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Engine Room Pressure Measurements onboard MT Suula

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SELVITYKSIÄ JA RAPORTTEJA 162

VAASA 2010

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1 INTRODUCTION

Fresh air is needed in an engine room for the fuel oil burning in the main engine, the auxiliary engines and the steam boilers. In addition constant fresh air flow is important to produce oxygen for the machinery crew onboard. Air is also ventilated from the engine premises for cooling purposes and to maintain sufficiently good air quality. Air supply fans are the main ventilators in the engine room; however, also smaller exhaust fans are used in vessels for removal of inflammable gases or smoke.

The ISO 8861 standard, Shipbuilding – Engine room ventilation in diesel-engined ships – Design requirements and basis of calculations (ISO 8861, 1998), specifies the design conditions for engine room ventilation. The external ambient temperature shall be 35 ˚C and the maximum temperature rise in the engine casing should be less than 12.5 ˚C. All normal conditions shall be taken into account. In principle, the air flow needed is a sum of combustion air and airflow for the evacuation of heat emissions in engine room. However, "the total airflow to the engine room shall not be less than airflow for combustion, engine(s) and boiler(s), plus 50 %" (ISO 8861, 1998). In the calculations air density is 1.13 kg/m^3, relative humidity 70 % and pressure 101.3 kPa.

In the standard part entitled "Guidance and good practice" it is recommended that approximately 50 % of the air should be delivered close to main engine turbocharger (Picture 9). Based on standard 8861 a slight positive pressure in the engine room is proposed, whereby this pressure should not exceed 50 Pa. (ISO 8861, 1998.)

Also classification societies have their own rules and regulations concerning the temperature in the engine room. Based on these rules temperature the range should be from 0 to 45 ˚C in enclosed spaces when the atmospheric pressure is 100 kPa and relative humidity 60 % (Germanischer Lloyd, 2009).

MT Suula's main engine is type Wärtsilä 8L46. The Wärtsilä 46 project guide for marine applications (Wärtsilä, 2001) states: "The dimensioning of blowers and extractors should ensure that an overpressure of about 5 mmWC is maintained in the engine room in all running conditions".

Excessive ventilation consumes energy and it may result in too low temperatures inside the engine room. Therefore ventilation flow is adjustable in ships. The main criterion for this adjustment is the engine room temperature. In case of fire, engine room ventilation is stopped, outlet openings are closed and typically high pressure carbon dioxide is released into the engine room to extinguish the fire.

Exhaust gas scrubbers are developed to prevent heavy fuel oil sulphur oxide emissions. One scrubber type is an integrated scrubber where all the exhaust gases produced onboard are washed in a single unit. Exhaust gas fans connected to scrubber control the correct pressure in the exhaust gas pipes. This pressure must be stable in all machinery loading cases and especially steam boiler burners are expected to be sensitive to the exhaust gas back pressure variations.

The purpose of this study was to collect data on the engine room pressure in a typical merchant ship under normal operations. Test vessel MT Suula (Picture 1) steamed from Porvoo to Sundsvall and back to Porvoo on 13.–16.3.2010 during the pressure measurements. Part of the sailed route was ice-covered.

These measurements were funded by the FCEP research program managed by Cleen Ltd.

Picture 1. Motor tanker Suula

2 ENGINE ROOM VENTILATION

2.1 Air fans and ducts

Fresh air is blown into the machinery spaces of the vessel by ventilation fans. A part of this air is consumed by diesel engines and oil-fired boilers and the rest of the air is ventilated back to the atmosphere. The fresh air suction inlet is behind the deck house (Picture 2).

Picture 2. Air suction grills

Two main fans (S10 and S11) with a capacity of 20.8 m^3/s are located below this grill (Picture 3). Fan S11 is reversible and has a second task as a smoke suction fan from the engine room after a fire. The other main fan S10 has two speeds with the same maximum capacity.

Picture 3. Main engine room ventilation fans

Fresh air supply to the engine room is divided to several branches on the main deck, the tween deck and at floor level. The main engine and two auxiliary boilers are the most outstanding consumers. In addition air is blown into three separate spaces; material storage, workshop and separator room.

The diesel generator room has a separate two-speed supply fan with a maximum capacity of 16.7 m^3/s. This space has an air exit to the main engine room for the air not consumed by auxiliary engines (Picture 4). The total air inflow design capacity is 58.3 m^3/h.

Picture 4. Ventilation air entrance ports from auxiliary engine room to main engine room

From the point of view of ventilation, the funnel and the engine room are one and a same space. The air main exit is on the back wall of the funnel (Picture 5). This exit and also the ducts after the supply fans are closed in a fire situation. In wintertime part of the exit air is mixed with the supply air to increase the temperature of incoming air. The mixing ratio can be selected manually.

Picture 5. Ventilation air main exit

Bilge gases and also ventilation air near the sewage treatment unit are exhausted to the atmosphere by a separate exhaust fan (Picture 6). Another exhaust fan is located inside the separator room to protect other machinery spaces from flammable oily gases (Picture 7). There is noxious air also in the ship's workshop. For example welding is a typical smoke source and during a welding process dirty air is removed from the workshop by two duct fans.

Picture 6. Bilge air suction

Picture 7. Separator room air exit grill

All doors and hatches to the engine room must be closed at sea and also in harbour. In addition to the main door and the engine casing door there are several emergency exits and also a hatch on the funnel top. The doors from engine room to workshop, diesel generator room and separator room can be either open or closed (Picture 8).

