

RESEARCH AND BUILD A MULTI-CHANNEL VIBRATION MEASUREMENT SYSTEM FOR DYNAMIC STUDYING OF THE MARINE PROPULSION PLANTS

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Abstract The article presents the results of the researching and building a modern multi-channel vibration measurement system (MVMS), based on the standard industry hardware (sensors and computer), with the Data Acquisition (DAQ) and the software LabView of National Instruments (USA). The MVMS consists of two measurement sub-systems. The first sub-system includes a set of sensors, DAQ NI-9234 and chassis cDAQ 9184 (Ethernet), used to form a system which has total 16 measurement channels. In this sub-system, the sensors are mounted on the non-rotate parts of the measurement machine. The second sub-system consists of the strain gauges to measure the shearing and axial stresses of the loaded rotate shaft, DAQ NI-9237 (DSUB, 4 channels) and the chassis cDAQ 9191. This sub-system rotates together with the shaft. The NI-9237 has 04 channels with the Wheatstone bridge (full, half or quarter modes) of the strain gauges. The highest sample rate of the DAQ 9237 is $F_s = 50$ kilo-samples/s/channel, but for the DAQ 9234 this $F_s = 51.2$ kilo-samples/s/channel. The outputs from the two DAQs are transferred to Wi-Fi Router and from this Router to computer through an Ethernet link. We use the MVMS to carry out some experiment researches of the different vibrations types on the diesel –generator set and on the main diesel propulsion plant of the training ship “SEA STAR” which belongs to Vietnam Maritime University (VMU). The MVMS software has many useful features, such as: automatic setting devices; processing of the measured signals in the real time domain, FFT, Cepstrum, 1/3 Octave, Order analysis; save data to files; read data from files and report the research results. The obtained results will be used to design the vibro-monitoring and diagnostic equipment. It also can be used to estimate the machine power with the training and education purposes of the high quality human resources (the post-graduated and PhD students, etc.) at the VMU, and other industry purposes.

Keywords: Vibration Measurement System, Accelerations, Torsional and Axial Vibrations.

1. Introduction

In the dynamic and vibration investigation on the marine diesel engines and plants there is a need to use a modern multi-channel vibration measurement systems (MVMS). The MVMS must be able to measure the different types of the linear and angle vibrations, such as linear vibrations (accelerations / velocity rate / deviations on the fundamentals, cylinder head, and turbocharger cover), the torsional and axial vibrations on the shaft –line of the diesel propulsion plants [3]. In the theoretical research works, Prof. DrSc. Minchev N.D has already proposed some dynamic –mathematical models for related torsional–whirling vibrations, torsional –axial, torsional – whirling –axial vibrations [2]. Today, marine diesel makers (for example, MAN B-W) introduce the axial vibrations of the two cycle engines for new building seagoing ship. In the technical exploitation of the diesel power plants we have strategies to manage technical conditions of the diesel engines (main and auxiliary), propeller and the hull for increasing economy efficiency and decreasing the environment pollutions. The condition management of the main diesel engine and the propeller is related directly with the power monitoring of the main diesel engine and propeller and un-directly related with the torsional moment on the shaft-line and rotation revolution. The second condition management of the propeller with a role such as power source and the hull - power consumption is related to the thrust force of the propeller and ship velocity. Therefore, building an equipment to measure torques and thrust forces has a mean for optimum exploitation of the marine diesel propulsion plants.

In the researching process, related with the education and training high quality human resources (PhD or master courses) we propose to build in Vietnam Maritime University a modern multi-channel vibration measurement system. The MVMS must have 10 - 20 channels for measuring vibration signals on the marine diesel engine and the marine propulsion plants. Today, using technology products of National Instruments (NI, USA), such as the compact and modern Data Acquisition (DAQ) and software LabView with other useful toolkits of NI –company, we've successfully built a new modern MVMS with following ability:(a) 8 channels for accelerations; (b) two channel –torsional vibrations according to electro-magnetic method; (c) 1 channel –torsional vibrations on the shaft-line; (d) 1 channel –axial vibrations on the shaft-line; (e) 1 channel –revolution of the shaft-line, and for remarking the phase and working cycle of the diesel engine. The software for MVMS has many useful features to analyze vibrations according to different desired tasks, such as characteristics in time and frequency domains

(RMS, peak –peak, FFT, 1/3 –octave, Order analysis). In this paper we will discuss about the MVMS and results of experimental vibration study on different marine diesel power plants with the MVMS.

