Investigation of exposure to whole body vibration for icebreaker crew

An investigation of whole body vibration exposure during ice-breaking in Arctic sea as a part in the “Oden Arctic Technology Research Cruise” 2015

Swedish Maritime Administration
HR & Development

The report is available at the Swedish Maritime Administrations website www.sjofartsverket.se

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Summary

Few investigations have been conducted regarding exposure to whole body vibration (WBV) and the impact it has on crews working on board ice-breaking vessels. Previous studies have focused on other types of vessels. This is the first study with this type of vessel.

Investigation took place in the icefield at latitude 82° north of Svalbard. The purpose was to do measurements in Arctic ice, which is much harder than the ice in the Gulf of Bothnia.

The aim was to measure the levels of whole body vibrations under normal operation during ice-breaking activities in the Arctic. The levels of exposure will be compared to levels of acceptance published by the Swedish Work Environment Authority and international standards.

To investigate the level of exposure meters and sensors (accelerometers) was used to log vibrations according to standards (ISO 2631, 6954). Data was collected with a handheld field instrument with a rubber plate measure probe.

Noise measurements have also been done in Oden and Frej during the vibration measuring.

Background data such as perceived comfort, ice thickness, ice type, speed, engine power usage, etc. was collected through interviews. Relevant data were also supplied from the NTNU project. The studies were done both at open sea and when breaking ice.

A lot of data has been collected from the two ice breakers Oden and Frej during two weeks in the OATRC-cruise September 2015. In total 274 vibration- and 102 noise measurement has been collected and analyzed.

The findings in this report indicate that the levels of vibration are low compared to levels of acceptance and health. The levels of vibration in living area and offices are close to Class A in standard ISO 6954. The results shows that the comfort level in these areas on these kinds of ships was high, even when breaking ice. This was also verified in the result of the questionnaire "Perceived comfort".

However even if the levels have been low, it was interesting to see what could impact to higher levels of vibration. Analyses in this report have shown that significant correlations exists.

Ice-breaking or open sea, position in the ship, perceived comfort, ice type, and ice-thickness are important factors that influence the vibration level.

The noise levels were normal to vessels like these and fulfills the Swedish provisions.

A correlation was found between perceived comfort (vibration) and measured noise level.

Norrköping 31 July 2016

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1 Background

Few investigations have been conducted regarding exposure to whole body vibration (WBV) for ice breaker crews. Numerous studies have been conducted before, but this is the first with the focus on icebreakers in normal operational conditions in the Arctic where the ice is harder than in the Baltic.

Referring to Forsell [3] asking 46 employees in ice-breaking ships, 72% were considered that WBV was a health and safety problem for them.

Whole body vibration denotes that the entire body is exposed to vibrations, either when someone is standing, sitting or lying down. Such vibrations are common, for instance, in buses, trains, heavy vehicles, airplanes and vessels, but also in rooms where the floor is in set motion by a vibration source.

In Sweden, health effects due to whole body vibrations have recently attracted greater interest. In a working environment investigation 2013 [2, 4, 5], 14 percent of the men and 2 percent of the women claimed that they had been exposed to whole body vibrations more than a fourth of their time at work. The professions that were most exposed to whole body vibrations are within the areas of farming, forestry, building work and transportation.

Exposure to whole body vibrations mainly affects the lower back. Studies show that the risk for pain in the lower back is doubled when people are exposed to whole body vibrations.

Crew and passengers of icebreakers often live and work on these vessels for long periods. Operation in ice with noise and vibration can have effect on verbal communication, telephone and radio conversations and clearness in emergency announcements. Unpredictable noise can face high levels of stress, affect rest and the sleep quality can degrade. Continuous noise and vibration also can increase the likelihood of fatigue symptoms. A. Sillitoe [17]

1.1 The OATRC cruise

In September 2015 the Norwegian-Swedish research expedition Oden Arctic Technology Research Cruise (OATRC 2015) was conducted with the Swedish icebreaker Oden and Frej in the Arctic Ocean north of Svalbard.

The expedition was collaboration between the Norwegian University of Science and the University of Trondheim (NTNU) and the Swedish Polar Research Secretariat. Two similar expeditions were conducted in 2012 and in 2013.

OATRC 2015 was a project under the Sustainable Arctic Marine and Coastal Technology (SAMCoT), which is a center for research-based innovation established by the Research Council of Norway with NTNU as the host.

On board the icebreakers the Norwegian research group investigate the physical and mechanical characteristics of ice and icebergs and studied icebreakers Oden and Frej performance and traction under various ice conditions.

More information about the cruise is published on the web of Swedish Polar Research Secretariat and NTNU.

1.2 Working in an icebreaker

The Swedish Maritime Administration is the owner of the two vessels Oden and Frej. Viking Supply Ships Ice-breaking Management AB, manage the crew on the ships.

During winter season Oden and Frej operate in the Baltic sea. Summertime Oden usually participate in different research cruises in the Arctic.

During this expedition the crew on each ship consisted of around 24 persons, all with specific tasks in the ships organization. The crew on board supports the scientists by helping them with a variety of different tasks.

The normal working arrangement on board is 8 hours of work followed by 8 hours of rest during a period of 2-4 weeks.

The crew consists of the followings ranks: Master, Chief. Officer, 2:nd Officer, Bosun, Able Seaman, Chief. Engineer, 1.st Engineer, 2nd Engineer, Oiler, Chief Cook, Messman, Electric Engineer, Fitter, Night Bosun, Medical Doctor.

Around 30 scientists participated on board each ship during the expedition.

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2 Purpose

The main purpose of the study was to measure the levels of exposure to whole body vibrations for crew during normal operating conditions in the Arctic.

Is there any correlation between concerns of health problems (WBV) of ice-breaker employees and objective measured vibration level?

The purpose was to collect data when operating in Arctic area.

The ice in Arctic is much harder than the ice in the Gulf of Bothnia where these vessels usually operate.

The investigation focused on two perspectives, health and comfort.

The levels of exposure will be compared to levels of acceptance as published by Swedish Work Environment Authority and international standards [6-15].

The purpose in this study was also to investigate whether problems with the lower back are more common among icebreaker crew. This area of the survey was later withdrawn because data collected showed only lower levels of WBV. These lower levels are not known to induce any back injuries.

There was also an interest of the author to confirm or not, many statements from icebreaker crew, that vibration (WBV) during ice-breaking is a potential working environment problem.

3 Methods

The methods used in the study include a variety of physical measurements and a questionnaire for each measurement. The level of exposure was performed using meters and sensors that log vibrations according to standards.

Background data such as perceived comfort, ice thickness, ice type, speed, engine power usage, weather etc. were collected from the questionnaire and through the NTNU project. The studies was conducted both at open sea and when breaking ice.

The study was conducted with support from Lage Burström and Hans Pettersson, Occupational and Environmental Medicine, Umeå University.

The measurements were performed according to standards ISO 2631, ISO 6954 and ISO 2923.

For every single measurement an interview/questionnaire has been done.
A large number of back-ground data has been documented. The questions of perceived comfort follow the ISO 2631 standard.

3.1 Planning and implementation of survey

Planning was done with support from ice breaking management at Sjöfartsverket and the crew management on the ships. Even the mentors in University of Umeå gave me excellent advices.

Literature searching was done via the internet.

The investigation took place in the icefield at latitude 82°north of Svalbard, 19/9-30/9 2015.
Measurements have also been done during transportation from Longyearbyen forth and back to the ice area for collecting reference data in open sea.

3.2 The measuring

Equipment list

-Hand held vibration meter
-Accelerator in rubber plate
-Sand sack (20 kg) placed on rubber plate for measuring “Stand” and “Recumbent” without the need of a person
-Hand held noise meter
-Questionnaire for back ground and instrumentation data
-Camera for documenting every measured place in ship
-Ear protection
-Designated protection gear (health hazard)

Duration of measuring WBV was 3 min with some exceptions. The measuring had to be representative for normal operational activity and conditions.

The positions during measurement were person “Sitting”, “Standing” or “Recumbent”.

Duration of noise measurements was 1 min with a hand held meter. The microphone was circling in the ear-area.

Usually one representative of the crew participated in measuring.

Measuring in Oden 18/9-24/9. Measuring in Frej 25/9-30/9 2015. Measurements were done during 09-22 every day.

3.3 Used equipment for measuring vibrations and noise

3.3.1 <u>Whole body vibration (WBV)</u>

A Svantek Human Vibration Analyzer SV 106 (serial no 45141) has been used for all vibration measurements.

The SV 106 is a six-channel human vibration meter and analyzer. The instrument meets ISO 8041:2005 standard and measurements according to ISO 2631-1,2,5 and ISO 5349.