Picture 8. Main engine room exit

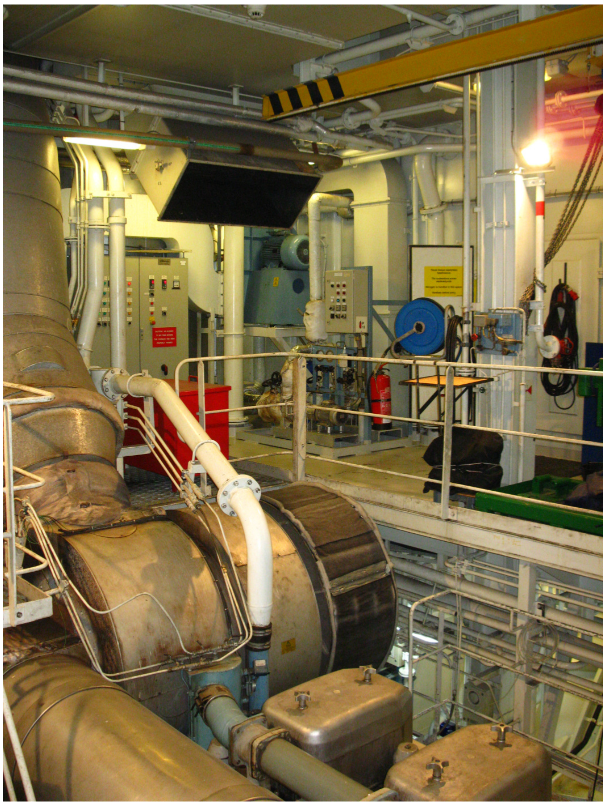
2.2 Air consumers

The main engine of the vessel has eight cylinders in line, type Wärtsilä 8L46C with a continuous output of 8400 kW at 500 RPM. The combustion air requirement at full power is 14.3 kg/s and the corresponding heat radiation from engine is 320 kW. Air feed to main engine is shown in Picture 9.

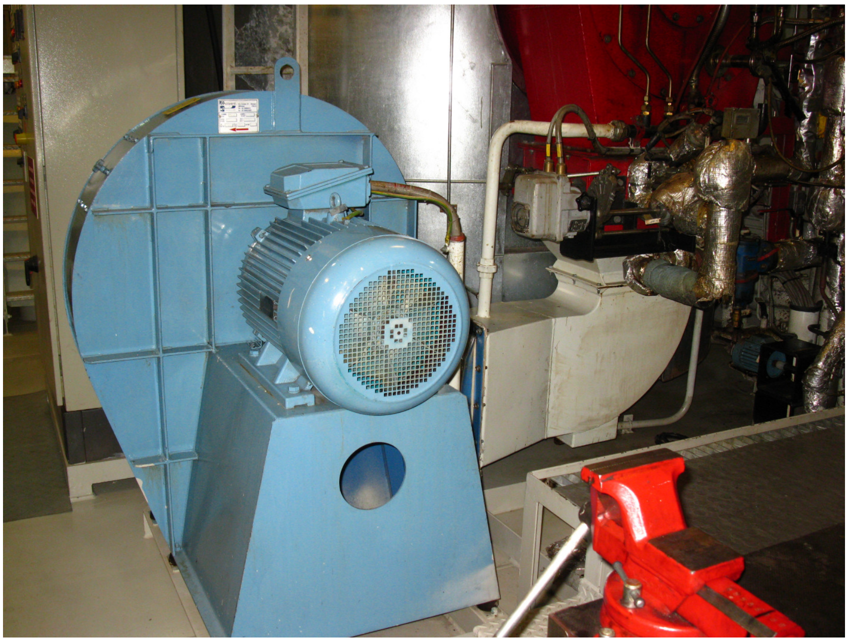
Also the auxiliary engines, located in their own engine room, are manufactured by Wärtsilä. Two of these constant speed engines are of type 6L20 (1020 kW) and one is a 4L20 (680 kW), all running at 900 RPM. The full power combustion air consumption in six cylinder engines is 2.1 kg/s and in four cylinder engines 1.25 kg/s (Wärtsilä, 2002).

A third type of air consumers are the two oil-fired boilers of type Aalborg UNEX CHB 10000 with a rated evaporation of 10 000 kg/h saturated steam. These boilers have a service pressure of 800 kPa. The combustion air consumption is 3.17 kg/s (maximum) and burning air is blown into the boilers by separate air fans (Picture 10). At low steam consumption, the burner stops and starts automatically. The burner has a modulating action with a stopping limit of 30-40 % of full steam production. Under normal conditions, only one boiler is on and the other one is on stand-by.

The maximum theoretical combustion air consumption is 26.1 kg/s. When the vessel is operating in practice, all engines and boilers are never used at the highest possible load at the same time. All the engine room air producers and consumers are listed in Table 4.



Picture 9. Main engine turbocharger and combustion air nozzle



Picture 10. Steam boiler burning air fan

3 MEASUREMENTS

3.1 Machinery loading cases

In principle MT Suula has five different kinds of operational modes as shown in Table 1:

- Harbour loading
- Manoeuvring
- Pilot onboard
- Service speed
- Harbour unloading

Engine room pressure in all the cases, except the first one, was measured during the tests. In addition a sixth mode of use was steaming in ice. The maximum thrust was not strong enough to break the pack-ice and therefore MT Suula had to back up and rush again towards the ice. When navigating in heavy ice the auxiliary engines were running. All the power available from the main engine was in the service of advance.

Table 1. Typical use of engines and boilers onboard MT Suula

Machine type	**Loading**	**Manoeuvring**	**Pilot onboard**	**Service speed**	**Unloading**
Main engine (1 pc)	Stopped	Running	Running	Running	Stopped
Generators (3 pcs)	One running	Three running	Stopped (shaft generator running)	Stopped	Two running
Steam boilers (2 pcs)	One running, intermittent use	One running, intermittent use	Stopped	Stopped	One running, intermittent use

3.2 Measurement arrangements

The main goal of the engine room pressure measurements was to determine the difference in air pressure between the engine room and outside. It was important to determine the prevailing conditions at the measurement points. The measured values were:

- Pressure difference between the engine room and the outdoor air
- Air temperature in the engine room
- Air relative humidity in the engine room
- Outdoor air temperature
- Outdoor air relative humidity
- Outdoor air barometric pressure

These measurements were carried out by means of a computerized data acquisition system. This system contains three main parts, namely a laptop computer, data acquisition devices, and sensors. All measurement results were stored in ASCII text files for further use. The data acquisition system used was based on National Instruments FieldPoint distributed components. The data acquisition system contained devices and sensors which are listed in Table 2.