2. Building MVMS.

2.1. Hardware configuration. We group the sensors into two sets: the first one consists of the different analog sensors, which are mounted on the non-rotation parts of the object and the second set – two vibrations types of the rotation shaft-line (torsional and axial vibrations, measured by strain gauges with the Wi-Fi transferred method for measured signals on the shaft). The first group sensors: 1 phase sensor (optical); 02 electro –magnetic sensors with the operation principle of induction impedance change and 08 vibration accelerators are connected with the DAQ NI -9234 (03 slots, each slot has 4 channels). These 3 slots are placed into the DAQ –chassis, cDAQ NI -9184 (has 4 slots with the 16 channels for analog signals). The output signals from cDAQ NI -9184 are transferred to computer by Ethernet cable. The maximum sample rate in the first sub-system is 51.2 kHz/ channel (51200 sample/ second/ channel).

The second measurement sub-system consists of two strain gauges, placed on the shaft and the cDAQ NI -9191 chassis with DAQ NI-9237 (DSUB) (4 channels, we only use 2 channels in this study). The output from cDAQ NI -9191 transferred to PC (Laptop) through Wi-Fi media. The maximum sample rate in the first sub-system is 50.0 kHz/ channel.

We modify the signal transmission with the new way. The output data from DAQs of the two sub-systems are transferred into Wi-Fi Router, after that the measured signals of the two sub-systems are transferred to PC by Ethernet cable [1]. By this way, the data transmission from measured sensors to PC is better and we don't have any problem in the carried out different experimental studies about the vibrations on the marine diesel plants. In the fig. 1 we show a modified principle scheme of the MVMS, using the Wi-Fi Router.

2.2. Software. Using the NI products (licensed): LabView version 15; Sound and Vibration Toolkits (SVT) and Report Generation, we create the software for the MVMS with the following abilities: Configuration the devices (sensors, DAQ with DAQ –chassis) –Setting up; Module for measurement and monitoring signals; Save measured vibration signals to files; Load (read) the measured signals from files; Process measured data to get final results; Save and Report results.

The software codes are written in the Block Diagrams (BD) and the Front Panel (FP) is created in LabView. Controls and Indicators are placed in the FP, and in the BD we write the algorithms for every task mentioned before.

2.2.1. Setting up interface devices and DAQ – assist.

Firstly, we need to connect correctly physical devices to MVMS. In the first step, MAX (Measurement and Automation Explorer of LabView) can be used for configuration. The devices are automatically identified by the MAX. Then, we create new tasks for channels. In the MAX configuration \Create New task, choose: Acquire Signals\ Analog Input\”Voltage” or “Accelerations” or “Strain” (according to types of the used sensors) and press the “finish” button. After that, we configure for every channel in “Device” - Fig.2 (for example the voltage signals), select the input signal types (DC for channel_1 and AC for channel-2 and 3), sample settings (sample rate, samples to read, Acquisition mode).

In the second step, after identifying devices, we set up DAQ using DAQ assist (in the “Express” or in “Measurement I/O”) in the written code on DB. In the “Create New...” function, we set up for every channels of the two chasses (cDAQ9184 (NI9234) and cDAQ9192 (NI9237)). For channel setting, we select signal type “Analog” –input signal \ Signal Input Range (for example [0, 5] V or [-5, +5] V (fig.3).

