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TIME DRIFT OF OCEAN BOTTOM SEISMOMETERS (OBS)

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Abstract – During the past decades, Ocean Bottom Seismometers (OBS) have played a key role in permanent seismic activity monitoring at sea as well as allowing a better understating of the earth interior. Data collected by the instrument can provide information on the ocean bottom sub-layers down to a depth of 40 km beneath the ocean floor. The accuracy of the results directly depends on the time drift of the equipment due to change of environmental conditions. Time base of the OBS is given by a unique stable crystal oscillator.

This paper presents the time drift study of an Ocean Bottom Seismometer in real environmental conditions. By means of a climate chamber, temperature and humidity tests of a general purpose time base generator were carried out and crystal temperature stability and time drift were calculated. Furthermore, the behaviour of the time drift of the instrument has been evaluated in order to correct the data in the data processing stage.

Keywords: Ocean Bottom Seismometer (OBS), crystal oscillator, time drift.

1. INTRODUCTION

Over the past few decades, Ocean Bottom Seismometers (OBS) have gained special attention by the geo-scientific community. They are autonomous instruments that are deployed on the sea-bed up to depth of 6000 meters, where they collect sea floor vibration and water pressure data. The OBS is equipped with two main sensors: a tri-axial geophone composed of three SM6 accelerometers placed at right angle (one for each axis) inside aluminium housing, collects the ocean bottom vibration and a hydrophone that registers water pressure data. A side arm holds the geophone during the freefall and drops the sensor when the OBS is on the sea floor. The datalogger, battery pack and other necessary electronic modules are placed inside a glass sphere which is sealed by means of a vacuum holding both semi-spheres together [1]. Fig. 1 shows a picture of the OBS.

In passive seismology, the equipment collects ocean floor vibrations caused by a natural source (earthquake), where the objective is to determine the magnitude and location of the activity. Passive seismology demands an autonomy of about one year, but when the OBS is used in a sea-floor observatory, it is powered through a marine cable and has no power limitations.

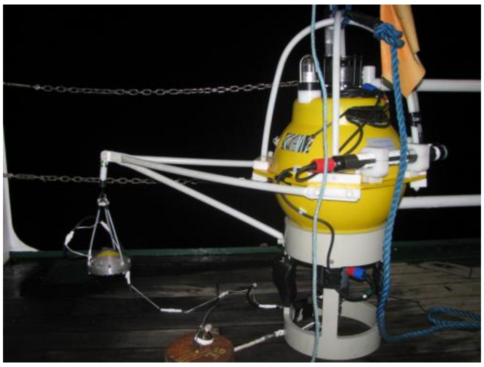

Fig. 1. Ocean Bottom Seismometer (OBS)

In active refraction experiments, a series of OBSs are deployed on the sea-bed and an artificial source (compressed air-gun) is dragged by the oceanographic vessel in order to generate acoustic signals every certain time during the experiment. The generated signal travels to bottom of the sea as well as through the earth being reflected and refracted by different ocean bottom sub-layers. These signals are collected by the OBS sensors, time stamped and stored in a compactflash memory card. Fig. 2 shows the diagram of a typical active refraction experiment.

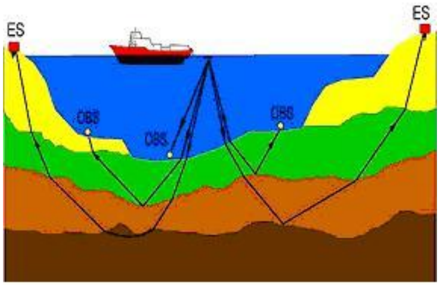

Fig. 2. Active refraction experiment diagram

When the experiment is over, an encoded acoustic signal is sent from the ship to the OBS which releases the anchor weight used to sink the instrument to the bottom of the ocean and the OBS rises to the surface due to its structural floatability.