Table 2. Measurement devices and sensors of the data acquisition system

Purpose	**Manufacturer**	**Type**
Ethernet connection module	National Instruments	NI FP-1601
Analog Input module	National Instruments	NI FP-AI-110
Difference Pressure Transmitter	HK Instruments	DPT3W
Barometer	Vaisala	PTB 110
Relative humidity and temperature transmitter	Thermokon	LC-FTA54 VV

National Instruments FieldPoint modules, a terminal block and the difference pressure transmitter were installed into a suitcase. All sensors were wired to the FieldPoint input module. The location of the measuring station was in the engine room on the main deck at frame 22 (Picture 11). The connection to the outside and to the measuring point of the engine room from the differential pressure transmitter was implemented with a plastic hose. The suction hose was routed from the measuring station via the engine casing and the funnel. It was connected to the lower pressure connection of the differential pressure transmitter. The other point of the pressure difference measurement was in the engine room between the auxiliary boilers at frame 11 on the tween deck. The plastic pipe from this measuring point was connected to the higher pressure connection of the differential pressure transmitter.

The temperature and relative humidity of the air from both measuring points were measured with combined relative humidity and temperature transmitters. The transmitters were wired to the FieldPoint analogue input module via the terminal block. The wiring diagram is provided in Appendix 1. The barometric pressure was measured with a Vaisala PTB 110 barometer. It was wired to the FieldPoint input module via the terminal block. The barometer was mounted on top of the funnel. The outdoor relative humidity and temperature sensor from outside was installed on the top of the steel pipe. The edge of the steel pipe was at the same level as the uppermost edge of the exhaust pipe of the oil-fired boiler (Picture 12). Any air flows to the sensors were avoided by placing the combined relative humidity and temperature sensor in a plastic bucket. The barometer and terminal block were installed into the link box. The location of this box was on the top of the funnel. The placing of the measuring station and sensors is shown in Appendix 2.

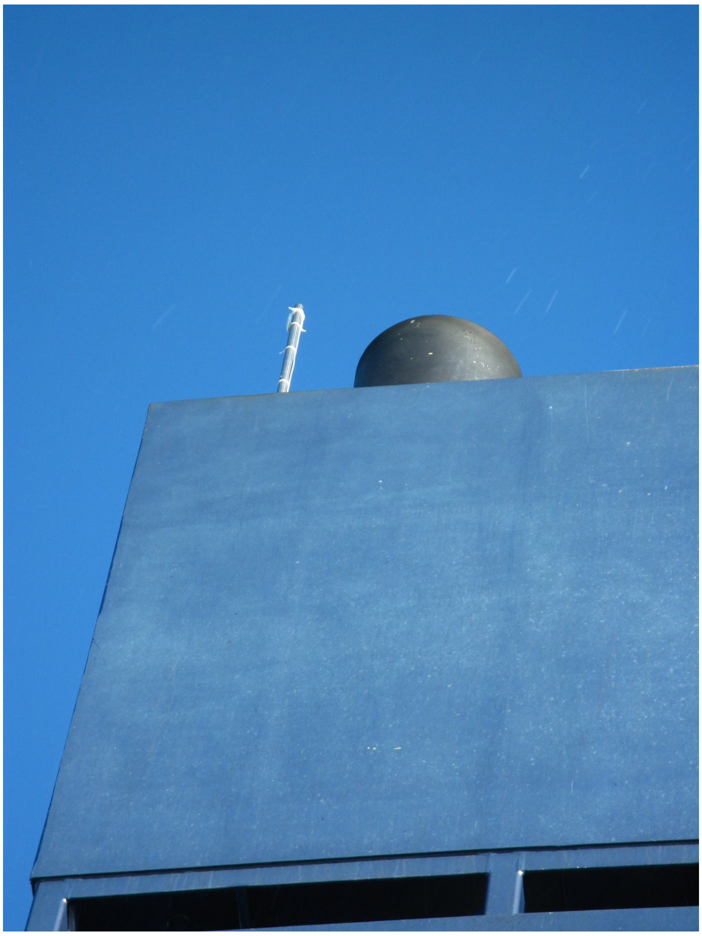
Picture 11. Measuring station

The channels of the FieldPoint analogue input module are configured in National Instruments Measurement and Automation Explorer software. The configuration of the channels is shown in Table 3.

Table 3. The configuration of the channels of the NI FieldPoint Analogue Input module

Channel	Subject	Voltage Area	Value Area
Channel 0	Pressure Difference	0…10 VDC	0…250 Pa
Channel 1	Temperature, outside	0…10 VDC	-20…+80 °C
Channel 2	Relative Humidity, outside	0…10 VDC	0…100 %
Channel 3	Temperature, engine room	0…10 VDC	-20…+80 °C
Channel 4	Relative Humidity, engine room	0…10 VDC	0…100 %
Channel 5	Barometric pressure, outside	0…5 VDC	500…1100 hPa

One part of the data acquisition system is the data acquisition software, the purpose of which is to read measured data from the sensors, show it to the user and save it in a file. The acquisition software was programmed with National Instruments LabVIEW 2009 by the Ship Laboratory of TUAS (Turku University of Applied Sciences). Version 1.1.3 of the software was used for all engine room pressure measurements. The file name of the software is Engine Room Pressure Test, FPv13.vi.



Picture 12. Pressure sensors on funnel top

3.3 Measuring progress table

The measured data was recorded periodically as shown in Table 4. The weather station was a separate permanent installation onboard and it was not connected to the data recording system.