It is a pocket-size instrument and enables simultaneous measurements with two triaxial accelerometers. The RMS, Peak, Peak-Peak, VDV, MTVV, A(8) or Dose results with all required weighting filters for the WBV measurements including band-limiting filters are available with this instrument. The instrument can also perform real-time 1/1 or 1/3 octave analysis.

Time-history logging and time-domain signal recording (according to the ISO 2631-5) to built-in Micro SD flash card give great capabilities of data storage. Results are downloaded to PC using USB interface and Svan PC software.

The Whole-Body vibration measurements are performed with SV 38V seat-accelerometer mounted in a rubber plate (serial no 47406 and 47407).

The plate can be placed directly on the seat-cushion, floor, placed in a bed or fixed to the back of the seat. The accelerometer follows the specifications in ISO 8041:2005.

Calibration
The instrument SV 106 and accelerometers are calibrated in factory august 2015.
The instrument has an internal calibration procedure in every start of the instrument.
On cruise even a back-up instrument SV 106 was brought. This instrument was even used for extra calibration checks.

3.3.2 Noise

The Norsonic 131 has been used for all noise measurements. The hand-held instrument is a Class 1 (precision) instrument.

Characteristics
Measuring Leq, Max, Min, SEL och Peak in dBA dBC/dBZ
18-140dB SPL 143dB Peak
Frequency analyzing in 1/1 and 1/3 octave
Logging function, L_{Aeq}, LA_{Fmax}, L_{C}, L_{z}, L_{peak}
Statistics with 8 percentiles

Norsonic Sound level meter Nor131, serial no 1313 187.
Microphone Nor-1228, serial no 01023
Pre-amplifier Nor-1207, serial no 12663
Used calibrator Norsonic Sound Calibrator 1251 (114 dB, 1000 Hz), serial no 32751
Data was transferred to Excel for further processing

Calibration
The instrument with microphone and calibrator are calibrated in March 2015.
The instrument has been calibrated before each start and at the end of measuring.

3.4 Questionnaire

For every single measurement an interview with a questionnaire has been done. Results from the questionnaire is found in Chapter 7.1.

The questionnaire contains questions of background factors and measuring data. See below.

OATRC 2015 WBV AND NOISE No

Background data

Ship:	ODEN ❑	FREJ ❑	
Date: …………………	**Time:** ………………………		
Location/area: ………………………	**Room No:** ……………	…………………………………………………	

Deck No:	1❑	2❑	3❑	4❑	5❑	6❑	7❑	8❑	9❑	10❑	Upper deck ❑	Bridge ❑

Occupation:	Deck Officers❑	Deck crew ❑	Engineer officers ❑	Engine crew ❑	Chief Cook ❑	Messman ❑
Actual task during measurement: …………………………………………………………………………………………………						
Position during measurement:	Sitting ❑	Standing (feet) ❑	Standing (sand sack) ❑	Recumbent ❑	Corr "z" along spine ❑	
Temp: ………	**RF:** …………					

Vessel activity:	Backing up ❑	Parking ❑	Ahead ❑	Break out from channel ❑
Power:	Low ❑	Medium ❑	Maximum ❑	
Where?	Open sea (sea state 3 or less) ❑		Channel/lead ❑	Ice field (type 1-7) ❑
Ice type:	1 New ice ❑	2 Open pack ice ❑	3 Close pack ice ❑	4 Compact pack ice ❑
	5 Rafted ice ❑	6 Ridged ice ❑	7 Level ice ❑	
Ice thickness (cm): …………………………				

WBV Measurements *Svantek 106 Human Vibration Analyzer s/n 45141*

Perceived comfort (ISO 2631)	1 Not uncomfortable ❑	2 A little uncomfortable ❑	3 Fairly uncomfortable ❑
	4 Uncomfortable ❑	5 Very uncomfortable ❑	6 Extremely uncomfortable ❑

***Health and safety**, ISO 2631-1, W_k* ***Motion sickness**, ISO 2631-1, W_f*

Measure No:	………………	Ch 1-3 ❑ Ch 4-6 ❑	SV38, 47406 ❑ SV38, 47407 ❑ TD-3, 14383 ❑	W_k ❑ W_f ❑ Note: ………………………………………
Measure No:	………………	Ch 1-3 ❑ Ch 4-6 ❑	SV38, 47406 ❑ SV38, 47407 ❑ TD-3, 14383 ❑	W_k ❑ W_f ❑ Note: ………………………………………
Measure No:	………………	Ch 1-3 ❑ Ch 4-6 ❑	SV38, 47406 ❑ SV38, 47407 ❑ TD-3, 14383 ❑	W_k ❑ W_f ❑ Note: ………………………………………
Measure No:	………………	Ch 1-3 ❑ Ch 4-6 ❑	SV38, 47406 ❑ SV38, 47407 ❑ TD-3, 14383 ❑	W_k ❑ W_f ❑ Note: ………………………………………

***Comfort**, ISO 6954, W_m*

Measure No:	………………	Ch 1-3 ❑ Ch 4-6 ❑	SV38, 47406 ❑ SV38, 47407 ❑ TD-3, 14383 ❑	W_m ❑ Note: ………………………………………

Noise Measurements *Norsonic Sound level meter 131 s/n 1313187, Microph Nor-1228 s/n 01023, Preamp Nor-1207 s/n 12663*

Measure No:	………………	Note: ………………………………………………………

Photo documentation ❑	**Calibration Svantek 106** ❑	**Calibration Norsonic 131** ❑
Notes: …………………………………………………………………………………		

Olof Johannesson, OH&S Engineer, HR & Development, Swedish Maritime Administration, sept 2015

3.5 Evaluating

The evaluating of measured data´s, collected data from ship, data from questionnaire, has been done in comparing with standards, regulations and literature.
Exposure time for crew was in mind, 8 or 24 h.

All collected data has been imported to an Excel-sheet.

Correlation analyses has been examined by statistician at Webropol, Linköping.

Evaluation has been done with the support from University of Umeå.

4 Icebreakers Oden and Frej

Oden is the primary ship for scientific expeditions. On this expedition it was the first time Frej operated in the Arctic sea. Icebreaker Frej does not have a polar ice class like Odens. One reason is Frejs two propellers in front of the ship but particularly the ice strengthening of the hull. Frej managed the task without any problems due to arctic conditions.

4.1 Ship data

A lot of ship data was collected all time during the cruise. The data output was different between the ships. Even more data can be collected from the scientists on board (NTNU). In this report the following data marked "*" has been used. More data excists and can be used for future studies.

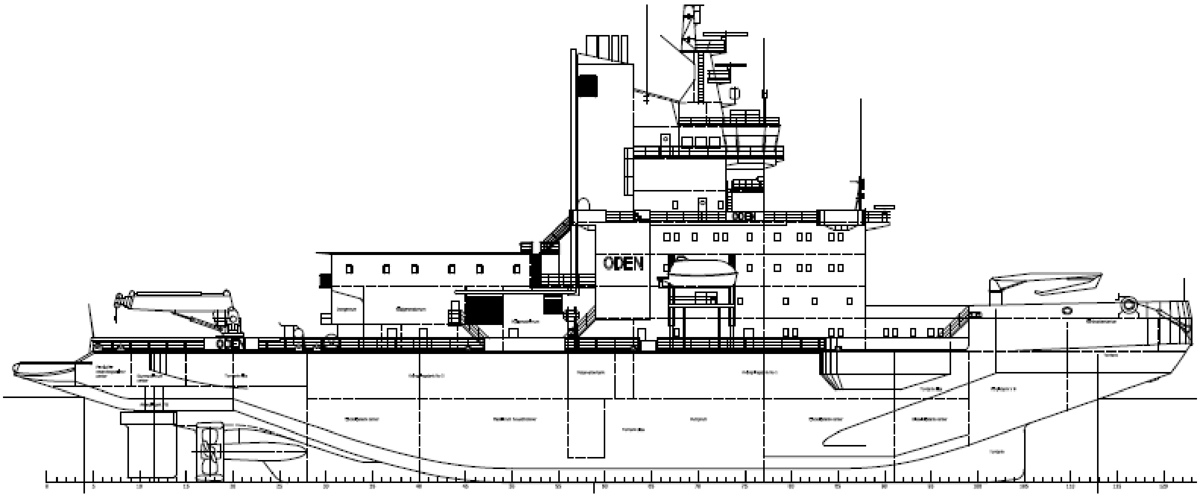
Oden

SOG (speed)*	Soundvelocitylab	Rudder port*
WindSpeed True*	Humidity	Rudder stbd*
Temp sea*	Heading	Pitch port*
Temperature*	COG	Pitch stbd*
Depth*		Rpm port*
Latitude Longitude*		Rpm stbd*
Wind Dir True		Torque port*
Wind Dir Rel		Torque stbd*
Wind Speed Rel		Power port*
Salinity lab		Power stbd*

Frej

SOG (speed)*	RPM1*
WindSpeedTrue*	RPM2*
Depth*	RPM3*
Latitude Longitude*	RPM4*
WindDirTrue	PWR1*
WindDirRel	PWR2*
Wind Speed Rel	PWR3*
Heading	PWR4*
COG	Rudder*

4.2 Ice breaker Oden



Oden is one of five icebreakers operated by the Swedish Maritime Administration. The vessel is designed for escort, ice-breaking and for Arctic research operations with non-limited trade areas. The icebreaker is also a research platform with a very flexible layout and can carry scientific equipment, container/van labs, frozen storage and equipment for geological sampling, oceanography, meteorology and other disciplines.