In active seismology, after data processing in the lab, a map of the sea-bed down to a depth of 40 km beneath the ocean floor is obtained, giving information on the width and material of each layer. In this case, the parameter that provides this information is the velocity of sound through different layers, which is estimated by accurate knowledge of the elapsed time between an acoustic signal generated by the artificial source and data collection by the OBS. It is known that the velocity of sound in the water column is 1500 m/s approximately [2]. While, air-gun shot timing is controlled by a GPS (Global Positioning System) [3] on the ship, the OBS has no access to such a signal for time synchronization during the entire experiment. The OBS clock is synchronized with a GPS signal prior to its deployment and clock time drift is calculated after OBS recovery by using the same signal. In the signal processing stage, data time marks are corrected assuming that the time drift of the OBS is linear during the experiment. While, marine institutes have put great effort in improving the data quality by minimizing the noise performance of the datalogger, the time mark correction of the data which has a direct effect on the final sound velocity model through the earth layers, has not been investigated in detail. This paper takes steps towards characterization of the time drift of the OBS in order to perform a more accurate correction and therefore obtain a better velocity model.

2. THE ACQUISITION SYSTEM

The acquisition system is divided into four separate modules:

- Microcontroller and storage module
- Time base module
- Power regulation module
- Analog-to digital conversion (ADC) module

The microcontroller module is based on a Motorola 68332 and the storage is based on a 4 GB Compactflash memory card. The communication with the ADC module is carried out through a QSPI (Queued Serial Peripheral Interface) bus. The microcontroller time marks the incoming data and after compression, stores the data in a Compactflash memory module.

The time base module is based on a Vectron 32.768 MHz TC-140 TCXO (Temperature Compensated Crystal Oscillator). The stability of the main clock with temperature variations has to be high as the instrument has no access to a GPS signal for time synchronization during the experiment, and as mentioned in section 1, precise timing of the input signal leads to a better data quality [4]. All the signals needed for the acquisition of the seismic signal are generated from the main crystal as phase difference between signals has to be minimized.

The power supply for the datalogger is a single battery pack based on Li-ion cells. In order to generate the different power supplies needed for different modules, a power regulation module based on the MAX1653 DC-DC converter. This regulator provides 96% efficiency while allowing output noise level control towards the ADC module for signal-to-noise optimization.

Fig. 3 shows a simplified block diagram of the acquisition system:

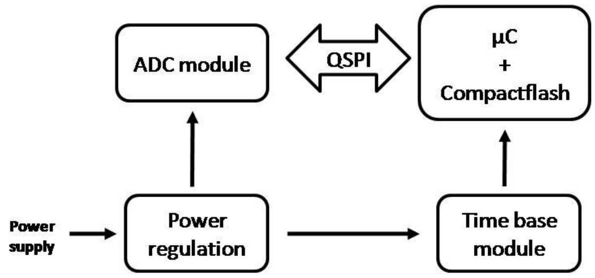

Fig. 3. Acquisition system block diagram

In order to generate all the necessary signals from a single crystal oscillator, a time base module is designed and implemented integrating an ICS52701 PLL (Phase Locked Loop). Fig. 4 shows the signals generated from the main crystal oscillator.

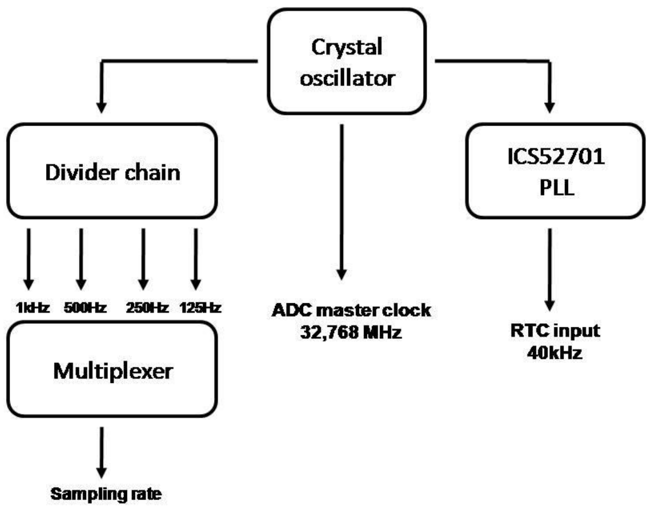

Fig. 4. Time base module block diagram

3. CRYSTAL OSCILLATOR TESTS

As the time drift of the instrument depends mainly on the drift of the crystal oscillator output frequency with change of environmental conditions, a series of tests were carried out in order to characterize the drift. As a preliminary study and in order to understand the crystal behaviour, we have used a 15 MHz general purpose crystal oscillator and not a compensated crystal as a TCXO.

