# DensX

## MODEL DX-01

# Accuracy of the DensX according to the IHO Special Order

*Revision 2*

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# Introduction

## System Description

The DensX is a high accurate in situ mud density measurement system on the market measuring densities between 1.0 $T/m^3$ and 1.5 $T/m^3$ with an accuracy of 0.25 %. The DensX technology is based on X-ray and is a direct measurement method. With a sampling speed of 10Hz the system supports fast profiling. The technology does not suffer from strong legislation restrictions like radioactive density measurement systems. The system weighs 70 kg and is able to deeply intrude in soft sediment layers.

Along with the DensX comes a user friendly software that controls a fully automated winch. The software visualizes the density profile, the winch speed, the winch torque and the tilt of the DensX. When several density profiles are taken the software generates a mud grid and interpolated dredging volume.

Today the DensX is applied in ports and access channels to characterize mud layers, to measure density based nautical bottom criteria and to prepare and evaluate dredging works. The accurate density measurement capability allows to determine precisely the ton dry weight of dredging material.

## Features

- X-ray based, direct measurement method
- High accuracy (0.25 %)
- Fast sampling (10 Hz)
- Standard Ethernet communication
- Software controlled Ethernet winch with variable speeds

## Benefits

- Fully integrated and automated fast profiling system
- Interpolated mud grid and dredging volume
- Live visualization of density profile, depth, inclination, winch speed and cable tension
- User friendly software

## Measurement principle

The principle is the transmission of X-rays emitted by a micro tube in the medium between source and detector. The photons emitted by the source interact with the electrons of the matter along their path. The higher the density, the higher the number of electrons. Only the photons interacting in the detector crystal NaI(Tl) are taken into account by the DensX. The signal received by the detector is an exponential function decreasing with the density of the mixture.

The relationship between medium density d and the value of the signal delivered by the detector is:

$$d = Kdo + Kd1 \,.\, (Nc/No - 1) + Kd2 \,.\, Ln\,(Nc/No)$$

Where:

- *d* is the medium density
- *No* is the signal delivered by the detector in clear water
- *Kdo, Kd1* and *Kd2* are the calibration coefficients of the DensX

This equation is presented here in a general form with 3 terms:

- The first term *Kdo* is mainly related to salinity
- The second term *Kd1 . (Nc/No - 1)* is used for a backscattering DensX
- The third term *Kd2 . Ln (Nc/No)* is used for a transmission DensX

Additionally, a corrective term can be used to correct the measurement in case of counting losses (can occur with X-ray DensX mainly). This correction depends upon the counting system and cannot be detailed here.

Associating density *d* and depth *P*, we obtain a vertical profile of density inside the mud deposit.

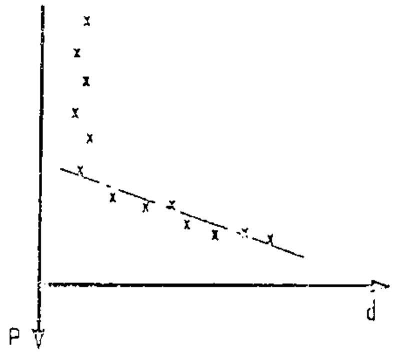


**Figure 1: Example of a vertical profile of density**

## Technical specifications DensX

| | |
|---|---|
| Model: | DensX |
| Type: | DX-01 |
| Weight: | 70 kg |
| Dimensions: | 70x34x13 (WxHxD in cm) |
| Density range: | 1 – 1,4 kg/l |
| Accuracy: | -2.5 +2.5 ‰ |
| Stability: | < 0.1 % (5 – 40 °C) |
| Radiation: | 1 uSv/h (distance < 10 cm) |
| X-ray voltage: | < 30 kV |
| Power consumption: | < 20 Watt |
| Activation depth | 5 m |
| Pressure range: | 0 – 3.5 bar |
| Resolution: | 0.00014 bar |
| Depth accuracy: | ± 1.5 % |