Götaverken Arendal delivered Oden in January 1989. Oden is built for a lifetime of 35 years and has carried out ice-breaking in the Baltic and expeditions to the Arctic and Antarctica. Oden has reached the North Pole on several expeditions.

In the year of 2000 extensive work was carried out in order to adapt Oden to scientific expeditions. Among other things a new laboratory and a seawater intake was built. In 2007 an EM 122 multibeam echo sounder was installed for bottom processes and seafloor morphology studies.

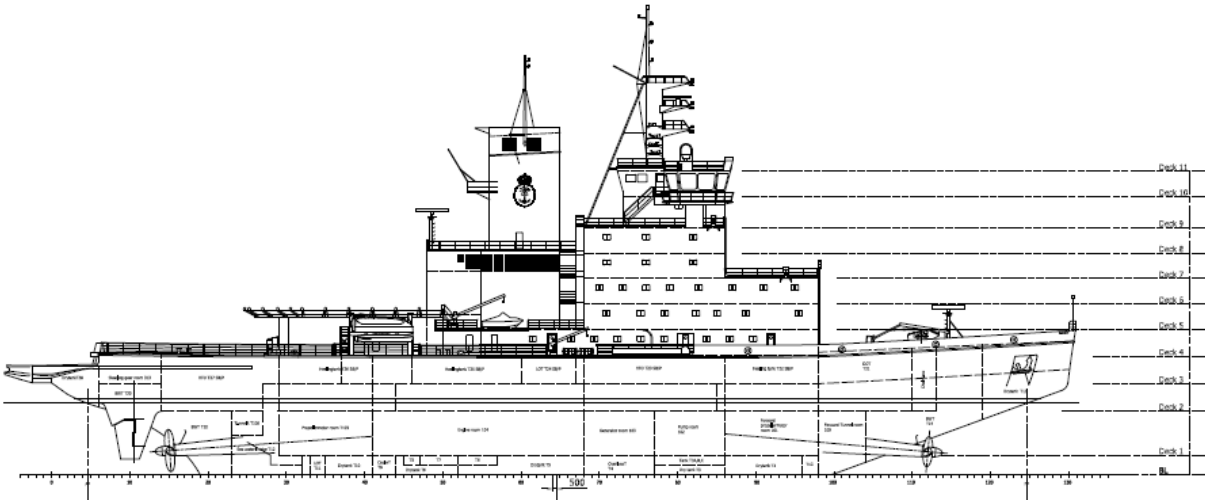
Main particulars

Length, LOA 107,7 m
Beam, amidships 25 m
Beam, main reamer 29,4 m   Crew < 22
Beam, turning reamer 31,2 m
Draught 7-8,5 m
Displacement max 13 000 ton
Gross 9438 GRT
Engine power 18 MW
Total persons on board 50

Max speed 16 knots
Max cruising range 27 000 M/13,5 knots

Ice-breaking capability 2(1) m, at 3(9) knots
Endurance > 100 days
Steel thickness max 60 mm
Arctic ice-class CAN POLAR 20
Computerized engine control (ABB)

4.3 Icebreaker Frej



Frej is one of five icebreakers operated by the Swedish Maritime Administration. The vessel is designed for escort, ice-breaking and for other special operations with non-limited trade areas.

Frej was delivered 1975. Frej is built for a lifetime of approximately 50 years' service and has carried out ice-breaking in the Baltic area.

Main particulars

Length, LOA 106,6 m
Beam, amidships 24 m
Draught 7,3-8,3 m
Displacement 7800 ton
Gross 9438 GRT
Engine power 16,2 MW 2+2 Propellers
Maximum Speed 19 knots. Service speed 12-14 knots
Ice-Class 1A Super Icebreaker
Ice-breaking capability 1,2 m at 3 knots
Computerized engine control (Lyngsö)
Crew 17-24 depending on operation
Total persons on board 50

4.4 Ship areas for measurements

It has been important to spread out the measurements as much as possible in the ship according to ISO 6954 [10]. Locations for measurements have been decided by the crew and represents areas with activity during normal operation.

For most of measurements the crew participated.

The ships have different layouts and numbering of decks. Therefore a special division has been done to be able to compare the two ships with each other.

Oden 18/9-24/9 2015

	Place for measurement	No of measure ments WBV	No of measure ments Noise	Test site in ship "Deck" (1-10) 1=top of ship
Top of bridge deck	Technichal room	2	1	1
Bridge deck	Maneuvering port side	10	2	2
	Maneuvering starboard	12	3	2
	Operator space	10	1	2
Deck 5	Machine room 507	3	1	3
Däck 4	Conference room	5	2	4
Deck 3 and helicopter deck	Dayroom deck officer	3	1	5
	Dayroom chief eng. officer	1	0	5
	Cabin 314, 2:nd nav. Officer	2	1	5
Deck 2	Laundry	3	1	6
	Workbench in store	3	1	6
	Cabin 204, Engineer officer	2	0	6
	Cabin 215, chief cook	2	1	6
	Cabin 257*	11	2	6
Deck 1	Relaxroom	4	2	7
	Cabin 122	1	1	7
	Cabin 127	2	1	7
	Cabin, fore, port side	1	1	7
	Back deck	2	1	7
	Emergency gen. room	3	2	7
Upper Deck	After deck	4	1	8
	Welding room	3	1	8
	Deck officers office	3	1	8
	Machine officers office	3	1	8
	Odenplan	1	1	8
	Mess room	4	2	8
	Pentry	2	2	8
	Caboose	4	3	8
	The bar	4	1	8
	Carpenter store	3	7	8
	Auxiliary engine room	3	1	8
	Bousen store room	8	3	8
	Boiler room	3	1	8
Middle Deck	Steering machine	3	1	9
	Entrance to steering machine	4	1	9
	Separator room	2	1	9
	Machinery control room	4	1	9
	Machine supplies room	4	1	9
Tank roof	Emergency fire pump room	3	1	10
	Main machine room, stern	3	1	10
	Main machine room, middle	3	1	10
	Pump room center	3	1	10
Total		**155**	**59**	

*The authors cabin

Frej 25/9-30/9 2015

	Place for measurement	No of measure ments WBV	No of measure ments Noise	Test site in ship "Deck" (1-10) 1=top of ship
Deck 10, bridge	Maneuvering, starboard	8	0	2
	Desk in rear bridge room	6	0	2
Deck 9	-			
Deck 8	Cabin 8-1	5	1	4
Deck 7	Cabin 7:2	2	2	5
Deck 6	Relax room next to sauna	2	1	6
	Cabin 6:17	2	1	6
Deck 5	Caboose	1	0	8
	Mess room, soft chair	4	0	8
	Mess room, fore, portside	6	2	8
	Scullery	2	0	8
Deck 4 Main deck	Afterdeck	1	0	8
	Foredeck	2	0	8
	Bousen store room	2	1	8
	Machine officers office	5	2	8
	Deck officers office	5	2	8
	Cabin 4:13*	11	1	8
Deck 3	Machinery control room	5	2	9
	Exercise room	3	2	9
	Carpenter store	3	2	9
	Weight exercise room	2	1	9
	Welding room	3	2	9
	Machine workshop	2	1	9
	Hold, computer desk	2	1	9
	Steering machine	4	2	9
Deck 2	Electric works	3	1	9
	Electric device room	3	2	9
	Boiler room	3	2	9
	Auxiliary engine room	3	2	9
Deck 1	Pump room 1	3	2	10
	Pump room 2	2	1	10
	Propeller engine room, fore	3	2	10
	Main machine diesels	3	2	10
	Separator room, next desk	3	1	10
	Propeller engine room, astern	2	1	10
	Tunnel room, astern	3	2	10
Total		**119**	**43**	

*The authors cabin

5 Standards and definitions

5.1 Whole body vibration (WBV)

The following standards have been used [7-12] for measuring and evaluation.

ISO 2631-1, *Vibration and shock – Evaluation of human exposure to whole-body vibration.* Part 1: *General requirements* [7]
This standard is the basic standard for all WBV-measurements.

ISO 2631-2, *Vibration and shock – Evaluation of human exposure to whole-body vibration.* Part 2: *Vibration in buildings (1 Hz to 80 Hz)* [8]
This standard is used for doing measurements in buildings and is connected with the ISO 6954.

