G_{4100} NO_x / O_2 Analyzing System

Emission Control

Document	**Test Plan**
Document status	Draft
Document version	14
Date	April 2012
Document Responsible	Arne Oxbøl

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2. INTRODUCTION

This test plan is the implementation of a test design developed for verification of the performance of an environmental technology following the DANETV method. See the verification protocol /1/ for details on organization and implications.

2.1. Verification protocol reference

The G_{4100} NO_x/O_2 Analyzing System, Emission Control (rev. 12, 2012) /1/.

2.2. Name and contact of vendor

Green Instruments A/S
Erhvervsparken 29
9700 Brønderslev
Denmark

Phone	+45 96 45 45 00
Contact	Poul Kodal Sørensen
E-mail	pks@greeninstruments.com

2.3. Name of centre / test responsible

Verification Test Centre (DANETV)	**Test responsible**
FORCE Technology	Arne Oxbøl
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2.4. Technical expert

The technical expert assigned to this verification and responsible for review of the test plan and test report documents includes:

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3. TEST DESIGN

The G_{4100} NO_X/O_2 Analyzing system (the candidate method) is a newly developed gas analyzer for onboard monitoring of NO_X concentrations. The analyzing system uses a new zirconia sensor technology, which provides a cost-effective solution to fulfill emission regulations as well as to support the effective operation for both diesel engines and boilers.

3.1. Test site

The test will be conducted at MAN Diesel & Turbo A/S , Filial of MAN Diesel & Turbo SE, Germany, R&D Engineering DK, Niels Juelsvej 15, 9900 Frederikshavn, Denmark.

The candidate NO_x analyzing system is "in-situ"-mounted and calibrated as necessary by the company Green Instruments. FORCE Technology will collect the results on a data logger. Green Instruments is not further involved in the test.

3.2. Tests

The candidate method will be tested for its ability to yield measurement results equivalent to the results of the reference method (ChemiLuminescence Detector - CLD) during stable operation of a reciprocating internal combustion engine.

The test will be performed according to ISO 8178-1/2/, ISO 8178-4 /3/ and Marpol Annex VI and NO_X Technical Code /4/. The candidate and reference methods measure NO_X simultaneously in the flue gas from a heavy-duty constant speed engine designed for ship propulsion. The engine is operated in four different loads (together named an IMO cycle). Each load is maintained for a stabile period long enough to split the measurement period in seven representative intervals (minimum 3 minutes each). The last 60 seconds of the first split interval for each load are combined to calculate an IMO-cycle value (see below). The second intervals are combined in the same way. Combination of seven split intervals for each load thereby yields seven pairs for each method. The relevant cycle is shown in Table 1.

Table 1 IMO cycle for constant- speed main propulsion engine

Test cycle type E2	Speed	100%	100%	100%	100%
	Power	100%	75%	50%	25%
	Weighting factor	0,2	0,5	0,15	0,15

After changing the mode the engine is allowed to stabilize. The results are logged with an interval of no more than 10 seconds.

The measurement is performed simultaneously with both the reference method and the candidate method. For each run of the cycle the cycle emission in g NO_X / kWh is calculated by means of the formula below.

$$IMOcycle\ value = \frac{\sum_{i=1}^{i=n} Specific\ emission(i) * Power(i) * WF(i)}{\sum_{i=1}^{i=n} Power(i) * WF(i)}$$

Where Specific emission is g NO_X/kWh

Power is delivered on the shaft

i = number mode in the cycle

WF = weighting factor for the mode

n = number of modes in the cycle (four in cycle E2)

The specific cycle emission is calculated for the results from both measurement methods. For each measurement method 28 results yields seven values for the specific cycle emission (seven pairs).

The seven pairs are statistically compared by means of a t-test (the accuracy) and a F-test (the repeatability) as described in ISO 8178-1, annex D, /2/.

The test is performed over one full working day. FORCE Technology measures with the reference method and log measurement data from the candidate method monitor.

3.2.1. Test methods

In order to calculate specific emission of NO_x (g NO_x/kWh) knowledge of power is necessary. If available, the power delivered on the shaft is logged in parallel to the measurements. If not available, thermal energy in the fuel is used.

