noise.

The value on the y-axis (ΔL_N) will be subtracted from the total noise level in order to get the actual emitted sound level L_S of the Facility for the verification

$L_S = L_{S+N} - \Delta L_N$

3.2 Measurements indoors

Measurements shall be performed according to Measurement of low frequency noise in rooms [1] p.41 measurement method 1 – constant noise method. This method has been presented in the 14th International Meeting on Low Frequency Noise and Vibration and its Control.

3.2.1. Average in the middle of the room.

This measurement is done by scanning in the middle of the room in a room volume of at least 1 m3. This measurement corresponds with building acoustic measurements carried out by in, e.g. ISO 10052 and ISO 140-5. The measurement lasts 30 seconds and the microphone shall not be closer than 1 meter from room surfaces.

3.2.2. Measurement in occupants' positions

The microphone should preferably be scanned through a hypothetical volume of 0.3 x 0.3 x 0.3 m in a normal working position for example at control room operators head position. The measuring locations need to be described in layout drawing to allow repeated measurements.

3.2.3. Reported measurement results

Arithmetic average of all relevant measurement results from one room shall be reported.

3.3 Plant Component Noise

3.3.1 Standard Measurement Procedures

- ISO 9614: Parts 1-3 Acoustics - Determination of sound power levels of noise sources using sound intensity
- ISO 8528 part 10: 1998 Reciprocating internal combustion engine driven alternating current generating sets – Measurement of airborne noise by the enveloping surface method.
    - Engine surface averaged sound pressure level is measured and defined according to this standard. Standard is followed until the end of paragraph 13.2 Calculation of the measuring surface sound pressure levels.
- ISO 6798: 1995, Reciprocating internal combustion engines - Measurement of emitted airborne noise - Engineering method and survey method. Annex 1.
- ISO 3746: 2010 Acoustics - Determination of sound power levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting plane
- ISO 3744: 2010, Acoustics – Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane

The applicability of each standard depends on the defined guaranteed noise level formulation either as A-weighted sound pressure level, sound power level or definition of those as octave-band sound pressure or sound power levels. Also the actual measurement environment will define the applicability of each standard and thus define the selection of applied method.

3.3.2 Measurement Positions

The measurement positions are defined in each applicable measurement standard.

3.3.3 Sampling Time

As defined in the applied measurement standard

3.3.4 Weather Conditions

As defined in the applied measurement standard. Mostly not relevant considering plant component noise level test.

3.3.5 Background Noise Correction

As defined in the applied measurement standard.

4 Reporting

After the test measurements have been completed, the Owner or an independent consultant shall prepare a preliminary measurement report for signing by the Contractor and Owner. A photocopy shall be made immediately and handed to the Contractor and the Owner.

The final detailed measurement report shall contain the following information (as a minimum):

- Sketch of the measurement site showing dimensions and data such as:
    - Plant dimensions
    - Job Site dimensions,

  - Measurement positions including mention of microphone height,
  - Site area; environment and topography
- Data on object being measured (e.g. Plant or Component load, etc.)
- Date and time when the measurements were performed, identity of the person who performed the measurements and location of the measurement positions.
- Applied measurement methods
- Measurement instrumentation
  - Weighting networks and detector responses used
  - Method of instrument calibration
  - Copy of the calibration certificate(s) of the measurement equipment showing the type(s) and serial number(s) of the instrument(s) used.
- Measured noise level
- Description of the type of sound (e.g. impulsive, continuous, tones etc.)
- Background noise level
- Environmental conditions (e.g. type of sound field, atmospheric conditions)
- Summary sheet

5 Uncertainties and Acceptance

5.1 Factors affecting the Uncertainty of Environmental Noise Measurement

Sources of uncertainty in an environmental noise measurement such as this test measurement include:

- the precision of measuring equipment
- the measurement method, or averaging and sampling time
- the variations in the sound radiation of the source
- the variations in the propagation from the sources, e.g. due to
  - Weather conditions
  - Changing foliage screening and ground factor (especially on the northern hemisphere)
  - Distance between the sound source and measurement position etc.
- existing background noise

Measurement uncertainty shall be defined according to ISO 1996/2 Acoustics - Description, measurement and assessment of environmental noise. Part 2: Determination of environmental noise levels. 2007 Paragraph 4. Measurement uncertainty.