The main environmental parameters that affect the crystal oscillator output frequency are [5]:

1- Temperature, humidity and Pressure
2- Acceleration effects
3- Electric and magnetic fields
4- Ionizing and radiation effects
5- Aging, warm-up and retrace

Due to design and operation of the OBS, the parameters that are taken into account are temperature and humidity. As mentioned in the previous section, all the electronic modules are placed inside a glass sphere housing sealed under vacuum. The pressure inside the housing remains constant during the entire experiment and therefore does not affect the crystal oscillator. The OBS is designed to move at constant velocity of 1 m/s during the free fall and rising stage eliminating the effects of acceleration on the crystal. The time base module is placed inside a shielded box minimizing the effects of electro-magnetic fields and no ionization nor radiation takes place inside the instrument during the experiment. Parameters as aging and warm-up are given by the crystal manufacturer and frequency retrace does not affect the correction as we are dealing with a time drift (time difference).

The dependence of the crystal output frequency with temperature and humidity is studied separately, as their effects are interrelated [5]. The crystal oscillator is placed inside a VC4060 environmental chamber where temperature and humidity are controlled.

In order to know the temperature and humidity close to the crystal, a temperature and humidity sensor are placed beside it and 4-wire measurements of both sensors are carried out. A HP34970A datalogger is used to measure the temperature and humidity and an Agilent 53132A universal counter with a temperature stability of 2.5 x 10^{-9} was used to measure the crystal output frequency. In order to obtain an improved resolution, frequency is measured within a time gate of 1s. The overall measurement system is controlled by a PC through a GPIB bus, where a software in LabVIEW 8.5 takes measurements every 10 seconds. Fig. 5 shows the measurement system in the lab:

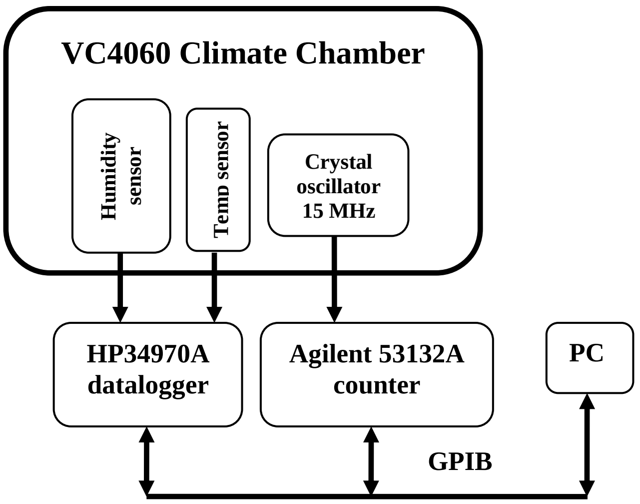

Fig. 5. Measurement system block diagram

Considering the measurement system above, two tests have been implemented:

3.1. Temperature test

In this test, temperature inside the chamber was set to simulate the OBS operation in a refraction experiment:

1) Constant temperature at 25^{o}C (OBS on the ship).
2) From 25^{o}C to 0^{o}C (OBS sinking to the sea-bed).
3) Constant temperature at 0^{o}C (OBS on the sea-bed).
4) From 0^{o}C to 25^{o}C (OBS rising to the surface).

In order to reduce the uncertainty of the measurements, temperature is decreased 5^{o}C from 25^{o}C to 0^{o}C, taking 1000 samples at every constant temperature. Data distribution of the data is found at every constant temperature.

In order to find out the dependence of the crystal output frequency with temperature gradient [6], temperature is cycled between 25^{o}C and 0^{o}C in 3, 6 and 9 hours and measurements are taken.

In all above cases humidity is kept constant at 30%.

3.2. Humidity test

In this test, temperature is kept constant at 30^{o}C and humidity is changed linearly as follows:

- 30% constant for 3 hours
- From 30% to 77% in 3 and 6 hours
- From 77% to 30% in 3 and 6 hours

The crystal output frequency is measured and data distribution of the measurements was found when humidity is kept constant.