In order to calculate the thermal energy of the fuel measurement of additional parameters are necessary. Consequently the concentration of oxygen, the temperature and the consumption of fuel are measured. The atmospheric pressure is recorded on the day. The characteristics of the fuel oil used for the test are to be determined by a fuel analysis. The caloriferic value is to be known as well.

The content of carbon dioxide is calculated based on the measured oxygen concentration and the $CO_{2,\,max}$ for the specific fuel (based on the elemental analysis) or for a general diesel fuel.

Other components (e.g. hydrocarbons and carbon monoxide) are present in ppm-level having consequently an insignificant influence on the density of the exhaust gas. Due to the insignificant influence they are not measured.

The results (IMO cycle values) are statistically tested by means of standard t-test and F-test, according to ISO 8178-1, Annex D, /2/.

In Table 2 an overview of all measuring parameters and respective methods is given.

Table 2 All measuring parameters and the respective methods

Parameter	Reference / standard	Measurement method	Calculations / results
NO_x (g NOx / kwh)	ISO 8178-1, annex D, /2/ ISO 8178-4, /3/ Marpol Annex VI and NOX Technical Code, /4/	**An E2 cycle (IMO) consists of:** – 4 modes (measurements points) – duration of 1 mode: min 70 min + time for stabilization after changing mode – 7 pair sample	– for each cycle the emission in g NO_X/kWh is calculated – 28 concentration results yields seven IMO cycle values for the cycle emission pr instrument – seven pairs for 2 instruments – the seven pairs are statistically compared by means of an s-test (the accuracy) and an F-test (the repeatability) as described in ISO 8178-1, annex D
Power		Readings of delivered power	
Oxygen (vol %)	e. g. EN 14789, /8/ ISO 12039 , /7/	Paramagnetisk Elektrokemisk	
Temperature (°C)	VDI 3511, /9/	NiCr / NiAl	
Fuel (g/s)		Volumetric and multiplication with density	
Fuel oil kg/kg		Compound analysis of C, S, H, H_2O, ashes, density and calorific value	

See Appendix 3 for a short description of the applied accredited measurement method, limits of detection, references and uncertainty. The design of the sampling site has an influence on the measurement uncertainty.

3.2.2. Test staff

The test staffs are:

Test responsible: Arne Oxbøl (AOX)
Test technician: Claus Degn (CDE)

3.2.3. Test schedule

The following Table 3 shows the test schedule.

Table 3 Test schedule (2011 & 2012)

Week number	40	41	48	49	50	15	17	20	21	22	23	24
Test plan	X	X	X				X					
Test period								X				
Measurement report									X			
Draft test report										X		
QA test report											X	
Review						X					X	
Final test report												X

3.2.4. Test equipment

A HCLD (Heated ChemiLuminescence Detector) monitor for reference method measurement is used together with a G_{4100} NO_X/O_2 monitor (candidate method). Appropriate equipment for measurement of oxygen and temperature are used.

Specification for the	HCLD monitor
Model	ECO PHYSICS CLD 700 EL ht
Range	0 – 10 000 ppm
Linearity	< 2 % of range
Converter efficiency	> 95 %
Sample flow	1,2 l/min
Sample line	PTFE Teflon 4 mm ID, heated to 180 °C
Quench / interference	total < 4 % of range (H2O and CO2)
Zero drift	X ≤ ± 2,0 % of the range/24 h
Span drift	X ≤ ± 2,0 % of the range/24 h

3.2.5. Type and number of samples

The measurement of concentration of NO_X will run continuously and the results are logged with an adequate time average (e.g. 10 seconds). Averages from each stable mode of each cycle will be calculated for both methods.

3.2.6. Operation conditions

The test shall be carried out during four days, with seven cycles as described above:

Stable operation at 100 % load, 75% load, 50% load and 25% load.

3.2.7. Operation measurements

During the test several operating parameters including load of the engine will be measured and logged. If possible, the results will be logged by the test team - alternatively the operator of the engine will log the data and transfer them to the test team as an EXCEL spreadsheet, and some additional parameters will be delivered from the plant instrumentation and monitoring system in a data file covering the whole test period.