ISO 6954, *Mechanical vibration – Guidelines for the measurement, reporting and evaluation of vibration in merchant ships* [10]
This standard is used for evaluation of habitability in ships. It contains guidelines for different areas on board.

Table 1

Table 1 — Overall frequency-weighted r.m.s. values from 1 Hz to 80 Hz given as guidelines for the habitability of different areas on a ship

	Area classification					
	A		B		C	
	mm/s^2	mm/s	mm/s^2	mm/s	mm/s^2	mm/s
Values above which adverse comments are probable	143	4	214	6	286	8
Values below which adverse comments are not probable	71,5	2	107	3	143	4
NOTE The zone between upper and lower values reflects the shipboard vibration environment commonly experienced and accepted.						

Three different classification areas are presented:

— Classification A;

— Classification B;

— Classification C.

NOTE For guidance, Classification A can be passenger cabins, Classification B crew accommodation areas, and Classification C working areas.

Measurement conditions according to the standard ISO 6954:
a) free-route test on a straight course
b) constant representative engine output
c) sea state 3 or less
d) full immersion of the propeller
e) water depth not less than five times the draught of the ship
Any deviation from the above measurement conditions shall be clearly stated in the test report.

ISO 8041:2005, *Human response to vibration – Measuring instrumentation* [11]
This standard contains performance specifications and tolerance limits for instruments designed to measure vibration.

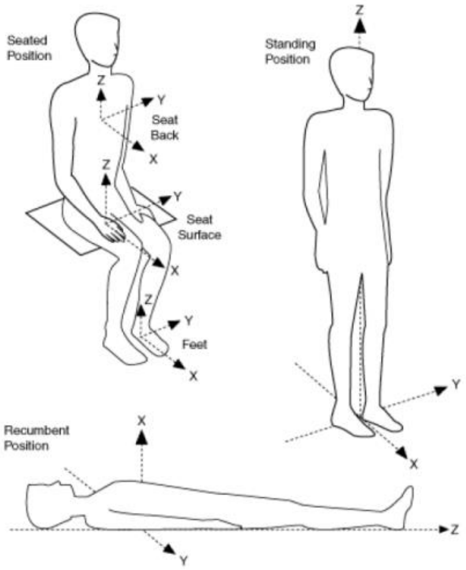
Vibration is measured in the frequencies 0,5 Hz to 80 Hz (1 Hz to 80 Hz in buildings and in ships, [8, 10]) on the vibrating surface were the person is in contact with vibrations, either sitting, standing or lying down.

Definitions

a_w: a_w is the weighted root-mean-square acceleration value (ISO 2631-1).
a_w and VDV are the most used parameters to analyze whole body vibration, WBV.

$$a_W = \left[\frac{1}{T} \int_0^T a_W^2(t)\, dt \right]^{\frac{1}{2}}$$

Two filters are used different for the three axes (W_d, W_k). The results of the maximum of the three axes x, y, z is chosen and then multiplied by their respective k-factors.



x-axis: W_d k=1,4
y-axis: W_d k=1,4
z-axis: W_k k=1,0

The z-axis is always the vertical in standing and sitting position, and along the spine in recumbent position.

When measuring according to ISO 6954 (habitability) in ships, the filter W_m is used.

VDV: Vibration dose value (VDV). The fourth root of the time integral of the fourth power of the instantaneous frequency-weighted vibration acceleration. VDV is measured in $m/s^{1,75}$.
VDV and a_w are the most used parameters to analyze whole body vibration, WBV.
VDV is more sensitive to peaks compared to a_w and shows more effects of possible shocks.

$$VDV = \left\{ \int_0^T \left[a_W(t) \right]^4 \, dt \right\}^{\frac{1}{4}}$$

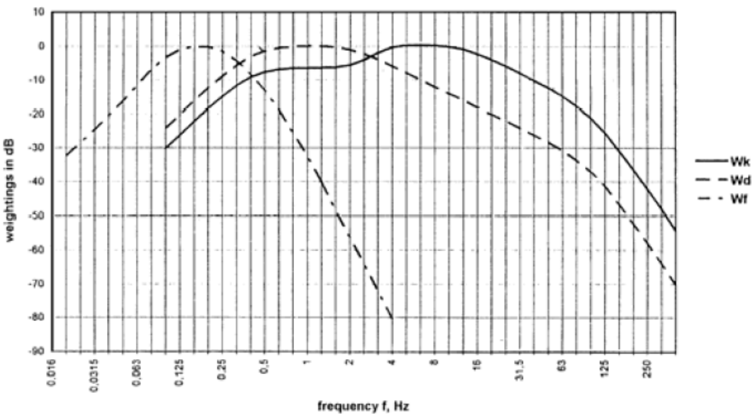
Peak: Peak vibration value. The maximum of the instantaneous (positive and negative) peak values of the frequency-weighted acceleration measured over the elapsed time.

CRF: Crest factor is the ratio of the Peak value to the root mean square (RMS) value of a quantity over a specified time interval. The crest factor is low if the Peak value is only slightly above the RMS value, indicating a rather smooth, steady vibration process. A large crest factor (>9) will indicate that the vibrations contains one or several strong transients, for example shocks.

MTVV: Maximum transient vibration value (MTVV). The maximum value of the running root mean square (RMS) acceleration measured over the elapsed time.

ISO 2631(Frequency weighting)

- Frequency weighting curves



Frequency range:

- Health, comfort and perception – 0,5 Hz to 80 Hz
- Motion sickness – 0,1 Hz to 0,5 Hz

5.2 Noise

The following standard has been used for measuring and evaluation.

ISO 2923:1996, *Acoustics measurements of noise on board vessels* [9]

Leq is the equivalent continuous sound pressure level. It is given by the following equation:

$$L_{peq,T} = 10 \lg \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p(t)}{{p_0}^2} \mathrm{d}t \right] \text{dB}$$

Where t_2-t_1 is the period T over which the average is taken, starting at t_1 and ending at t_2.

6 Regulations

Following regulations are useful in risk assessment of WBV and noise.

1. Swedish provisions, TSFS 2009:119, *Regulations and general advice on health and safety on ships. Chapter 4, appendix 2.* Swedish Transport Agency [13]

2. Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) [6]

3. Swedish provisions, AFS 2005:15, *Vibrations.* Swedish Work Environment Authority [14]

4. Swedish provisions, AFS 2005:16, *Noise.* Swedish Work Environment Authority [15]

6.1 Swedish provisions, TSFS 2009:119, Chapter 2, 4, app. 2, *Vibration and noise*

Except vibration and noise, this regulation comprises many working environment areas.
References are often made to AFS 2005:15 and AFS 2005:16

Whole body vibrations (WBV)

Freely translated:
64§. *When the whole body vibration is caused or transmitted by the vessel's hull, do not apply the threshold for whole body vibration, if having regard to the current technological and workplace specific nature is not possible to fulfill these obligations. The risk assessment shall pay particular attention to the extension of exposure beyond normal working hours of workers on vessels and the risks associated with disturbed sleep as a result of vibrations.*
Author's comment: The threshold values are “valid” to prevent health problems in ships anyway. Preventive activities are highly recommended.

65§. *New construction should be sought to ship vibrations not exceed the values according to ISO 6954, Table 1, is expected to generate complaints.*

Noise

Annex 3 Calculation of daily noise exposure
If the working day depart from 8 hours the calculated employee's daily noise exposure $L_{Ex,h}$ expressed in dBA, using the formula below.

$L_{EX,h} = Lp_{AeqTe} + 10\log_{10}T_e/T_0$. L_{pAeqTe} = during time T_e measured equivalent noise level
Te = worker's daily exposure, expressed in hours, noise with equivalent noise level LpAeqTe
$T_0 = 8$ hours
If $T_e=T_0=8$ h then $L_{EX,h} = L_{pAeqTe}$

TSFS 2009:119 Annex 2 Maximum noise levels on board ships
Applicable on Oden and Frej (the text in the table is translated from Swedish by the author)

Working space	**dBA**
Machine space	
Control and operation room	70
Workshops and stores	75
Manned or periodically unmanned engine-room with control-room	100
Manned engine-room without control-room	85
Special room for propulsion, steering, generator, etc. when engine is stopped	85
Navigation space	
Outdoors on the bridge wing and control console	70
Indoor navigation cabin	65
Cargo holds and decks	
Noise from fans when loading and unloading as well as noise at maneuvering ramp, crane or winch	65
Cabin for staff, office and radio cabin	
Monotonous noise at sea or in port	55
Intermittent noise in port	65
Mess rooms, day rooms etc.	
Monotonous and intermittent noise at sea and in port	65
Kitchen, hobby room, exercise room and similar rooms	
Monotonous background noise at sea	65
Maximum noise level with equipment in operation	75
Deck space intended for residence during leisure time	65

Exceptions
Noise while operating in ice
“For ships constructed before 1 January 2006, the above values may be exceeded when navigating in ice. The noise level in residential and living rooms are not allowed to exceed 85 dBA”

6.2 Directive 2002/44/EC

According to Directive 2002/44/EC, Article 3, Exposure limit values and action values. [6]

2. For whole-body vibration:
(a) the **daily exposure limit value** standardized to an eight-hour reference period shall be 1,15 m/s^2 or, at the choice of the Member State concerned, a vibration dose value (VDV) of 21 $m/s^{1,75}$;

(b) the **daily exposure action value** standardized to an eight-hour reference period shall be 0,5 m/s^2 or, at the choice of the Member State concerned, a vibration dose value (VDV) of 9,1 $m/s^{1,75}$.