2.2.2. Build VI for measurement, data processing and monitoring

We have to control measurement process by monitoring necessary number of measured signal graphs. In addition, we calculate the rotation revolution of the shaft by using the phase sensor and remark the beginning point to save the sample period (length). In the FP, there are 6 graphs of the following signals (from left to right and top to bottom). In the first graph, we place the phase signal (after its filtering) to define shaft rotation revolution, the marked number of the pulses via number sample order, corresponding to the measured phase signal in the cDAQ NI-9184. In the top of the fig.4, we show the position vector (calculated vector $P_1 = [553, 1580]$) of the increase –left edges of the I^{rst}, IInd pulses, and other vector - the position vector ($P_2 = [573, 1603]$) of the decrease –right edges of the impulses, relatively. The average calculated revolutions of the shaft-line in the ½ work cycle of the 4-stroke diesel engine are estimated by following equations: $N_1 = f_1(\Delta P_1, F_s)$ or $N_2 = f_1(\Delta P_2, F_s)$, where: $\Delta P_1 = P_1(2) - P_1(1)$; $\Delta P_2 = P_2(2) - P_2(1)$; F_s –sample rate. For example in measurement $F_s = 25600$ sample/s/channel = 25600 Hz/channel. In these cases, there are calculated revolutions (rpm): $N_1 = 1494.63$; $N_2 = 1491.26$ and $N_{mean} = (N_1 + N_2) / 2 = 1493.4$ With the calculated revolution, we can decide the number of samples to save in the file for processing later. In the example, we select $N = 1500$ rpm and the end, the 4096 sample will be saved to files for further study experiment.

On the second graph (in the fig.4), the data received from Electro-Magnetic Sensors (EMS) are shown. The operation principle of EMS is drawn in the fig.5. On the third graphs, we group the 4 waveforms of the 4 acceleration signals, measured on the 4 cylinder heads. And the next graph

(under the third), we present the 4 waveforms of the 4 acceleration signals, measured on the 4 frame positions of the diesel –generator set (support of the generator, shaft for measurement – addition making, diesel position under flywheel and the 1st cylinder). On the last graph (on the right side) we show the two waveforms of the torsional vibrations (in the fourth graph) and the axial vibrations (in the sixth graph), measured by the strain gauges. The values on the y-axis are in strain unit (ϵ strain –relative, without dimension).

2.2.3. Build VI for saving measured data to file

Saving is one of the important tasks in any software building for measurement and data processing. The saving data need to have the same length of the sample arrays, corresponding to the work cycle of the cylinder (for the 4 stroke diesel we have to organize the data via 2 revolutions). To increase the accuracy while reading the cycle revolution, due to the un-stability diesel working condition and the expensive experiments, we save the measured data for 2 cycles, which means 4 working cycles of 4-stroke diesel.

For organizing repeatable measurements in the same regime, we program the SAVE.VI with the ability to auto-write the file name, such as Hour –Minute –Second –Moon –Date –Year _00x. Therefore, only one press (quickly) on the SAVE button (in the fig.4), the measurement software save data files with the same time period of the diesel working. We save the measured data of the two different sub-systems into two separate files with different length of the data arrays, corresponding to the sample rates of the DAQs features (for example, for the channels with the DAQ NI9234, $F_{s,max} = 51.2$ kHz/channel, we set $F_s = 25.6$ kHz; but with the DAQ NI9327 for strain measurement, $F_{s,max} = 50.0$ kHz/channel, we have $F_s = 50$ kHz). When we release the SAVE button, on the caption of this button is changed to “NO-SAVE”, click on this button again, "SAVE" is displayed.

2.2.4. Build VIs for reading data from data files and data processing

We build module in the BD to read the measured data from files, using the “Read Measurement File” from Express panel. There are two files need to be read for data processing of the torsional or axial experiments, because we have to use information of the phase signal, which is written in different file with the strain data for these vibrations, but for analyzing the accelerations or EMS signals we need to read only one file. This file is contained the combination of the different channel signals (with the same sample rate), which are able to measure by the cDAQ NI-9234. Firstly, we analyze the phase signal to track only one working cycle of the measures data by the technique mentioned above. The output of this process shows us the exact positions of the samples, corresponding to the exact one working cycle of the 4-stroke diesel engine. Using these results we can track the other measured signals, which we want to process in future.

For analyzing every type vibrations we need to use relatively algorithms, for example, for the EMS, the accelerations and the strain signals to receive torsional or axial vibrations. For building code in the BD, we re-use already made existing VIs of the Sound and Vibration Toolkits (SVT, licensed), it meets us convenience (fast and exact) for building the MVMS software.

-The accelerations signal are analyzed in the real time and frequency domain to receive the following parameters: RMS (root mean square), peak –peak, mean; FFT (amplitude, phase via frequency); 1/3 –Octave.

-The torsional and axial vibrations are processed to output the following parameters in the time and frequency domain: RMS, peak –peak, mean; FFT (amplitude, phase via frequency); Orders.