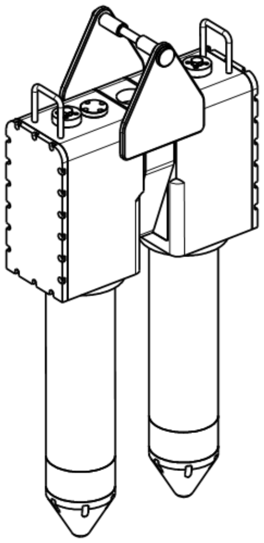

Figure 2: DensX

# Comparison specifications of the DensX with the Navitracker

## Accuracy

The accuracy of a radiation measurement is determined by the number of photons N detected by the detector in a given sampling time. This process has a Poisson distribution. According to the specification of the current density meter Cs-137, a Berthold Sz-5 scintillator of the type LB-386 is used. According to the specification of this device, the sampling time is 250ms and the maximum number of pulses is approximately 16 000 per second.

The X-ray source has a sampling time of 100ms and the maximum number of received pulses is also 150000 per second.

The accuracy of a radiation measurement for a Poisson distribution is given by N ± √N for 1σ. Thus, the relative accuracy is √N / N = 1 / √N for σ 1 with σ = √N.

This results in the following table:

**Table 1. Accuracy in function of the number of pulses.**

| N (pulses) | $\sqrt{N}$ | $1/\sqrt{N}$ |
|---|---|---|
| 1000 | 31.6 | 3.16 % |
| 10000 | 100.0 | 1.0 % |
| 100000 | 316.2 | 0.31 % |
| 120000 | 346.4 | 0.29 % |
| 150000 | 387.3 | 0.25 % |
| 200000 | 447.2 | 0.22 % |

In case of 16000 pulses per second, the Cs-137 density meter has an accuracy in the order of 0.8%, in case of 150000 pulses per second, the DENSX has an accuracy in the order of magnitude of 2.5 ‰.

## Resolution

The resolution is the system's ability to distinguish different density values. This depends on the geometry, the material to be examined and the radiation energy.

In case of a fixed geometry in which the distance between source and detector is fixed and for the same sediment, the source is determining the resolution.

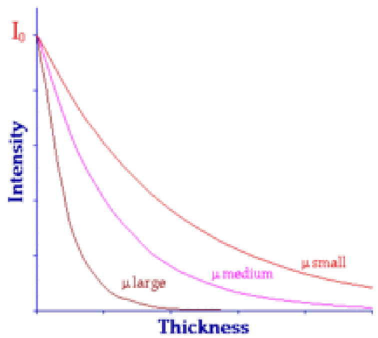


Figure 1: Influence of the attenuation coefficient on the resolution

The larger the µ, the sharper the curve and the greater the variation of the intensity as a function of the density (Figure 1, the variation is expressed in terms of thickness of the material, but density is equivalent). The resolution of the DensX is by consequence 3.5 times better than the resolution of the Cs-137 densitometer.

## Spatial resolution

The spatial resolution is determined by the surface area of the scintillator crystal, the speed of the winch and the sampling time.

The Cs-137 density meter uses a NaI crystal with a diameter of 50 mm and a length of 50 mm. The DensX, on the other hand, uses a NaI crystal with a diameter of 38 mm and a length of 25 mm. By consequence, the static spatial resolution is better with the DensX.

The dynamic spatial resolution is determined by the combination of the speed of the winch and the sampling rate. The sampling rate of the Cs-137 density meter is 4 Hz and the sampling rate of the DensX is 10Hz.

Table 2. shows the dynamic spatial resolution when applying different winch speeds for given sampling rates and sampling times.

**Table 2. Dynamic spatial resolution (cm).**

| **Winch Speed (cm/seconds)** | | 14 | 50 | 100 |
|---|---|---|---|---|
| Sampling Time (ms) | Sampling Rate (Hz) | | | |
| 1000 | 1 | 14 | 50 | 100 |
| 250 | 4 | 3.5 | 12.5 | 25 |
| 100 | 10 | 1.4 | 5 | 10 |

The dynamic spatial resolution at a winch speed of 14 cm/s is 3.5 cm for the Cs-137 density meter and 1.4 cm for the DensX. This means that the same dynamic spatial resolution can be achieved using the DensX during a 2.5 times faster measurement (winch at a speed of 35 cm/s instead of 14 cm/s).