Workers' exposure to whole-body vibration shall be assessed or measured on the basis of the provisions of Point 1 of Part B of the Annex.

1. Assessment of exposure
The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (rms) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes ($1{,}4a_{wx}$, $1{,}4a_{wy}$, a_{wz} for a seated or standing worker) in accordance with Chapters 5, 6 and 7, Annex A and Annex B to ISO standard 2631-1(1997).

The assessment of the level of exposure may be carried out on the basis of an estimate based on information provided by the manufacturers concerning the level of emission from the work equipment used, and based on observation of specific work practices or on measurement.

In the case of maritime shipping, Member States may consider only vibrations of a frequency exceeding 1 Hz.

2. Measurement
When measurement is employed in accordance with Article 4.1, the methods used may include sampling, which must be representative of the personal exposure of a worker to the mechanical vibration in question. The methods used must be adapted to the particular characteristics of the mechanical vibration to be measured, to ambient factors and to the characteristics of the measuring apparatus.

6.3 Swedish provisions, AFS 2005:15, *Vibrations*

Annex 3 [14]

Exposure values for whole body vibration

Exposure value relates to the daily vibration exposure, A (8h).

Daily exposure action value WBV 0,5 m/s^2
Daily exposure limit value WBV 1,1 m/s^2

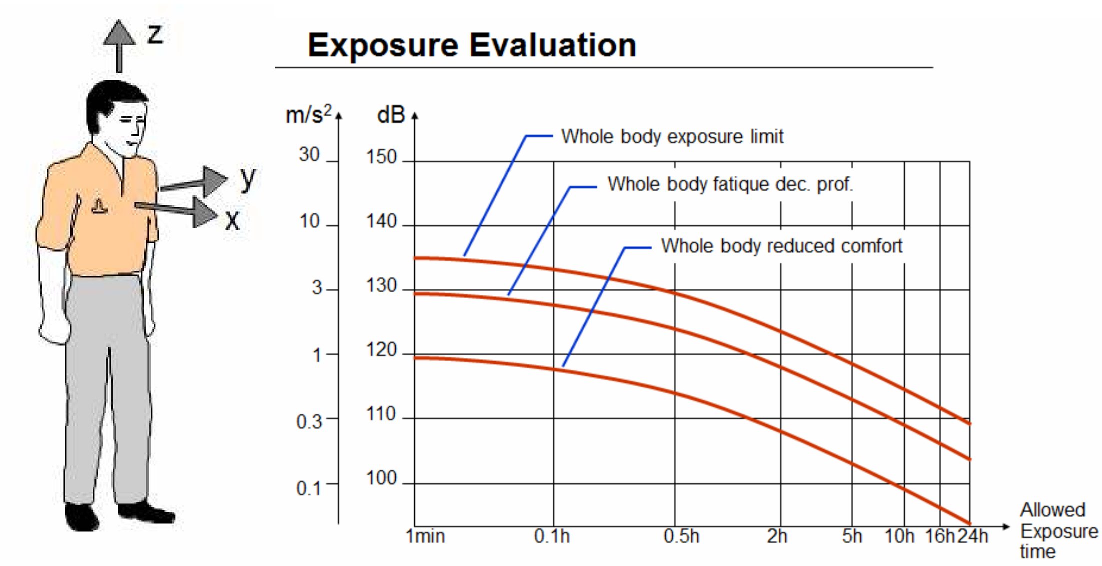
Annex 2

Estimation of daily exposure

If several machines are used in the same working day or more operations with different vibration acceleration needs to be summed, exposure to the contributions of the various machines and work areas summarized as follows:

$$A(8) = \sqrt{\frac{1}{8}\sum_{i=1}^{n} a_i^2 T_i}$$

a_i is the total frequency weighted acceleration for each "machine" or operation during time T_i.



6.4 Swedish provisions, AFS 2005:16, *Noise*

Exposure value relates to the daily vibration exposure (8h) [15]

	$L_{ex, 8h}$ (dBA)
Lower exposure action value	80
Upper exposure action value	85
Exposure limit value WBV	85

7 Results

7.1 Results from questionnaire

Referring used questionnaire. Chapter 3.4

Profession/rank

The purpose of documenting profession/rank was to see if any group of employees was more exposed to WBV than others.

Result

The measurements showed only lower levels of WBV and therefore there was no reason to divide the results per profession/rank.

Actual task during measurement

Result

During data collection normal and representative activities were ongoing.

Position during measurement

The standard 2631-1 gives three opportunities of positions for measurement, “Sitting”, “Standing” or “Recumbent” [7] Most of the measurement were in “Standing” position. Chapter 7.3.

Vessel activity

The four options were “Backing up”, “Parking”, “Ahead”, “Break out from channel”.
The main purpose of this question was to make it possible to compare with other reports like A. Bekker [1]

Result

All measurements were done with the vessel activity “Ahead”.

Power

The three options for the measurement period.
Actual used power of the engines 1 Low, 2 Medium, 3 Maximum.
Information of used power can also be found in the output ship data.
Unfortunately the outputs are different for Oden and Frej. The data is therefore more difficult to compare. (Chapter 4.1)

Result

For both ships the power varied between 1-2. Mean value 1,6 and median 2,0.

Where? (operational conditions)

The three options were 1 Open sea (sea state3 or less) , 2 Channel/lead and
3 Ice field (type 1-7)

Result

In both vessels most of the measurements were done during ice-breaking.

Open sea	27%
Channel/lead	9%
Ice field	64%

Ice type

Six options were given to characterize the ice type

Result

Most of the measurements were done in breaking “Close pack ice”.
More data can be found from the NTNU projects.

	Percent
1 New ice	20
2 Open pack ice	8
3 Close pack ice	49
4 Compact pack ice	23
5 Rafted ice	0
6 Ridged ice	0
7 Level ice	0

Ice thickness

Result

When ice breaking the ice thickness varied 0,3-2,0 m
Mean value 1,5 m
Median 1,5 m

More data can be found from the NTNU projects.

Perceived comfort (ISO 2631)

Six options were given to characterize the vibration comfort.
The standardized ratings are according to the ISO 2631-1.
To simplify the correlation analyses the six grades were divided into three.
1-3 = High comfort
4-6 = Low comfort

Result

Perceived comfort in the ships was high during the cruise.
96% of the answers showed “High comfort”.

	Number	*Percent*
1 Not uncomfortable	127	47,2
2 A little uncomfortable	99	36,8
3 Fairly uncomfortable	32	11,9
4 Uncomfortable	10	3,7
5 Very uncomfortable	1	0,4
6 Extremely uncomfortable	0	0
Sum	*269*	

ISO 2631-1, Annex C, C.2.3
Acceptable values of vibration magnitude for comfort

Less than 0,315 m/s^2:	not uncomfortable
0,315 m/s^2 to 0,63 m/s^2:	a little uncomfortable
0,5 m/s^2 to 1 m/s^2:	fairly uncomfortable
0,8 m/s^2 to 1,6 m/s^2:	uncomfortable
1,25 m/s^2 to 2,5 m/s^2:	very uncomfortable
Greater than 2 m/s^2:	extremely uncomfortable

7.2 Results of ship data

A lot of data has been collected during the cruise. Some of the results are presented here.

Location for measurements

	Latitude	*Longitude*
Operating in ice	82,061449 - 82,092036	16,333748 - 16,566681
Operating in open sea	78,072403 - 80,984498	08,585102 - 13,328389

Sea depth

Operating in ice, variation 1000 -5388 m
Operating in open sea, 208-1927 m

Speed

Operating in ice, average 4,9 knots, variation 0,2-9 knots.
Operating in open sea, 11-19 knots.

Wind speed

Operating in ice, average 7 m/s, variation 3-14 m/s.
Operating in open sea, average 7 m/s, variation 7-8 m/s.

Temperature in air

Operating in ice, average -6,3 ºC, variation -11,6 - +1,5 ºC.
Operating in open sea, average +2,2 ºC, variation +0,9 -3,6 ºC.

