Precise Measurement Module for Laser Two Frequency Gyroscope-Based Seismometer

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We present a precise frequency and amplitude measurement module designed for a multidimensional seismometric system based on set of Laser Two Frequency Gyroscopes (L2FG). The novelty of this system is that the monitoring of tracked vibrations is based on the precise measurement of the frequency deviation of two laser beams with different wavelengths, not on the measurement of the Sagnac Effect. The main measurement functions of the module are performed by a dedicated frequency counter implemented in a medium complexity FPGA device, while the control of the measurement process, fast data processing and transmission are provided using of a popular microcontroller. The use of the modified reciprocal frequency measurement method with linear regression (Ω counter) provides high measurement precision well below 1 Hz@600MHz for measurement gate durations longer than 1 ms.

Keywords—frequency measurement module, data processing, seismometric system, laser gyroscope, FPGA;

I. Introduction

Seismometric systems are widely used to register vibrations resulting from the Earth's seismic events (quakes, faults, etc.), but also to monitor mines and post-mining areas, hydrotechnical facilities, large engineering structures, and even complex automated production systems [1]. Modern high-sensitivity seismometers are complex measurement systems, the operation of which is based on the use of technologically advanced, low-noise, high-resolution and fast electronic components. The operation of commonly used seismometers is typically based on the precise phase measurement of signals that carry information about the rotation of gyroscopes. However, achieving high precision in phase measurement requires complex systems that are sensitive to measurement conditions and difficult to use in extensive outdoor installations. Therefore, in the presented solution, we propose an innovative application of frequency measurement, and in particular the measurement of frequency changes of signals received from the observed L2FG. Precise frequency measurement is relatively easy to implement in a digital system, which is much more resistant to any interference and susceptible to integration and to portable battery power supply. Since the sensitivity of the entire seismometric system depends to a large extent on the accuracy of frequency evaluation, the design of the measurement module and the methods used become crucial.

II. Precise Measurement Module Design

Ultimately, the seismometric system under development will enable the measurement of the Earth's gravity vector components in 12 active planes. For research and testing purposes, a system model with 3 components (3C) L2FG sensor was developed (Fig. 1).

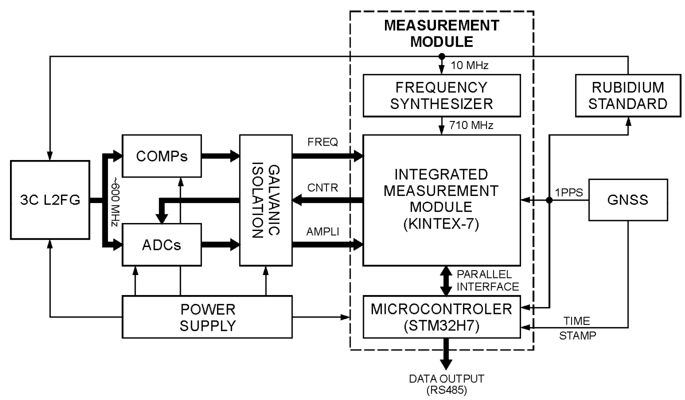

Fig. 1. Simplified block diagram of multidimensional seismometric system.

High long-term stabilization of the 3C L2FG and measurement module operation is provided by the use of 10 MHz reference clock from the rubidium standard, which in turn is disciplined by the 1PSS signal from the GNSS block. The signals from 3C L2FG, carrying information about the rotational speeds in tested axes, are simultaneously fed to (1) the comparators (COMPs) that form their steep edges and standardize amplitude, and (2) A/D converters (ADCs) to evaluate their amplitudes. Then, the signals are transmitted through galvanic separators to the measurement module, which is one of the elements that has the greatest impact on the quality of the entire system. The module precisely measures frequencies of signals providing information about rotations in three axes. This measurement is performed in an integrated measurement module implemented in a programmable FPGA device Kintex-7 (*AMD Xilinx*) [2]. In addition, the measurement module provides (1) measurement results time stamping synchronized to the satellite navigation system, (2) creation of a dedicated data frame and sending it to the master system, and (3) support for additional diagnostic peripherals. All the tasks above are performed by the microcontroller STM32H7 (*STMicroelectronics*), which controls the operation of the whole module and ensures communication with the master computer that collects, processes and displays the measurement data.

For communication between the microcontroller and the FPGA device, a 27-bit parallel interface was developed that covers 16 data, 6 address and 5 control lines. The results of frequency and amplitude measurements of signals from 3C L2FG sensor, formed in 144-bit data, are sent from the FPGA to the microcontroller at the rate of 120 Mbps. The control software running on the microcontroller converts the results of frequency measurements into the value of angular velocity and forms a dedicated data frame with a fixed width of 78 Bytes containing, among others, time stamps from satellite navigation system.