## Accuracy of the pressure sensor for the determination of depth

The position is determined by the pressure sensor. The Cs-137 density meter uses a Druck pressure sensor of the type PTX 630/5 bar, with an accuracy of ± 1% between -20 ° C and + 80 ° C. The DensX uses a SSI pressure sensor of Sensor Technics with a measuring range of 3.5 bar and an accuracy of ± 1.5% between -20 ° C and + 85 ° C.

The accuracy of both sensors for a temperature variation of 100 ° C is identical; 5 bar x = ± 0,01 ± 50 mBar and 3.5 bar x = ± 0.015 ± 52.5 mBar. These numbers indicate that both sensors are in the same order of accuracy. These values also indicate the error to a temperature variation of about 100 ° C and this is not representative of an actual in-situ temperature variation.

However, the specifications of the two pressure sensors indicate that the accuracy is determined differently. The deviation of ± 1% for the Druck PTX 630 pressure sensor is considered only to the variation of temperature relative to room temperature while the deviation of ± 1.5% for the SSI pressure sensor is considered for all contained temperatures.

# Calculation of the total accuracy

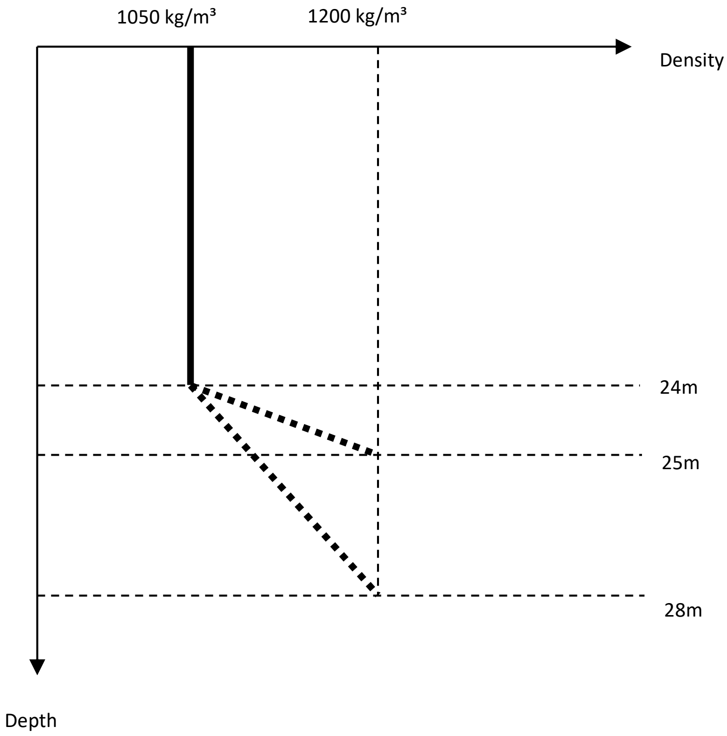


Figure 2: Water column

The calculation of the total accuracy is based on two models. The first model consists of a water column of 24m with a density of 1050kg / m³ and a sediment layer of 1m with a rising density of 1050 kg/m³ to 1200 kg/m³. The second model contains the same water column but with a mud layer of 4m and a linear density increase from 1050 kg/m³ to 1200 kg/m³.

The total error in the measured depth where the density of the sediment reaches a level of 1,2T / m³ is composed of the following errors: the error on the depth measurement and the error on the density measurement.

## Error on the depth measurement

The overall accuracy of the SSI pressure sensor (DensX) is ± 1.5% for temperatures ranging from -20 ° C to 85 ° C and pressures up to 3500mBar. The overall accuracy is determined by the combined error of the offset, calibration range, linearity, hysteresis and temperature. The Druck PTX630 pressure sensor (CS-137 densitometer) is used as a reference and has an accuracy of ± 1% for pressures up to 5000 mbar at room temperature. The remaining errors are not taken into account.

Since the temperature during the measurement of one profile only varies up to about 10 degrees, e.g. from + 10 ° C to 0 ° C, the total error is ± 0.15%. At a depth of 24m, the error in the depth measurement is ± 3,6 cm. Having a sediment thickness of 1m (1,2T / m³) (model 1), an error on the depth measurement of ± 3,75cm is found. Having a sediment thickness of 4m (model 2), an error of ± 4,2cm on the measurement of depth of the sediment layer is found. The total error in the depth measurement will be respectively $\Delta z\_(d\ model1) = \pm \sqrt{(3{,}6^2 + 3{,}75^2)}$ for Model 1 and $\Delta z\_(d\ model2) = \pm \sqrt{(3{,}6^2 + 4{,}2^2)}$ for model 2, resulting in $\Delta z_(d\ model1) = \pm 5{,}19$cm and $\Delta z_(d\ model2) = \pm 5{,}53$cm. These errors are calculated on the minimum of 2*sigma.