In both tests, the stability (frequency offset) [7] [8] of the crystal is calculated as:

$$f_{offset} = \frac{f_{osc} - f_{nom}}{f_{nom}} \qquad (1)$$

where f_{osc} is the crystal output frequency measured and f_{nom} is its nominal frequency. Time drift in (s/day) is related to the frequency offset in the following way:

$$T_{drift} = f_{Offset} * 3600 * 24 \qquad (2)$$

4. RESULTS

The results of temperature and humidity tests described in the previous section are gathered below:

4.1. Temperature test results

Fig. 6 and 7 show the crystal frequency offset when temperature is linearly cycled between 25^{o}C-0^{o}C-25^{o}C:

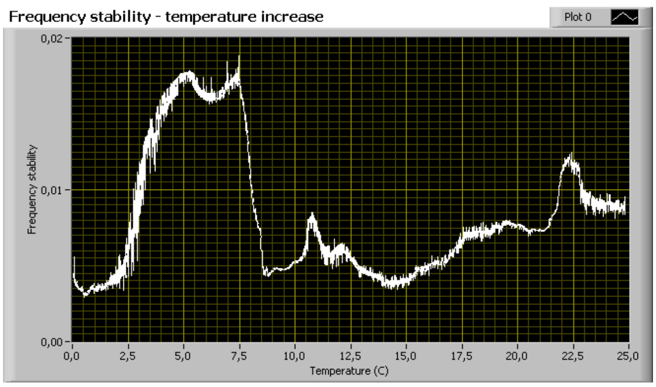

Fig. 6. Crystal frequency offset when temperature is increased from 0^{o}C to 25^{o}C.

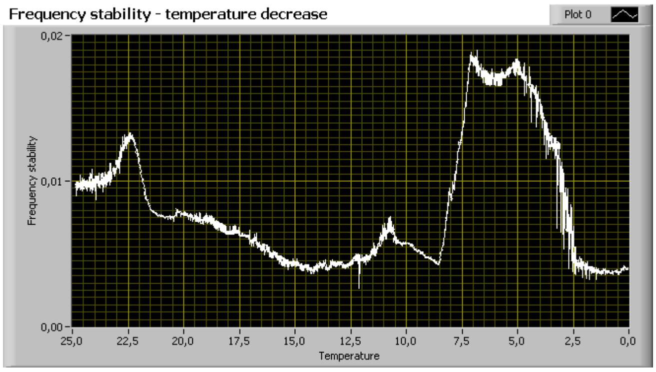

Fig. 7. Crystal frequency offset when temperature is decreased from 25°C to 0°C.

These figures show that the crystal output offset changes symmetrically. The results have shown repeatability over 4 cycles. The stability peaks in both figures are due to crystal turn over temperature. In order to find the distribution of the frequency offset data, histogram of the offset is drawn with 200 intervals between minimum and maximum values measured. The number of samples is 1000. The results have shown normal (Gaussian) distribution at every temperature between 25°C and 0°C with a change of 5°C. Fig. 8 and 9 show the results at 0°C and 25°C respectively.

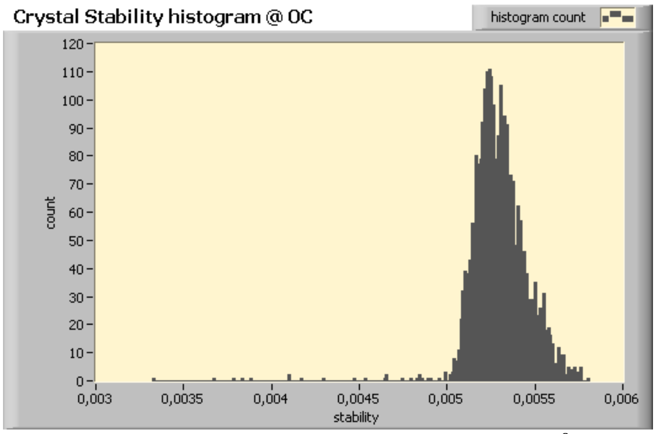

Fig. 8. Crystal frequency offset distribution at 0°C.

In this case, stability mean and standard deviation are 0,005299 and 0,000165 respectively.