Example:

Measurement will be performed at 100 m distance from power plant at 1.5 m height with IEC 61672-1:2002 class 1 instrumentation.

Uncertainties: Instrumentation 1 dB

Weather and ground conditions 2 dB

Combined standard uncertainty 2.2. dB

Resulting expanded measurement uncertainty ±4.5 dB

5.2 Factors affecting the Uncertainty of Plant Component Noise Measurement

The uncertainty of plant component measurement is defined in the corresponding measurement method and standard.

5.3 Noise Test Acceptance

The test result L_{test} is defined by correcting the measurement result L with relevant environmental, operational and background noise corrections C_{i}. or:

$$L_{\text{test}} = L - \Sigma C_i$$

The test item is defined to comply with set noise performance guarantee level, if the test result L_{test} from which the relevant measurement uncertainty ΔL is subtracted, is less than or equal to the guarantee level L_{gtd}, or

$$L_{\text{test}} \leq L_{\text{gtd}} + \Delta L$$

6 Appendices

Appendix No 1: Standard noise test report form (to be completed after the measurements)

Appendix No 2: Equipment list (to be added after the measurements)

Appendix No 3: Equipment calibration certificates (to be added after the measurements)

Appendix No 4: Facility site plan and position of receptors for measurement (to be added on site)

7 References

1. Measurement of low frequency noise in rooms, Finnish Institute of Occupational Health, D. Oliva, V. Hongisto, J. Keränen, V. Koskinen, 2011.

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Reliability Test Guidelines

LG Engines

Draft Reliability Test Guidelines

Appendix 7A – DRAFT TEST GUIDELINES – Reliability Test

1 Objective

The objective of the reliability test is to demonstrate the Engine generator sets meet the Guaranteed Reliability over the reliability test period of 48 hours.

If the test is interrupted by a failure Owner's Equipment, Contractor shall have the option to either continue with the test, restart the test or resume the test after the failure has been corrected.

2 Test Location

The test will be performed at the Plant. The test may be conducted concurrently with other performance tests and may be conducted with multiple units in service within the transmission systems limitations for dispatch of the Plant.

3 Testing methods

Owner will provide the load schedule, which may include startups, shutdowns, and operation at any load between 50% and 100%.

Data collection during the test shall include Gross Electrical Output and operations logs which shall be maintained to document the status of Equipment generation material and equipment, as appropriate throughout the Reliability Test run.

4 Reporting

A report will be produced which calculates the reliability to determine compliance with the guaranteed value, in accordance with the formula below.

$$R = \frac{(A + B + \sum C_i \alpha_i + D) \times 100\%}{PH}$$

Where:

R	=	Reliability in percent.
A	=	Total number of hours during the test the facility is demonstrating maximum load operation.
B	=	Total number of hours during the test the facility is available for maximum load operation to produce "A" hours, but the Facility is under a load restriction attributable to the Owner.
C_i	=	Number of hours accumulated during a specific facility load restriction event attributable to the Contractor. Load restrictions attributable to the Contractor include facility operation below the lesser of maximum load operation or any load restrictions attributable to the Owner
α_i	=	Partial load percentage for a specific load restriction event attributable to the Contractor.

Partial load percentage is determined as the measured Net Electrical Output resulting from the restriction event divided by the Net Electrical Output measured just prior to the load restriction (during the most recent "A" or "B" hour).

i	=	Subscript denoting each load restriction event attributable to the Contractor (i.e., 1, 2, 3, etc.).
D	=	Total number of hours during the test the facility is not operating but is operable and available for normal operation up to maximum load, including startup and cool down
PH	=	48

Upon completion of the Reliability Run, the Guaranteed Reliability shall be deemed achieved if the calculated Reliability Factor is greater than or equal to the Reliability Guarantee. At any time during the test the Supplier may choose to forfeit the test and restart at a later time.