## Error on the density measurement

The maximum error on the density measurement is ± 2.5 ‰ for an integration time of 1s and 1*sigma. For an integration time of 100ms, the maximum error is ± 0.79%. And for 2*sigma, this is 1.6%. If we take the temperature into account over a range of 10 ° C at a temperature range from the source of 60 ° C, an error in the density measurement of ± 0.27% is measured.

The error on the density of the top of the sediment is $\Delta\rho 1$ = 1050 kg/m³ x ± 0.27% = ± 2,835 kg/m³. The error on the 1200 kg/m³ density is $\Delta\rho 2$ = 1200 kg/m³ x ± 0.27% = ± 3,24 kg/m³.

Model 1 has an error on the density according to the depth following the equation $\Delta\rho = 150\,\Delta z$. Model 2 with a sediment thickness of 4m is following the equation $\Delta\rho = 37.5\,\Delta z$.

The total error in depth by the error on the density becomes:

$$\text{model 1}: \ \Delta z_{\rho\ model1} = \pm\sqrt{\left(\frac{\Delta\rho 1}{150}\right)^2 + \left(\frac{\Delta\rho 2}{150}\right)^2} = \pm\sqrt{(\Delta z_{11})^2 + (\Delta z_{12})^2} = \pm\sqrt{2{,}16^2 + 1{,}89^2}$$

$$\text{model 2}: \ \Delta z_{\rho\ model2} = \pm\sqrt{\left(\frac{\Delta\rho 1}{37{,}5}\right)^2 + \left(\frac{\Delta\rho 2}{37{,}50}\right)^2} = \pm\sqrt{(\Delta z_{21})^2 + (\Delta z_{22})^2} = \pm\sqrt{8{,}64^2 + 7{,}56^2}$$

This results in an error $\Delta z_{\rho\ model1}$ = ±2,87 cm for model 1 and $\Delta z_{\rho\ model2}$ = ±11,48 cm. These errors are calculated on the 2*sigma.

**Total error at the corresponding depth with a density of 1200 kg/m³**

The overall error on the depth Model 1 is the sum of the errors in the measurement of depth and density measurement: $\Delta z_{d\ model1}$ + $\Delta z_{\rho\ model1}$ = ±5,19cm ±2,87cm = ±8,06cm.

The overall error on the depth by model 2 is the sum of the errors in the measurement of depth and density measurement: $\Delta z_{d\ model2}$ + $\Delta z_{\rho\ model2}$ = ±5,53cm ±11,48cm = ±17,01cm.

## IHO special order of Order 1a

For the total accuracy according to "IHO special order", the multibeam loading has to be taken in account as well. The deviation in the multibeam loading is determined by the 2*sigma deviation of 20.6 cm at a water depth of 24 meters. The IHO standard is described as follows:

*Since constant and depth dependent uncertainties determine the uncertainty of the z-value, the formula given below is used for the determination of the maximum allowable TVU (Vertical Total Uncertainty) with a confidence level of 95%. The parameters for the norm 1a are: "a" = 0.5 and "b" = 0.013. Together with the depth "d" = 24m, the maximum allowable TVU for a certain depth can be calculated with the following formula:*

$$\sqrt{a^2 + (b \times d)^2}$$

*wherein:*

- *a: part of the uncertainty that does not vary with the depth;*
- *b: part of the uncertainty that varies with the depth;*
- *d: the reduced depth;*
- *b x d: part of the uncertainty that varies with the depth.*

The above formula results in 59 cm for the maximum allowable TVU. Minus the 2*sigma deviation of 20.6 cm for the multibeam, there remains a maximum tolerance in the DensX of about 38 cm. The calculations in section 2.3 show that a maximum deviation of 17.01 cm, which is well below the maximum of 38 cm.