Table 4. Engine room pressure test phases

Mode	Service speed	Ice conditions	Manoeuvring	Harbour	Pilot onboard	Ballast condition
Date	2010-03-13	2010-03-14	2010-03-14	2010-03-15	2010-03-15	2010-03-15
Time	18.00-18.20	18.40-19.25	19.35-19.55	8.30-9.10	10.20-10.45	11.05-11.25
Fans						
Engine room fan S10, 75000 m^3/h	off	low		low	low	low
Engine room fan S11, 75000 m^3/h	supply	supply		off/supply	supply	supply
AE room fan S13, 60000 m^3/h	off	low		low	low	low
Separ. room exh. fan, 7 000 m^3/h	on	on		on	on	on
ER bilge exh. fan, 3500 m^3/h	on	on		on	on	on
Boiler 1 fan, 9750 m^3/h	off	off		off	off	off
Boiler 2 fan, 9750 m^3/h	off	off		on/off	off	off
Engines						
Ship speed (knots)	13,2	5,3-14,3	0-2,8	0	7,1-14,9	15,1
Main engine fuel rack (%)	71	75-83	33-49	off	39-92	
Auxiliary engine 1	off	off	on	off	on/off	off
Auxiliary engine 2	off	on	on	on	on	on
Auxiliary engine 3	off	on/off	on	on	on	on
Doors						
Main door	closed	closed		open/closed	closed	closed
Separator room door	open/closed	open		open	open	open
Engine casing door	closed	open/closed		closed	closed	closed
Engine casing top exit hatch	open/closed	closed		closed	closed	closed
Eng. casing ventilation outlet	open	open		open	open	open
AE room door	open/closed	open		open/closed	open	open
General						
Barometric pressure (mbar)	994,7-995,4	997,8-998,7	998,6-999,1	1001,1-1001,2	997,8-998,5	1001,2
Wind speed, true (m/s)	9				2-7	3
Wind speed, apparent (m/s)	-			2	3-8	4
Wind direction, true (degr)	southwest			274	315-327	318
Wind direction, apparent (degr)	11 (sb bow)			193sb	51sb-11bb	11bb
Air temperature, outside (°C)	-1			-6		
Air temperature, on funnel top (°C)	3	4,0-10,6	0,7-2,6	-4,5-(-3,2)	0,7-3,5	5
Air temperature, in engine room (°C)	22,4	19,8-20,1	20-20,6	17,6-18,1	17,5-18,4	18,3
Air humidity, on funnel top (%)	71,8	41,5-67,4	65,8-83,4	81,2-86,7	64-67,3	56,7
Air humidity, in engine room (%)	16,7	12,4-13,5	14,8-17,7	13-13,6	15,3-17,3	16,4
Engine room overpress (Pa)	25-36	21-65	12-68	14-47	8-50	20-24

3.4 Results

The measured pressure difference curves between the sensors on funnel top and in engine room are shown in Figures 1–6. The black line is the average value of 25 measurements recorded at 0.5 second intervals. By looking at Figure 1 we can see that at open sea the pressure level in the engine room was quite stable, approximately 30 Pa.

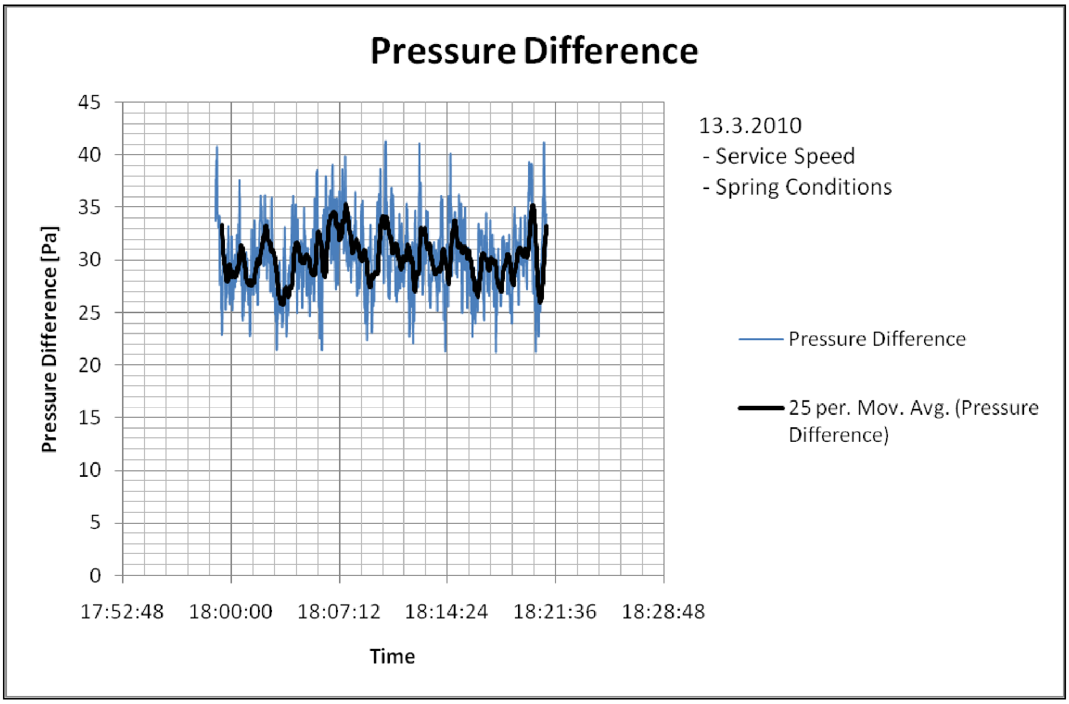
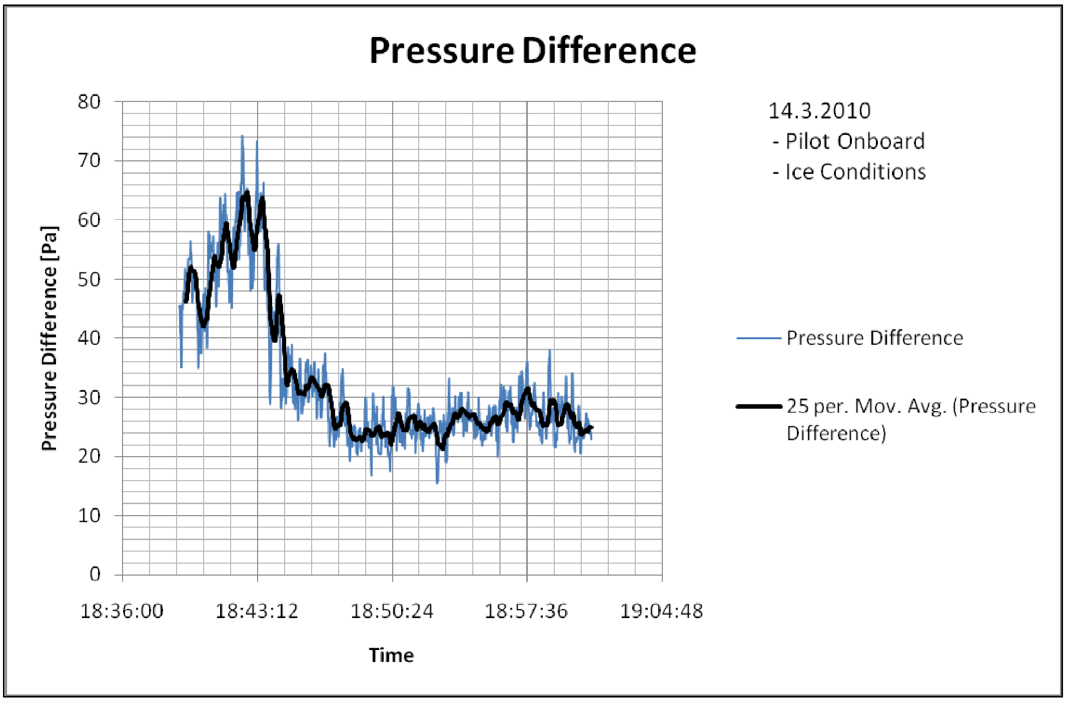