3.2.8. Product maintenance

The sensor must be installed in a location where it can be serviced and also secure representative gas sampling. Due to the design of the probe and measuring chamber pressure and pulses variations are limited but in order to eliminate any small pressure variations, the ZrO_2 sensor is arranged with pressure compensation /10/.

The most important routine maintenance task is to check and calibrate the analyzer regularly. The analyzer has to be calibrated after each start up of the G_{4100} NO_X/O_2 Analyzer and frequently following the requirements of each application.

The analyzer does not require any special maintenance. The LCD display shall be kept clean in order to give a clear view and allow proper operation of the touch screen.

Routine inspection and maintenance of the air flow system and connections is required to make sure no gas is leaking from the system. The flow meter and control valve does not require any special maintenance. The ejector probe filter element is normally cleaned by back-flushing.

For further information see Appendix 4.

The sensor in the system (an electrode with zirconia electrolyte) must be changed regularly depending of the concentrations in the flue gas (once or twice a year).

Maintenance is not normally necessary for three days of measurements.

3.2.9. Health, safety and wastes

The use of the product does not imply special health, safety and waste issues.

The work during testing will be done according to the FORCE Technology Safety Rules that are compliant with the extensive Danish rules for safe occupational health and the European regulations of work with chemicals.

4. REFERENCE ANALYSIS

We refer to our accreditation no. 51 at Danish Accreditation Board (DANAK) /5/.

5. DATA MANAGEMENT

Handling of data and calculation of results is performed according to the FORCE Technology DANAK accreditation no. 51 (also for parameters not covered by the accreditation). Calculations will be performed by approved spread sheets and controlled spread sheet calculations.

5.1. Data storage, transfer and control

All reading data will be stored in handwritten form on paper and schemes.

All the data stored in data loggers will be transferred to the FORCE computer system, which is regularly backed up for data safety.

6. QUALITY ASSURANCE

All measuring, handling of data and calculation of results will be performed according to the FORCE Technology DANAK accreditation no. 51 (also for parameters and data not covered by the accreditation) /5/.

All measuring data will be present in handwritten form or as printout from the test site instrumentation.

Approved spread sheets for calculations of results has been subjected to an intensive control, to assure correct calculations, and consequently no further control is necessary.

6.1. Test plan review

The test plan will be subject to internal review by the verification responsible from FORCE Technology Test Centre:

Marianne Ørbæk
E-mail: mko@force.dk
Phone +45 4326 7062
Cell phone: +45 2269 7565

External review of the test plan will be done by the expert group assigned to this verification / see paragraph 2.4).

6.2. Performance control – reference analysis

We refer to our accreditation no. 51 at Danish Accreditation Board (DANAK) /5/.

6.3. Data integrity check procedures

All transfer of data from handwritten form to computer, will be subjected to 100 % control by another person. New calculations in spread sheets will be subjected to 100 % check of all formulas and spot check of at least 20 % of all copies of the formulas.

6.4. Test report review

The test report will be subject to internal review by the verification responsible from FORCE Technology Test Centre (see paragraph 6.1).

External review of the test report will be done by the expert group (see paragraph 2.4) as part of the re-view of the verification report, that will include the full test report as an Appendix.

7. TEST REPORT

The measurement and test reports will follow the template of the FORCE Technology verification test centre quality manual /6/ and will be included as an Appendix in the verification report. The test report will contain the test plan, except for this Chapter 7, which will be replaced by the measurement report and statistical calculation, which will include the data and records from the test.

7.1. Test site report

All relevant data which is not recorded in a scheme will, together with other relevant information and observations, e.g. deviations from the test plan during the test, be noted in a test journal.

7.2. Test data report

All test data recorded during the test are filed on a FORCE Technology server

7.3. Deviations report

The report section on deviations will compile all deviations from this test plan with justification of deviations and evaluation of any consequences for the test data quality.