Temperature in sea

Operating in ice, average -1,7 ºC, variation -1,9 - +0,2 ºC.
Operating in open sea, average +2,5 ºC, variation +0,0 - +5,3 ºC.

7.3 Results of measured vibration WBV and noise

A lot of data has been collected from the two icebreakers Oden and Frej during two weeks in the OATRC-cruise September 2105. In total 274 vibration- and 102 noise measurements have been collected and analyzed.

The measured levels are compared to the European and Swedish regulations and relevant ISO standards.

Result whole body vibration, WBV

In this report the findings indicate that the levels of vibration are very low compared to levels of acceptance and health. The occurrence of shocks is also low. There is one exception, in the steering machine room in Oden.

The levels of vibration in living area and offices are close to Class A in standard ISO 6954. Chapter 5.1

The results show that the comfort level in these areas on this kinds of ships was high, even when breaking ice. This result is also supported in the result "Perceived comfort" in the questionnaire. Chapter 3.4.

Mean values, variation and median (n=274)
a_w: 67 mm/s^2, variation 13-744 mm/s^2, median 46 mm/s^2.
VDV: 545 mm/s^2, variation 70-21928 mm/s^2, median 318 mm/s^2.

Frequency analysis is possible to do, but not published here.

Compared with Swedish legal requirements and EU directives, the measured levels are low and therefore the risk of injury due to WBV is very low.

Result noise

Mean values (n=102)
L_{Aeq}: 71 dBA, variation 45-112 dBA. Median 67 dBA

Frequency analysis is possible to do, but not published here.

Compared with Swedish legal requirements AFS 2005:16 and TSFS 2009:119, the measurements show normal noise levels and the requirements are for filled in most places in both ships.

7.3.1 Results Oden and Frej WBV and Noise

		a_w (mm/s^2)	**VDV** (mm/s^{1,75})	**Peak** (mm/s^2)	**MTVV** (mm/s^2)	**CRF**	**L_{Aeq}** (dB)	**Number of measure** WBV	**Number of measure** Noise
All	***Oden + Frej***								
measurements	Mean value	**67**	**545**	**729**	**204**	**10**	**71**	274	102
	Median	46	318	425	134	8	67		
	Min	13	70	65	22	3	45		
	Max	744	21928	10827	3404	57	112		
	Open sea								
	Mean value	**51**	**332**	**530**	**134**	**9**	**71**	74	54
	Median	37	206	257	78	6	63		
	Min	13	70	65	22	3	47		
	Max	378	3552	10827	1515	57	112		
	Mean value (Sit)	43	403	872	199	12		20	
	Mean value (Stand)	56	316	420	114	7		51	
	Mean value (Recumbent)	28	142	125	47	5		3	
	Breaking ice								
	Mean value	**72**	**623**	**804**	**228**	**11**	**72**	200	48
	Median	52	352	513	154	9	72		
	Min	15	81	112	34	3	45		
	Max	744	21928	8831	3404	33	111		
	Mean value (Sit)	49	328	507	170	10		42	
	Mean value (Stand)	79	703	882	246	11		158	
	Mean value (Recumbent)	-	-	-		-		-	

7.3.2 Results Oden WBV and Noise

IB Oden		**a_w** (mm/s^2)	**VDV** (mm/s^{1,75})	**Peak** (mm/s^2)	**MTVV** (mm/s^2)	**CRF**	**L_{Aeq}** (dB)	**Number of measure** VBV	**Number of measure** Noise
All	***Oden***								
measurements	Mean value	**75**	**650**	**856**	**245**	**10**	**68**	155	59
	Median	47	325	432	149	8	63		
	Min	13	70	65	22	3	47		
	Max	744	21928	10827	3404	57	104		
	Open sea								
	Mean value	**53**	**346**	**549**	**149**	**9**	**68**	51	39
	Median	36	214	246	80	6	62		
	Min	13	70	65	22	3	47		
	Max	378	3552	10827	1515	57	104		
	Mean value (Sit)	43	408	915	197	12		18	
	Mean value (Stand)	61	329	371	130	7		30	
	Mean value (Recumbent)	28	142	125	47	5		3	
	Breaking ice								
	Mean value	**86**	**799**	**1006**	**292**	**11**	**69**	104	22
	Median	57	367	549	195	10	70		
	Min	17	105	132	55	3	50		
	Max	744	21928	8831	3404	33	89		
	Mean value (Sit)	55	378	614	197	11		23	
	Mean value (Stand)	93	908	1111		11		81	
	Mean value (Recumbent)	-	-	-	-	-		-	

IB Oden	**Place for measurement**	**a_w** (mm/s²) Open sea **S**it, **St**and, **Rec**umbent	**VDV** (mm/s^1,75^) Open sea **S**it, **St**and, **Rec**umbent	**a_w** (mm/s²) Ice breaking **S**it, **St**and, **Rec**umbent	**VDV** (mm/s^1,75^) Ice breaking **S**it, **St**and, **Rec**umbent	**L_{Aeq}** (dB) Open sea/ Ice breaking	**Number of measure** WBV/L_{Aeq}	**Test site in ship "Deck"** (1-10) 1=top of ship
Top of bridge deck	Technichal room	97 (Stand)	479 (Stand)	61 (Stand)	344 (Stand)	59/-	2/1	1
Bridge deck	Maneuvering port side	33-51 (Stand)	163-246 (Stand)	43-100 (Stand)	309-1012 (Stand)	49/-	7/2	2
		-	-	52-84 (Sit)	384-1074 (Sit)		3	2
	Maneuvering starboard	35-36 (Stand)	172-173 (Stand)	40-65 (Stand)	255-499 (Stand)	48-51/-	5/3	2
		36-40 (Sit)	192-304 (Sit)	43-71 (Sit)	265-514 (Sit)		7	2
	Operator space	30 (Stand)	187 (Stand)	31-64 (Stand)	191-380 (Stand)	48/-	5/1	2
		32 (Sit)	258 (Sit)	33-41 (Sit)	202-383 (Sit)		5	2
Deck 5	Machine room 507	21 (Stand)	105 (Stand)	32 (Stand)	178 (Stand)	64/-	2/1	3
		29 (Sit)	206 (Sit)	-	-		1	3
Deck 4	Conference room	-	-	30-35 (Stand)	169-186 (Stand)	52/54	2/2	4
		191 (Sit)	3552 (Sit)	33-37 (Sit)	197-332 (Sit)		3	4
Deck 3 and helicopter deck	Dayroom deck officer	-	-	27-39 (Stand)	196-352 (Stand)	-/54	2/1	5
	Dayroom chief eng. officer	-	-	35 (Stand)	339 (Stand)	-/-	1	5
	Cabin 314, 2:nd nav. Officer	-	-	53-85 (Stand)	983-1456 (Stand)	-/54	2/1	5
Deck 2	Laundry	15 (Stand)	80 (Stand)	17-28 (Stand)	105-198 (Stand)	56/-	3/1	6
	Workbench in store	41 (Stand)	207 (Stand)	33-43 (Stand)	169-238 (Stand)	61/-	3/1	6
	Cabin 204, Engineer officer	-	-	28-43 (Stand)	158-214 (Stand)	-	2	6
	Cabin 215, chief cook	-	-	65-117 (Stand)	735-1300 (Stand)	-/50	2/1	6
	Cabin 257	56 (Recumbent)	268 (Recumbent)	23-66 (Stand)	121-1654 (Stand)	54/56	11/2	6
Deck 1	Relaxroom	15-24 (Sit)	84-127 (Sit)	23-40 (Sit)	132-212 (Sit)	54/54	4/2	7
	Cabin 122	15 (Recumbent)	86 (Recumbent)	-	-	47/-	1/1	7
	Cabin 127	-	-	76 (Stand)	965 (Stand)	-/53	2/1	7
	Cabin, fore, port side	13 (Recumbent)	70 (Recumbent)	-	-	53/-	1/1	7
	Back deck	36 (Stand)	191 (Stand)	115 (Stand)	752 (Stand)	62/-	2/1	7
	Emergency gen. room	28-30 (Stand)	149-296 (Stand)	42 (Stand)	251 (Stand)	63-104/-	3/2	7
Upper Deck	After deck	25 (Stand)	125 (Stand)	113-143 (Stand)	1015-1406 (Stand)	74/-	4/1	8
	Welding room	63 (Stand)	308 (Stand)	58-72 (Stand)	288-350 (Stand)	66/-	3/1	8
	Deck officers office	-	-	36 (Stand)	183 (Stand)	-/-	1	8
		59 (Sit)	499 (Sit)	44-56 (Sit)	260-304 (Sit)	55/-	3/1	8
	Machine officers office	62 (Stand)	356 (Stand)	-	-	-/-	1	8
		30 (Sit)	159 (Sit)	47 (Sit)	334 (Sit)	56/-	2/1	8
	Odenplan	-	-	42 (Stand)	325 (Stand)	-/61	1/1	8
	Mess room	-	-	39 (Stand)	203 (Stand)	-	1	8
		15 (Sit)	79 (Sit)	49-178 (Sit)	366-912 (Sit)	60/74	3/2	8
	Pentry	78 (Stand)	875 (Stand)	100 (Stand)	518 (Stand)	61-81/-	2	8
	Caboose	36 (Stand)	405 (Stand)	45-50 (Stand)	344-369 (Stand)	71/78-80	3/3	8
	The bar	47 (Stand)	230 (Stand)	47 (Stand)	244 (Stand)	56/-	2/1	8
		35 (Sit)	175 (Sit)	66 (Sit)	344 (Sit)	-	2	8
	Carpenter store	23 (Stand)	126 (Stand)	75-142 (Stand)	397-1484 (Stand)	62/82-89	3/7	8
	Auxiliary engine room	102 (Stand)	506 (Stand)	160-274 (Stand)	753-1216 (Stand)	102/-	3/1	8
	Bousen store room	33 (Stand)	162 (Stand)	39-51 (Stand)	217-351 (Stand)	66/69-72	4/3	8
		44 (Sit)	288 (Sit)	51-77 (Sit)	291-484 (Sit)	-/-	4	8
	Boiler room	46 (Stand)	226 (Stand)	127-153 (Stand)	610-655 (Stand)	86/-	3/1	8
Middle Deck	Steering machine	32 (Stand)	178 (Stand)	91-207 (Stand)	587-2682 (Stand)	90/-	3/1	9
	Entrance to steering machine	18 (Stand)	90 (Stand)	188-744 (Stand)	2216-21928 (Stand)	85/-	4/1	9
	Separator room	53 (Stand)	254 (Stand)	90 (Stand)	426 (Stand)	83/-	2/1	9
	Machinery control room	33 (Stand)	163 (Stand)	45-67 (Stand)	229-359 (Stand)	63/-	3/1	9
		33 (Sit)	302 (Sit)	-	-	-/-	1	9
	Machine supplies room	126 (Stand)	543 (Stand)	72-89 (Stand)	371-421 (Stand)	68/-	3/1	9
		39 (Sit)	333 (Sit)	-	-	-/-	1	9
Tank roof	Emergency fire pump room	68 (Stand)	319 (Stand)	88-112 (Stand)	548-725 (Stand)	88/-	3/1	10
	Main machine room, stern	88 (Stand)	427 (Stand)	156-313 (Stand)	827-1669 (Stand)	99/-	3/1	10
	Main machine room, middle	378 (Stand)	1845 (Stand)	258-371 (Stand)	1352-1760 (Stand)	102/-	3/1	10
	Pump room center	114 (Stand)	551 (Stand)	222-229 (Stand)	1131-1140 (Stand)	89/-	3/1	10