Figure 1. Pressure difference between the funnel top and engine room at service speed

When the ship was steaming in ice conditions, two engine room fans were on and there was substantial pressure variation (Figure 2). Engine power was high and at least once MT Suula stopped in heavy ice. She had to reverse and ram again towards the ice ridge.



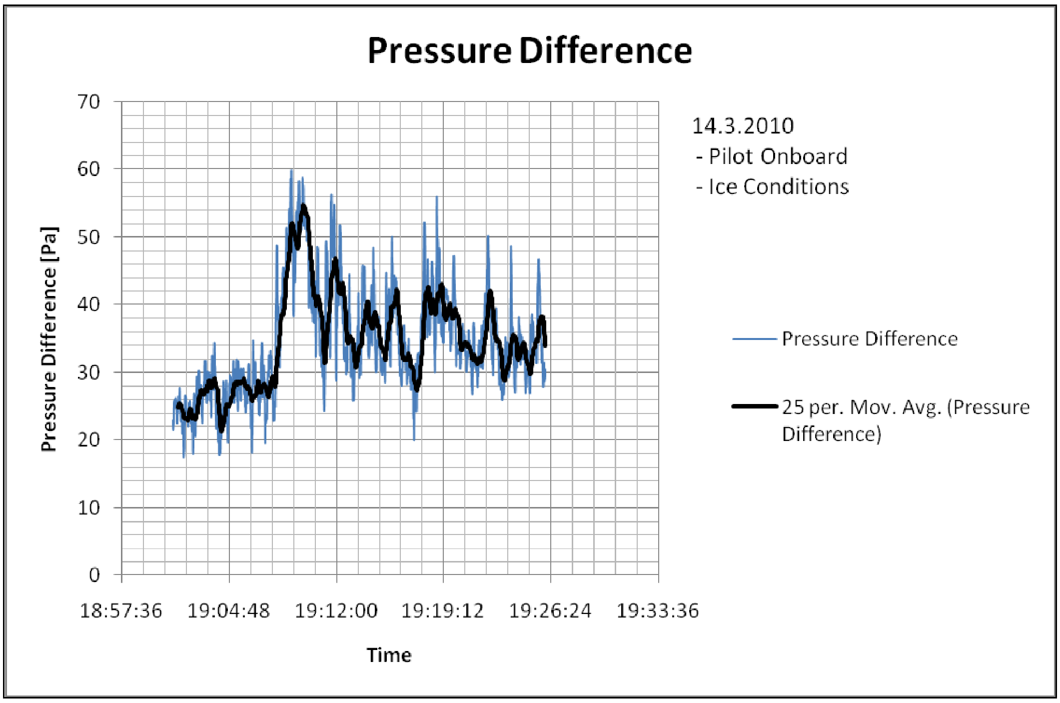


Figure 2. Pressure difference between the funnel top and engine room when navigating the ship in ice conditions

When MT Suula was manoeuvring, pressure variation was intense. This was obviously due to the speed and engine power variations (Figure 3).