Appendix 1

Terms and definitions

ETV	Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application, under defined conditions and adequate quality assurance.
Evaluation	Evaluation of test data for a technology product for performance and data quality
IMO	International Maritime Organization
Method	Generic document that provides rules, guidelines or characteristics for tests or analysis
Performance parameters	Parameters that can be documented quantitatively in tests and that provide the relevant information on the performance
QA	Quality assurance
Test/testing	Determination of the performance of a product for parameters defined for the application
Verification	Evaluation of product performance parameters for a specified application under defined conditions and adequate quality assurance

Appendix 2

References

/1/	The G_{4100} NO_x/O_2 Analyzing System, Protocol, November 2011
/2/	International Standard ISO 8178-1. Reciprocating internal combustion engines / Exhaust emission measurement. Part 1: Test-bed measurement of gaseous and particulate exhaust emissions
/3/	International Standard ISO 8178-4. Reciprocating internal combustion engines / Exhaust emission measurement. Part 4: Steady state test cycles for different engine applications.
/4/	Marpol Annex VI and NOx Technical Code 73/78. Regulations for the prevention of air pollution from ships.
/5/	DANAK accreditation no. 51
/6/	DANETV Centre Quality Manual, FORCE Technology, February 2009.
/7/	International Standard ISO 12039 (2001). Stationary source emissions. Determination of carbon monoxide, carbon dioxide and oxygen. Performance characteristics and calibration of automated measuring systems.
/8/	European Standards EN 14789 (2005). Stationary source emissions. Determination of volume concentration of oxygen (O2). Reference method. Paramagnetism.
/9/	The Association of Engineers Collection – VDI 3511. Temperature measurement in industry - Principles and special methods of temperature measurement.
/10/	G_{4100} NOx/O_2 Analyzing System – Manual (version 2.04, Revision February 2011 – part No.: 01271)

Appendix 3

Analytical Methods

In the following a short description of the applied measurement methods, limits of detection, references and uncertainty are given. The design of the sampling site has an influence on the measurement uncertainty.

Detection limits and uncertainties:

Continuous emission monitoring (monitors, thermo couples etc.): The limit of detection is given as the normal achievable at emission measurements. For monitors as three times the average of monitor drift in the span point at repeated field measurements. Lower limits of detection can be achieved by optimized choice of calibration gas and higher frequency in the calibrations. The uncertainty is based on measurements performed in a homogeneous gas stream as described in EN 15259. The uncertainty is given in % of the measured value (95 % confidence level). At low concentrations between 5 and 1 time the limit of detection, the uncertainty will increase from the stated %-value (at 5 times the limit of detection) up to 100 % of the measured value at the limit of detection.

NO_X-concentration: In a dry partial flow of flue gas free of particles the NO_X-concentration is determined by a Chemiluminescence monitor. The sample transfer line is heated.

Ranges: 0 - 100, 0 - 1000, 0 - 10000, 0 - 100000 ppm

Limit of detection: 1 ppm

Uncertainty: 5 % of measured value (95% confidence interval).

FORCE Technology method: EM-10-01

Reference/standard: EN 14792

Appendix 4

Maintenance

G_{41} NO_x/O_2 Analyzer

GREEN INSTRUMENTS

7 Routine Maintenance

7.1 Calibration

The most important routine maintenance task is to check and calibrate the analyzer regularly. The analyzer has to be calibrated after each start up of the G_{41} NO_X/O_2 Analyzer and frequently following the requirements of each application.

7.2 Analyzer

The analyzer is tested from the factory. The analyzer does not require any special maintenance. The LCD shall be kept clean in order to give a clear view and allow proper operation of the touch screen. The touch screen shall be cleaned by using a soft damp cloth or soft tissue. Dirt and oil on the surface of the analyzer(s) need to be removed carefully using neutral detergent and a clean rag.

Appendix 4

Maintenance

14 Routine Maintenance

14.1 Air Flow System

Routine inspection and maintenance of the air flow system and connections is required to make sure no gas is leaking from the system. It is important that air flow and pressure are stable. Failure to periodically inspect and maintain the above requirements may lead to imprecise analyzer readings and thus a malfunction of the system.