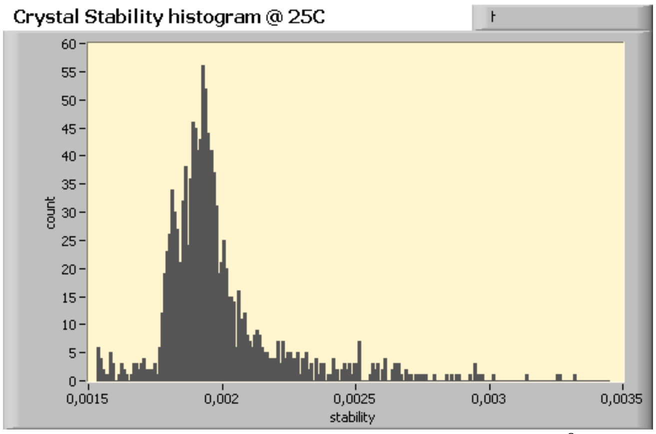

Fig. 9. Crystal frequency offset distribution at 25°C.

Stability mean and standard deviation are computed as 0,001988 and 0,000233 respectively.

Fig. 10 shows the effect of temperature gradient on the crystal stability where temperature is increased linearly from 0°C to 25°C in 3, 6 and 9 hours.

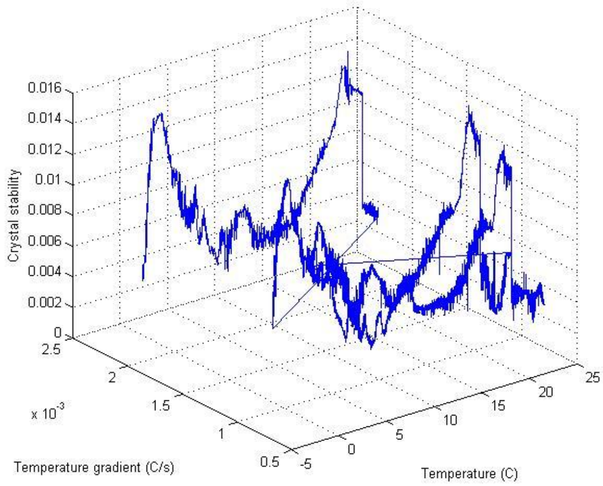

Fig. 10. Effect of temperature gradient on crystal stability when temperature is increased from 0°C to 25°C in 3, 6 and 9 hours.

We can observe that the crystal stability follows the same pattern as the temperature gradient increases, showing that the temperature gradient does not have any effect on the frequency offset.

4.2. Humidity test results

When humidity is increased linearly from 30% to 77% and then decreased back to 30%, frequency offset has been found as shown in Fig. 11 and 12:

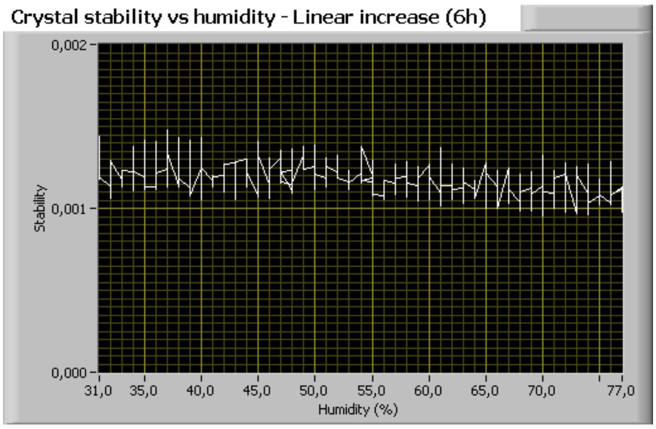

Fig. 11. Crystal frequency offset when humidity is increased from 30% to 77% in 6 hours.

These figures show a random behaviour of the stability when the humidity is increased and decreased. The distribution of the stability is found to be normal. The mean and standard deviation of the stability are 0,0012 and 7,34 x 10^{-5} for humidity increase and 0,0011 and 6,62 x 10^{-5} for humidity decrease respectively.