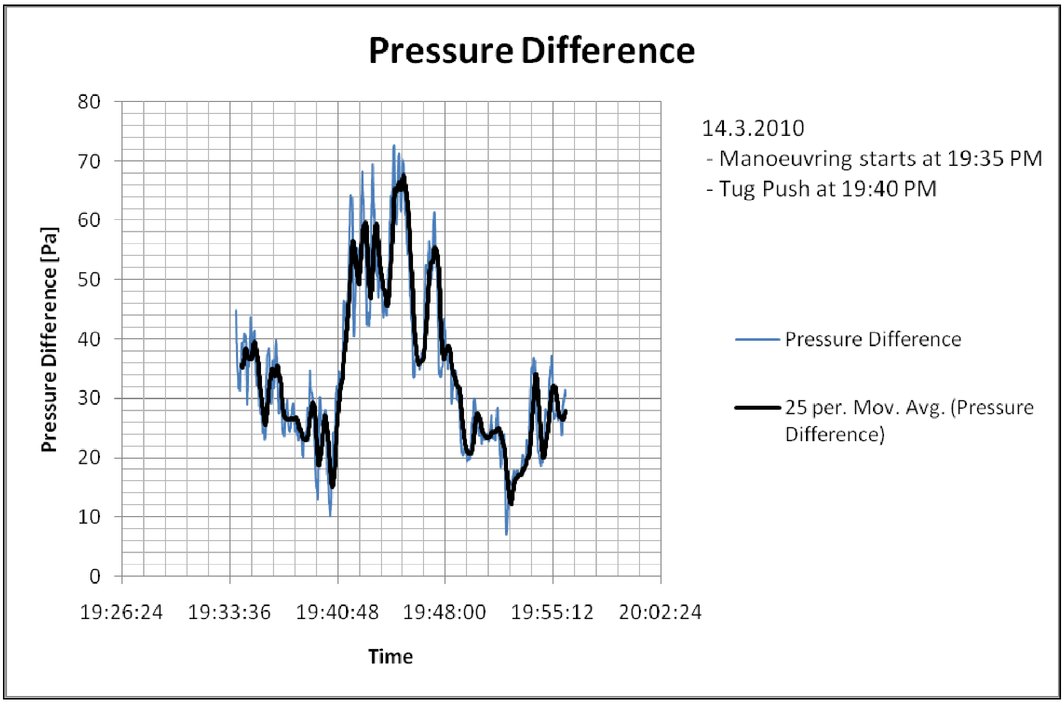


Figure 3. Pressure difference between the funnel top and engine room when manoeuvring the ship

In harbour the pressure level was low, about 20 Pa. After starting engine room fan S11, the pressure level rose rapidly. On the other hand the starting of the steam boiler (steam boiler fan) reduced the pressure level as shown in Figure 4 (notes of start-stop times do not quite tally with the curve). A clear reduction in pressure level was observed after switching off the fan S11.

At low speed with the pilot onboard, the pressure was low, i.e. less than 10 Pa. Simultaneously the main engine was working at high load. A change in engine load increased the pressure to 50 Pa (Figure 5). The main engine fuel rack adjustment varied from 39 to 92 %. Also the wind speed and direction alternated.

At open sea in ballast condition the pressure in the MT Suula engine room was stable, about 22 Pa (Figure 6).