Make sure that the maximum allowed pressure for the reduction station is 8 bar and temperature 60°C. Prevent ultraviolet rays and the adhesion of organic solvents to the reduction unit. Depressurize the reduction station before cleaning and servicing.

The flow meter and control valve does not require any special maintenance. Dirt and oil on the surface of the flow meters are to be removed carefully using neutral detergent and a clean dry rag.

14.2 Ejector Probe

The ejector probe filter element is normally cleaned by back-flushing. The period between back-flushings is determined based on the actual flue gas condition and how dirty the filter gets. Regular back-flushing will normally keep the filter clean. However, slow response to O_2 changes in the flue gases indicates that the ejector probe filter or the ejector probe venturi air nozzle may be contaminated. In that case, manual cleaning of the filter is required.

To clean the filter manually, follow the following steps:

- Remove the blue cover plate of the ejector probe and unplug the sensor and the two sampling tubes.

Appendix 4

Maintenance

- Take out the ejector probe with the mounting plate from the socket by unbolting 6 screws on the front of the back plate.
- To clean or change the ejector probe filter, remove the filter element by unscrewing the filter bolt.

To clean the ejector probe venturi air nozzle:

- Remove the mounting plate of the ejector probe by unbolting 3 screws on the back of the mounting plate.
- Separate the ejector probe head top and bottom by unbolting the 3 bolts on back of the ejector probe heat bottom.
- Clean the ejector probe venturi air nozzle in the ejector probe head bottom and the gas canals in the ejector probe head top.

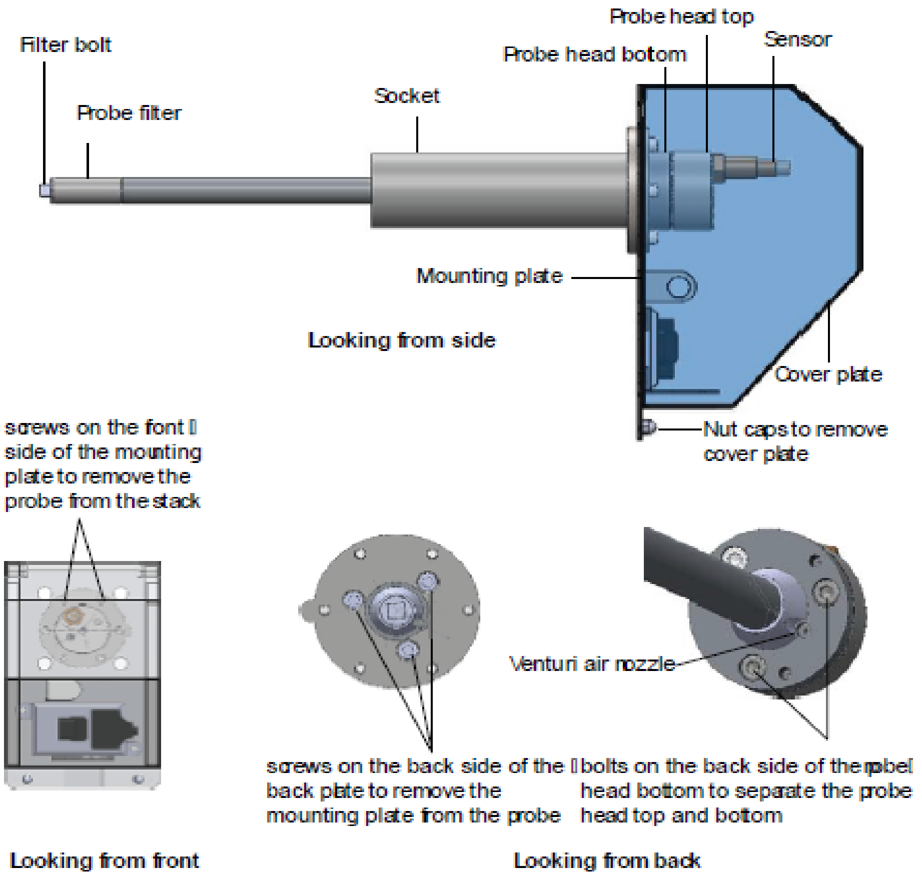

Figure 14-1: Sampling ejector probe