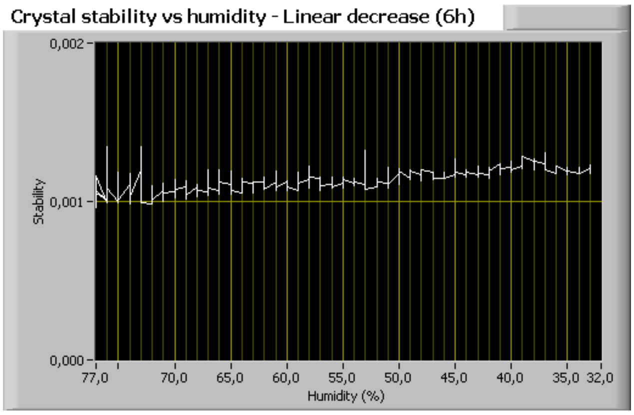

Fig. 12. Crystal frequency offset when humidity is decreased from 77% to 30% in 6 hours.

Furthermore, the distribution of the stability when the humidity is 30% is given in Fig. 13. The number of intervals between maximum and minimum values of stability is 100 while total number of samples is 1000.

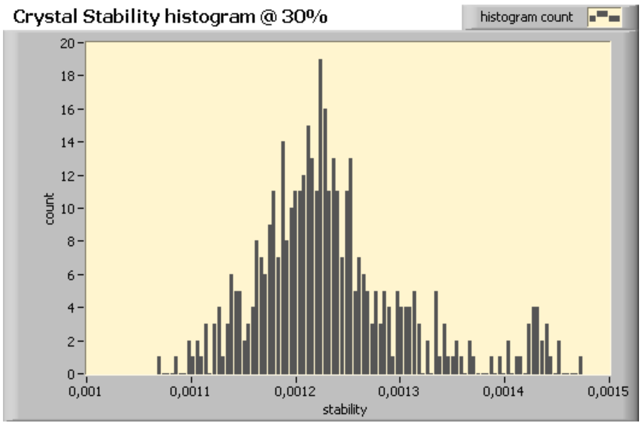

Fig. 13. Crystal frequency offset distribution when the humidity is 30%

In this case, a normal distribution of the frequency offset can be seen. The offset mean and standard deviation are calculated as 0,00123 and 7,34 x 10^{-5} respectively. The crystal offset results with negative humidity gradients of 3 and 6 hours between 77% and 30% are given in Fig. 14.

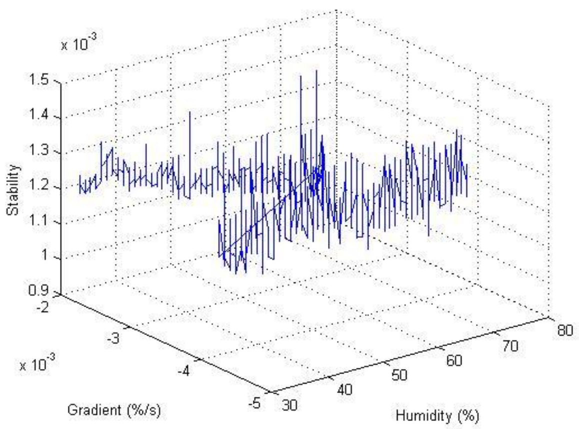

Fig. 14. Effect of humidity gradient on crystal frequency offset when the humidity is decreased from 77% to 30% in 3 and 6 hours. Temperature is kept at 30°C constant.

5. CONCLUSIONS

In this paper, frequency offset general purpose crystal oscillator with change of environmental conditions (temperature and humidity) has been investigated. The results presented here are a preliminary study in order to obtain a more accurate time drift correction of Ocean Bottom Seismometers (OBS). These results show that frequency offset is symmetrical when the temperature is increased and decreased linearly between the same values. When the temperature is constant, the distribution of the stability is normal. Furthermore, increase of temperature gradient has not shown any effect on the crystal stability. The humidity tests have shown random values of frequency offset when the humidity is increased and decreased linearly between the same values. At constant humidity, the distribution of crystal stability is normal and increase of humidity gradient has no effect on the crystal stability. These results lead to a better understanding of the frequency offset of crystal oscillators. Future work will include similar tests using a TCXO crystal used in an OBS and analytical study of the time drift.

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