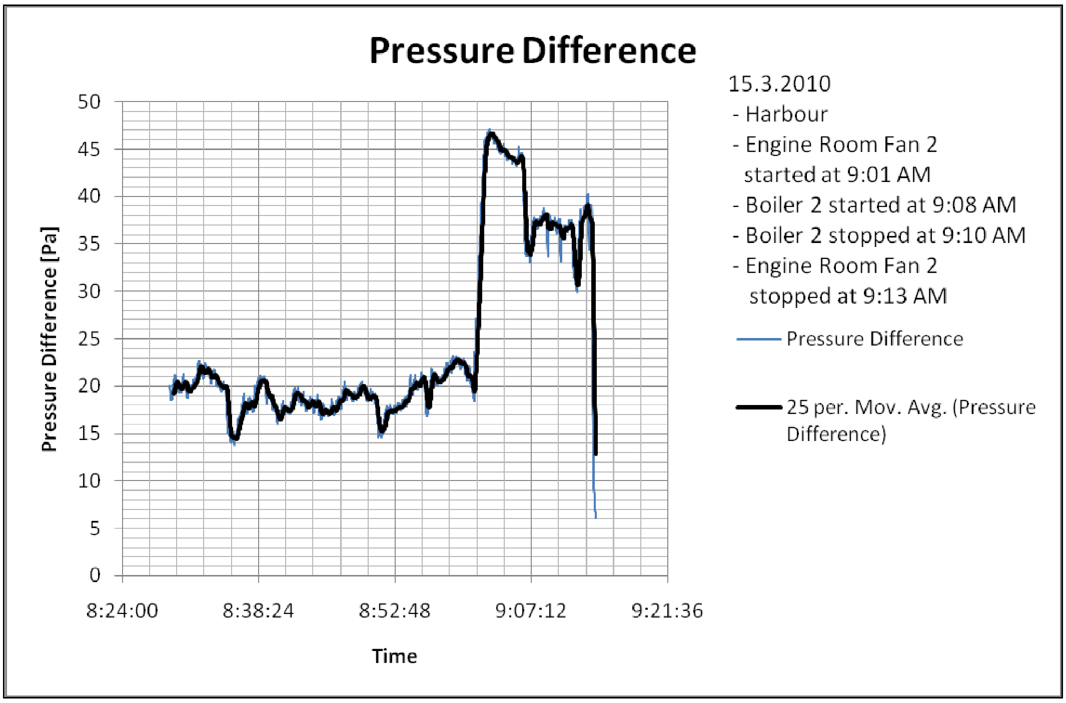


Figure 4. Pressure difference between the funnel top and engine room in harbour

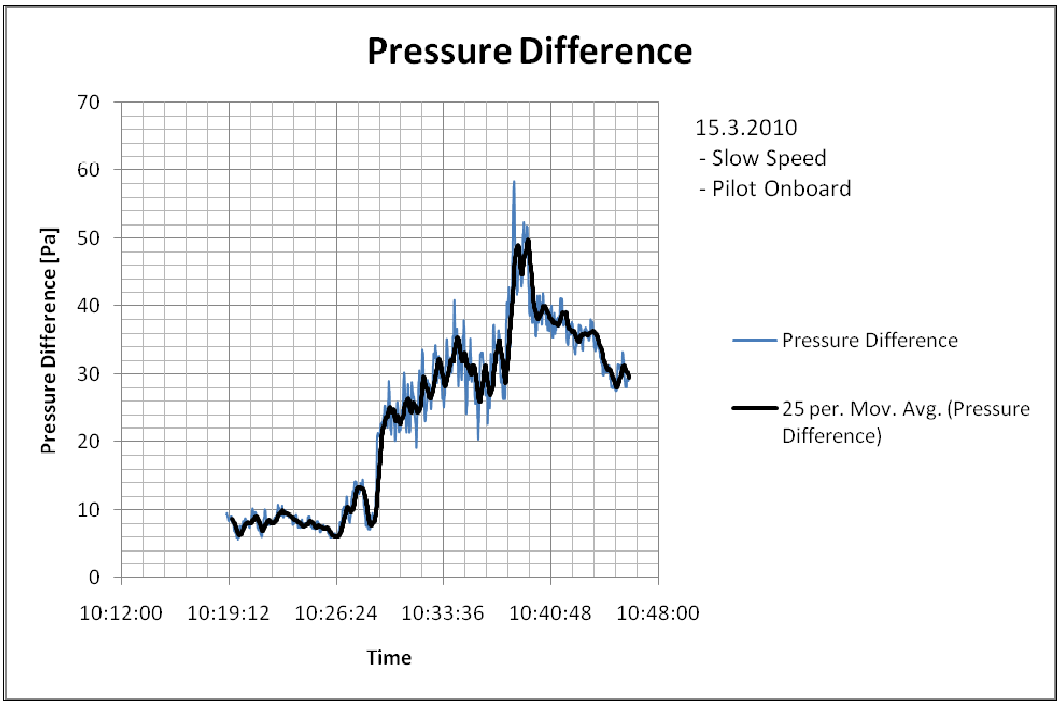


Figure 5. Pressure difference between the funnel top and engine room at slow speed

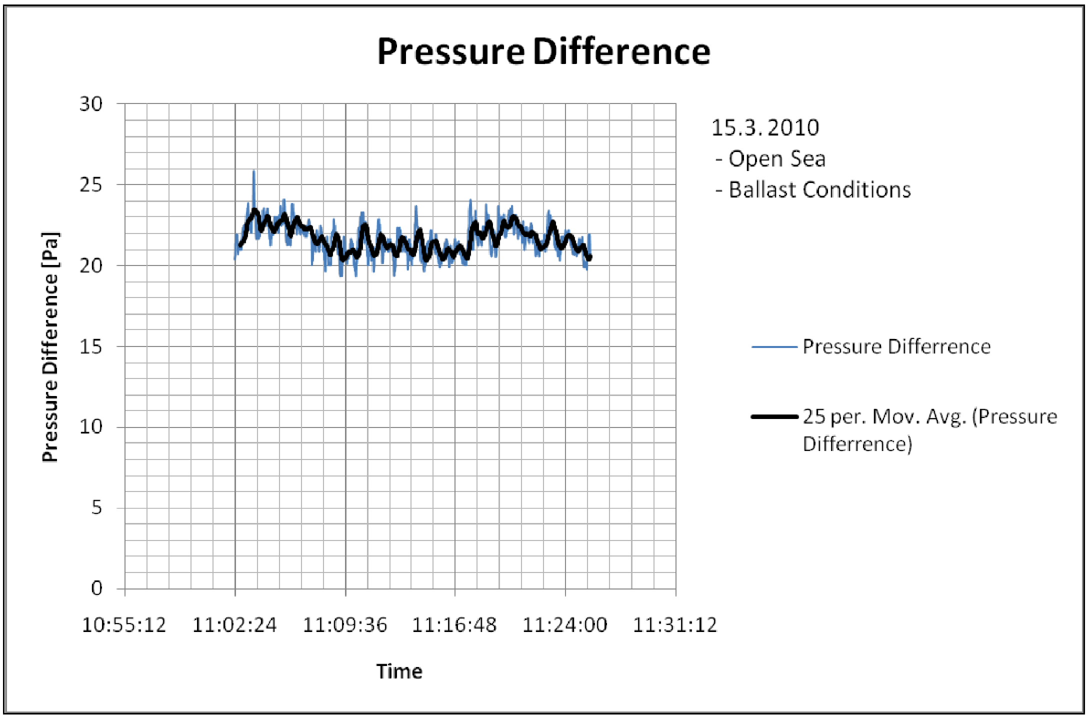


Figure 6. Pressure difference between the funnel top and engine room at service speed in ballast condition

4 PRESSURE ANALYSES

4.1 The effects of ship speed and engine power

In general the pressure in the engine room was very stable at open sea when the ship speed and main engine power of the ship were steady. In ice conditions pressure variation was more significant under constant change in speed and power. Onboard MT Suula the greatest measured pressure variation was 40 Pa. In harbor the starting of the main engine reduced the pressure by approximately 3 Pa.

The auxiliary engines are located in a separate space with their own ventilation fan. On the exit side of the auxiliary engine room there is an open connection to the main engine room. The starting and stopping of the auxiliary engines had minor effect on engine room pressure.

4.2 The effects of wind

There is not enough reliable test data available to draw any conclusions about the effects of wind. One problem in the data recording process was the separate weather station which was not connected to the main data acquisition computer. Especially gusty wind readings were difficult to synchronize manually with the computerized data recording. If MT Suula had sailed an extra 360 degree circle, the effects of wind direction could have been measured. Apparent wind speed influence on engine room pressure is difficult to estimate. If vessel speed is raised, also the power of the main engine increases. This higher engine load is in connection with the air consumption inside the engine room and the effect of wind speed on engine room pressure remains unclear.

4.3 The effects of air fans and steam boiler

The engine room main fans had an influence on air pressure. The starting of fan s11 increased the pressure by approximately 25 Pa. On the other hand the fan of the steam boiler oil burner consumes air and pressure drops in the engine room were about 12 Pa with the starting of this fan. The steam boiler is started automatically and the starting load is obviously low.