The frame is sent via the RS485 interface to the master computer every 1 ms. Due to the relatively long lines of the RS485 interface (~1km) in the seismometric system and the data transmission speed of 0.6 Mbps, there is a risk of temporary loss of connection or data corruption. Therefore, in the frame, the distinctive fields such as Header and CRC are also provided for detecting the beginning of data frame and checking its integrity. Such solution allows the master computer to detect potential transmission errors.

III. Mesurement Method and Test Results

For the most precise frequency measurements performed in integrated counters, modified reciprocal methods are currently used. In the designed measurement module, we applied an advanced version of such method with the additional use of linear regression, referred in the literature as Ω counter [3]. In general, this method is based on the precise registration of time stamps, related to selected edges of measured signal, and identified on a common timeline. Precise evaluation of the time stamps values is performed using the interpolating time interval measurement method [4]. To verify the precision of time interval evaluation in our module, we measured several time intervals in the range from 100 ns to 1 ms, created by counting periods of signal from the GPS-89 rubidium standard (*Pendulum Instruments*). The precision calculated as standard deviation from a sample of 1000 measurements is relatively high and is better than 5 ps within the whole tested range (Fig. 2).

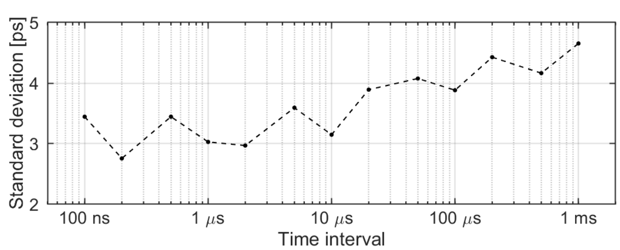

Fig. 2. Time interval measurement precision.

The precision of frequency measurement was then verified by measuring the signal at 600 MHz, which is the fundamental frequency of signals from the system 3C L2FG. For the test purposes the measured signal was generated by HP8648 (*Agilent*) signal generator. The precision of frequency measurement in a 1 ms measurement gate is about 1 Hz (Fig. 3).

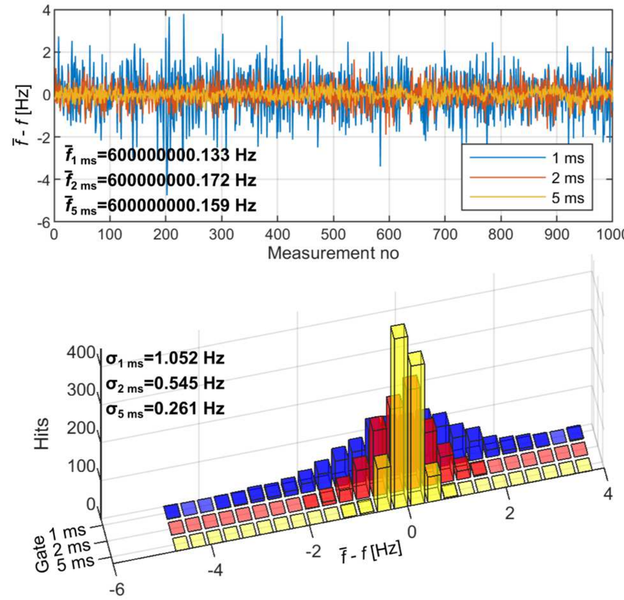

Fig. 3. Frequency measurement precision for selected meas. gate durations.

Further improvement in the measurement precision can be obtained by extending the measurement gate duration. Fig. 3 shows the amount of improvement in precision when the gate duration was extended consecutively to 2 ms and 5 ms. Extending the measurement gate twice improves the frequency measurement precision by almost 2 times (to 0.545 Hz), while extending it five times improves the precision approximately 4 times (to 0.261 Hz). This meets the requirements for the precision of frequency measurement in the developed system.

IV. Conclusions

The described measurement module provides both the measurement precision (below 1 Hz) and data throughput (0.6 Mbps) high enough to be used in the newly developed multidimensional seismometric system based on 3C L2FG sensor. The new system, together with the dedicated in-situ calibration procedure, is capable of measuring the components of the Earth's gravity vector in more than three basic orthogonal axes, and also allows for much more accurate measurements of surface, sub-surface and underwater seismic events as well as geodetic measurements of earth movements such as tilt, fall and uplift, and for the stabilization of power generation systems, e.g. wind farms.

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