7.3.3 Results Frej WBV and Noise

IB FREJ		a_w (mm/s^2)	VDV (mm/s^{1,75})	Peak (mm/s^2)	MTVV (mm/s^2)	CRF	L_{Aeq} (dB)	Number of measure VBV	Number of measure Noise
All	***Frej***								
measurements	Mean value	**56**	**409**	**565**	**151**	**10**	**76**	119	43
	Median	46	317	399	123	9	74		
	Min	15	81	91	24	4	45		
	Max	177	1740	2710	500	25	112		
	Open sea								
	Mean value	**49**	**302**	**490**	**103**	**8**	**79**	23	15
	Median	39	189	268	53	6	82		
	Min	18	90	91	24	4	55		
	Max	148	1086	2710	331	23	112		
	Mean value (Sit)	46	353	486	211	10		2	
	Mean value (Stand)	49	297	491	92	8		21	
	Mean value (Recumbent)	-	-	-		-			
	Breaking ice								
	Mean value	**58**	**435**	**583**	**163**	**10**	**74**	96	28
	Median	47	325	458	133	9	73		
	Min	15	81	112	34	4	45		
	Max	177	1740	2099	500	25	111		
	Mean value (Sit)	41	267	377	138	9		19	
	Mean value (Stand)	62	476	634	169	11		77	
	Mean value (Recumbent)	-	-	-		-			

IB FREJ	Place for measurement	a_w (mm/s^2) Open sea Sit, Stand, Recumbent	VDV (mm/s^{1,75}) Open sea Sit, Stand, Recumbent	a_w (mm/s^2) Ice breaking Sit, Stand, Recumbent	VDV (mm/s^{1,75}) Ice breaking Sit, Stand, Recumbent	L_{Aeq} (dB) Open sea/ Ice breaking	Number of measure WBV/L_{Aeq}	Test site in ship "Deck" (1-10) 1=top of ship
Deck 10, bridge	Maneuvering starboard			21-35 (Stand)	117-200 (Stand)		4	2
				41-60 (Sit)	248-444 (Sit)		4	2
	Desk in rear bridge room			16-39 (Stand)	92-258 (Stand)		3	2
				23-51 (Sit)	140-294 (Sit)		3	2
Deck 8	Cabin 8-1	26 (Stand)	125 (Stand)	23-44 (Stand)	304-602 (Stand)	-/45	5/1	4
Deck 7	Cabin 7:2			15-22 (Stand)	318-452 (Stand)	-/47	2/1	5
Deck 6	Relax room next to sauna			38-48 (Sit)	203-260 (Sit)	-/60	2/1	6
	Cabin 6:17			21-33 (Stand)	374-575 (Stand)	-/45	2/1	6
Deck 5	Caboose			29 (Stand)	160 (Stand)		1	8
	Mess room, soft chair			32-55 (Stand)	194-325 (Stand)		2	8
				43-53 (Sit)	237-457 (Sit)		2	8
	Mess room, fore, portside	30 (Stand)	160 (Stand)	17-55 (Stand)	92-323 (Stand)	55/60	5/2	8
		40 (Sit)	263 (Sit)	23-53 (Sit)	200-457 (Sit)		5	8
	Scullery	18 (Stand)	90 (Stand)	33 (Stand)	202 (Stand)		2	8
Deck 4 Main deck	Afterdeck			31 (Stand)	195 (Stand)		1	8
	Foredeck			46-62 (Stand)	256-385 (Stand)		2	8
	Bousen store room			22-33 (Stand)	114-171 (Stand)	-/63	2/1	8
	Machine officers office	81 (Stand)	385 (Stand)	23-38 (Stand)	120-191 (Stand)	60/53	4/2	8
				23-32 (Sit)	130-180 (Sit)		1	8
	Deck officers office	42 (Stand)	203 (Stand)	15-43 (Stand)	81-398 (Stand)	-/52	3/1	8
				30-46 (Sit)	236-423 (Sit)		2	8
	Cabin 4:13	38-59 (Stand)	183-1086 (Stand)	35-79 (Stand)	583-1740 (Stand)	-/60	11/1	8
Deck 3	Machinery control room	66 (Stand)	336 (Stand)	34-80 (Stand)	186-571 (Stand)	59/56	3/2	9
				22-67 (Sit)	151-449 (Sit)		2	9
	Exercise room	25 (Stand)	130 (Stand)	45-64 (Stand)	256-356 (Stand)	63/65	3/2	9
	Carpenter store	27 (Stand)	135 (Stand)	73-164 (Stand)	414-1040 (Stand)	69/80	3/2	9
	Weight exercise room			126-152 (Stand))	824-934 (Stand)	-/65	2/1	9
	Welding room	78 (Stand)	373 (Stand)	75-77 (Stand)	382-397 (Stand)	78/78	3/2	9
	Machine workshop			52-67 (Stand)	282-372 (Stand)	-/74	2/1	9
	Hold, computer desk			52-63 (Stand)	283-372 (Stand)	-/71	2/1	9
	Steering machine	19 (Stand)	97 (Stand)	56-164 (Stand)	309-903 (Stand)	86/88	4/2	9

IB FREJ	**Place for measurement**	**a_w** (mm/s²) Open sea **S**it, **St**and, **Rec**umbent	**VDV** (mm/s^{1,75}) Open sea **S**it, **St**and, **Rec**umbent	**a_w** (mm/s²) Ice breaking **S**it, **St**and, **Rec**umbent	**VDV** (mm/s^{1,75}) Ice breaking **S**it, **St**and, **Rec**umbent	**L_{Aeq}** (dB) Open sea/ Ice breaking	**Number of measure** WBV/L_{Aeq}	**Test site in ship "Deck"** (1-10) 1=top of ship
Deck 2	Electric works			32-55 (Stand)	173-323 (Stand)	-/74	2/1	9
				46 (Sit)	244 (Sit)		1	9
	Electric device room	24 (Stand)	116 (Stand)	30-35 (Stand)	179-202 (Stand)	84/73	3/2	9
	Boiler room	68 (Stand)	317 (Stand)	108-155 (Stand)	515-728 (Stand)	100/103	3/2	9
	Auxiliary engine room	148 (Stand)	828 (Stand)	174-177 (Stand)	846-948 (Stand)	112/111	3/2	9
Deck 1	Pump room 1	62 (Stand)	336 (Stand)	91-96 (Stand)	469-522 (Stand)	82/83	3/2	10
	Pump room 2			83-90 (Stand)	469-838 (Stand)	-/84	2/1	10
	Propeller engine room, fore	24 (Stand)	122 (Stand)	52-55 (Stand)	283-328 (Stand)	90/93	3/2	10
	Main machine diesels	95 (Stand)	719 (Stand)	49-95 (Stand)	274-460 (Stand)	108/98	3/2	10
	Separator room, next desk			68-154 (Stand)	394-716 (Stand)	-/94	3/1	10
	Propeller eng. room astern			62-79 (Stand)	336-431 (Stand)	-/102	3/1	10
	Tunnel room, astern	38 (Stand)	186 (Stand)	33-49 (Stand)	194-286 (Stand)	91/90	3/2	10

7.4 Correlation analysis whole body vibration and noise

In this report the findings indicate that the levels of vibration are low compared to levels of acceptance and health. The levels of vibration in living area and offices are close to Class A in standard ISO 6954. The comfort level in measured areas on board is high, even when breaking ice.