4.4 The effects of doors and hatches

The opening and closing of doors and hatches had no measurable influence on engine room pressure. Ventilation air recirculation was not shut off during the tests but would probably result in some reduction in pressure. If the main funnel exit and the recirculation had been closed, the highest possible pressure could have been measured. However, this mode of engine room ventilation is normally never in use. The engine casing main ventilation air exit is always open and it will be closed only in case of fire in the engine room.

5 CONCLUSIONS AND RECOMMENDATIONS

The measured engine room overpressure compared to the barometric pressure at funnel top varied between 6 Pa and 68 Pa. The ISO 8861 standard (1998) mandates that overpressure should not exceed 50 Pa. Most of the measurements onboard MT Suula were below this limit. On the other hand the main engine manufacturer recommends an overpressure of about 50 Pa and compared to this, the measured readings were rather low. Thus the two specifications of engine room pressure level are somewhat inconsistent.

The air temperature inside the engine room was within the limits set by classification societies. The maximum theoretical air inflow (65.9 m^3/h) fulfilled the 50 % extra air requirement of the standard. During the tests there was no need for such high ventilation flow. This high air flow had cooled the engine room excessively; the temperature outside the ship was quite low. Doors and hatches had practically no effect on the pressure in the engine room.

The original trigger for this study was the need to verify boiler operational reliability irrespective of pressure fluctuation in the engine room. The largest fluctuation was low, 60 Pa (~6 mm H_2O) which according to the burner manufacturer opinion should not disturb burner operation. However, the pressure level in the engine room should always stay positive to ensure boiler operational reliability. Ice conditions and maneuvering are the most problematic situations for the ship if the engine room pressure variation is the criterion. In general, the engine room ventilation system of MT Suula works well.

In future the following measures should be considered:

- Developing the engine room ventilation control on the basis of both temperature and pressure (if less pressure fluctuation is needed)
- More measurements should be conducted to clarify the effects of wind and wind direction on the engine room pressure. Such a future study would mainly be of academic significance.

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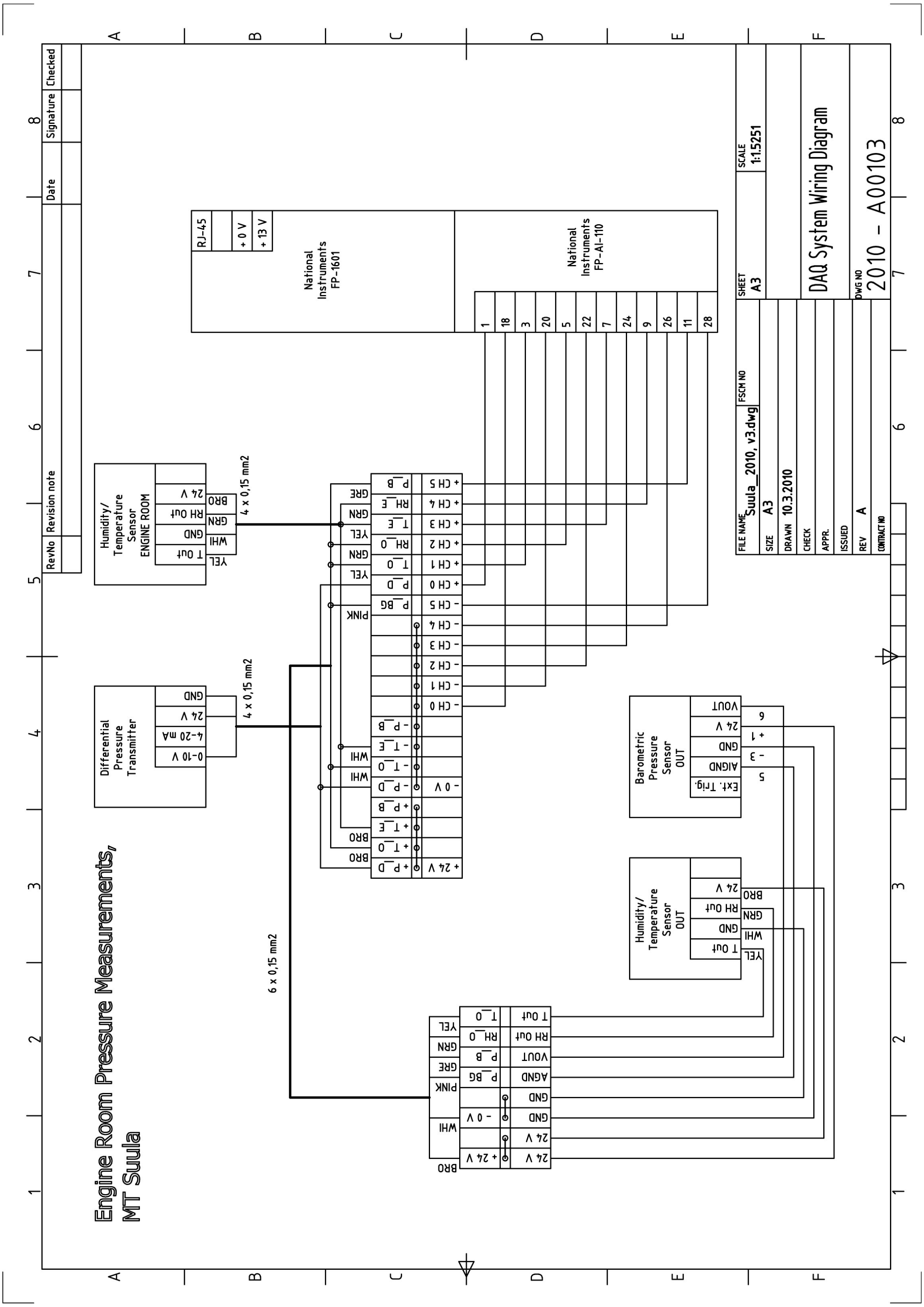
Appendices

Appendix 1 Pressure measurement system wiring diagram onboard MT Suula



Appendix 2 Pressure measurement arrangements onboard MT Suula