Measured acceleration levels are low based on health risk. Measured values are interesting based on comfort perspective. In this report therefore work has been done to seek any correlation between comfort levels with other variables.

What parameters will influence to higher or lower WBV or noise? This can be useful information for the crew and preventive activities. The results can also be useful in designing new ice breakers.

Data is analyzed by non-parametric methods. Kruskal-Wallis and Mann-Whitney tests were used. The most common level of significance is 0.05 which is used here.

The tests provide a p-value. A p-value <0.05 is required to ensure if relation exists or not.

The results from the analysis are as follows:

7.4.1 Correlation analysis whole body vibration WBV

1. The acceleration values during ice breaking activities are significantly higher than when operating in open sea.

2. For the variable "Test site in ship", with ten groups (Decks), there are statistically significant differences in terms of acceleration values between the groups. In general, the measured acceleration values are higher at lower decks on board which could be expected.

3. Acceleration Value at perceived "Low comfort" was significantly higher than the perceived "High comfort".

4. There are no statistically significant differences in the levels of vibration between the vessels Frej and Oden.

5. There are significant differences in the acceleration value between operating in different ice types.

Levels are higher when operating in operating in ice type 3, "Close pack ice" and type 4, "Compact pack ice", compared to Type 1 "new ice" and Type 2 "Open pack ice".

There is no difference between operating in "New Ice" and "Open pack ice".

6. There are significant differences in the acceleration value between breaking ice in different ice thickness. Measured vibration level was higher when breaking ice >1.5 m compared to operating in the open sea.

7. There are statistically significant differences between the value of acceleration in the various positions for measuring “Sit” and “Stand”.
Comment This result is expected when “Sit” positions always is about a chair with a padded seat.

8. There are no statistically significant differences in the acceleration value due to the ship's power output, "Low", "Medium", "Maximum".

9. It is not possible to find any statistically significant correlations between the ship's speed and vibration level.
Comment The speed was low during ice breaking up to 9 knots and higher in open sea, Oden 12 knots and Frej up to 18 knots.

Table 2

	Significance p<0,05
Ice-breaking or not	Yes
Position in ship	Yes
Perceived comfort	Yes
Oden-Frej	No
Ice type	Yes
Ice thickness	Yes
Position in measuring	Yes
Power	No
Speed	No

7.4.2 Correlation analysis noise

Measured noise levels are harmful to hearing in several areas such as the engine room. On a ship, it is of great importance that the noise level is low in the areas of navigation, offices and in cabins.

In this report work has been done to seek any correlation with other variables. Data is analyzed using the same methodology for the analysis of vibration levels above.

1. There is no statistically significant differences in noise between operating in open sea or in ice. Mean values are identical.

2. For the variable "Test site in ship" (10 groups), i.e. were in the ship you are, there are statistically significant differences in noise levels between the groups. The further down in the vessel, the higher the noise level, as would be expected.

3. The noise level when operating in the perceived "Low comfort" (vibration) is significantly higher than the perceived "High comfort".

4. The noise levels on board Frej is significantly higher than on board Oden.

Table 3

	Significance p<0,05
Ice-breaking or not	No
Position in ship	Yes
Perceived comfort	Yes
Oden-Frej	Yes

Comment
A relationship between perceived "vibrational comfort" and measured sound level has been found. One hypothesis is that when staff complained of much vibration during ice-breaking activities, it could also involve a high clattering noise level in some areas. This requires more measurements and studies to determine if the link exists.

8 Discussion

The main purpose of the study was to measure the levels of exposure to whole body vibrations for crew during normal operating conditions in the Arctic.

The findings in this survey showed very low levels of vibration. The risk of getting low back pain is according to the results of this study negligible. [14]

Measured vibration levels are within recommended limits defined in standards for habitability and comfort in ships as can be seen in Table 1. [10]

Even low levels of vibration may induce discomfort, fatigue and lowered performance capacity. [17] "Shipboard vibration that interferes with duties or reduces comfort is objectionable and often results in adverse comments from crew and passengers. " [10]

Working in an icebreaker is not only entail a normal 8 hours working day. It is to both work and live in a ship, all hours of the day, for many weeks. It is therefore always of importance to keep the ship vibration levels as low as possible from the perspectives of a functioning working environment, worker efficiency and passenger comfort.

Harmful noise levels have been measured at several locations in both ships. There is also a well know correlation between noise and vibration when looking at risk of hearing loss.
"The risk of hearing loss may even rise when simultaneously exposed to both high levels of noise and vibration".[14]

Only one previous study was found that focused on whole body vibration exposure on icebreakers, A. Bekker. [1] In this study, measurement performed at the bridge of S.A. Agulhas II in the bay of Bothnia 2012, show acceleration levels between 8-84 mm/s^2 during ice breaking and 7-29 mm/s^2 in open sea. These values agree well with the measurement results presented in this report. Comparatively, results presented in this report are more detailed, showing results for more locations in the ships and under some heavier operating conditions (the harder polar ice).

Findings from correlative analyses show an interesting correlation with good accuracy to perceived comfort and vibration levels. Maybe our body's receptiveness to vibration and noise levels is at a resolution comparable to that of our instrumentation? In that case a reoccurring questionnaire given to the crews of the icebreaker would be a valuable source for judging health risks of the work place. The good correlation with measured acceleration, will maybe replace physical measurements? The questionnaire of perceived comfort should then be very useful.

A relationship between perceived "vibrational comfort" and measured sound levels has been found. One hypothesis is that when staff complained of much vibration during ice-breaking activities, it could also involve a high clattering noise level in some areas. This requires more measurements and studies to determine if the link exists.

The measurement results show that residing deep in the vessel increases the vibration exposure. At one of the measurement sites the vibration levels are close to the advised limits. These areas are normally used only for shorter time periods, but the personal should be informed of the increased health risks associated with these areas.

Many of the correlation analyses show "obvious" connections e.g. the vibration level is higher when operating in ice compared to open sea. Even ice type and ice thickness are of importance. This investigation has nevertheless helped to validate even these "obvious" relationships.

Regarding further investigation of the prevalence for back injuries, seems not to be needed because of the low measured levels found in this investigation.

Low vibration and noise levels should be a primary design requirement when designing new icebreaking ships.

Is an icebreaker a “Healthy workplace” (WBV and noise)? In many ways yes, but in some ways no. It probably requires more measurements to confirm the findings that have emerged in this report.

It is always important to minimize vibration and noise in ships, especially in quieter working and recreational areas like offices, library, cinema room and cabins. It could be beneficial for icebreakers to have a dedicated room specifically built for silence. The need for “silent rooms” will probably increase in our more stressful society. Such rooms could also be useful for meditation and prayer.

9 Conclusions

The levels of exposure to whole body vibrations for crew during operating conditions in the Arctic are very low. The risk of getting low back pain is according to the results of this study negligible. [14]

Measured vibration levels were found to be low and below the recommendations found in relevant standards. [10]

The measured noise levels were found to be normal for big vessel like icebreakers.

Minimizing vibration and noise levels in ships is always an area of importance. Therefore some correlation analyses have been done. Explained in detail in the results.

Ice-breaking or open sea, position in the ship, perceived comfort, ice type, and ice-thickness are important factors that influence the vibration levels.

The correlation between perceived comfort (questionnaire) and measured levels of both vibration and noise is of special interest. Perceived high comfort is well correlated to low vibration levels as is the opposite i.e. low comfort to higher levels. This knowledge can be useful in preventing discomfort and health hazards.

More studies have to be done to validate the conclusions of this report.

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