-The electro –magnetic signals (EMS) are used to investigate torsional behaviors (angle deformation and angle velocity differences between the two gears, see fig.5, placed on the measurement shaft between diesel and generator). The algorithms for torsional vibrations detection work in the two ways:

+ The immediate revolutions $n_1(t)$ and $n_2(t)$ of the two gears are calculated by two EMS, using the procedure mentioned above to calculate the average revolution per $\frac{1}{2}$ working cycle of the 4-stroke engine (one pulse, relatively one tooth). We receive: $n_{12}(t) = n_1(t) - n_2(t)$, and the next step we calculate angle deformation: $\varphi_{12}(t) = \varphi_1(t) - \varphi_2(t) = \int n_{12}(t)dt$, then by using the approximation formulas, the trapezoid area is calculated.

+ The immediate angle deformation (vibrations) is calculated directly by using phase difference of the two EMS. In this case, we transform the EMS to square signals and use the logical procedure to detect these phase differences. The XOR logical command has a characteristic, that is: $XOR(x_1, x_2) = XOR(x_2, x_1)$. Therefore using the XOR command, we cannot identify the sign of the phase difference. For overcoming difficulties to calculate the angle deformations between two gears (relatively the EMS₁ and EMS₂) we make a modified logical algorithm, which is written in the following code m.file (in MatLab):

```

counter =0;
for k=1:N
    if and(x1(k) >0,x2(k)<0)
        counter =counter +1;
    elseif (and(x1(k) <0,x2(k)>0)
        counter =counter -1;
    else
        counter =0;
    end
end
end

```

In the next step, we use the m.file and Mathscript node of LabView to build the virtual instrument to calculate the angle vibrations. In the fig.6 are shown the results of the EMS processing. In this case, the angle deformations are calculated by using the XOR logical command and modified procedure mentioned above.

3. Vibration experiment study on the diesel propulsion plants

Using the MVMS we carry out the vibration experiment research on the D –G set 110 kW in the lab of the Institute of Research Development (VMU) and on the main diesel propulsion plant of the training M/V ‘Sao Bien’ (Sea-Start, VMU). In the experiments we measure 11 signals using the cDAQ NI 9184 with 3 slots DAQ NI-9234 such as mentioned before. For measuring the torsional and axial vibrations on the immediate shaft, we use two strain gauges and the cDAQ NI-9191 with DAQ NI -9237 (DSUB). In the section, we will show some received results of the experiment study and data processing, using the MVMS.

Experiments are carried out in the diesel revolutions: 1000, 1200, 1350 and 1500 rpm. In every speed regime, we carry out the measurement process when all of cylinders are work normally and others experiments, when the sixth cylinder is misfired. The measured data is written in files when carrying out the measurements. After that, we read the measured data and place this data in proper form. In the fig.7, fig 8 and fig 9 we show some results of the experiment studies.

4. Results and discussion

On the front panels of the data processing module, the received results are shown in fig.(7, 8, 9) and indicate that these output satisfy the requirements states in torsional vibrations standards documents (calculated in the FFT, 25 Orders for 4-stroke diesel and in time domain with the RMS, peak -peak). This data also present the linear vibrations on the D-G set (in the 1/3 – Octave, unit mm/s and dB) [3]. The results are shown in the table forms, which makes convenience for more easily signals processing.

The results of the vibration data processing in the FFT are calculated with high accuracy label by resampling according to exactly defined diesel revolution in experiment moments and filtering the received measured vibration signals. The results of the torsional signal analysis show that the main harmonics (orders 3, 6, 9) of the 4-stroke diesel are considerable, but other second ones are very small. The results of the axial vibration signal processing show that the second harmonic is bigger than others. The behavior needs to be studied more in the future.

5. Conclusion

The MVMS is satisfied for dynamic researching of the different types vibrations on the diesel propulsion plant and could be developed to apply for vibro-diagnosing and vibro-diagnostics purposes.

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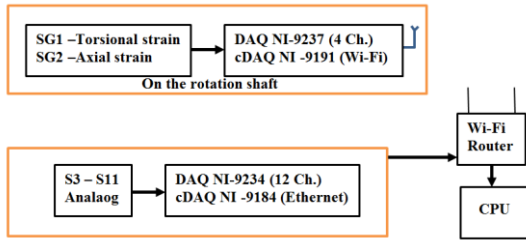


Fig.1 Principle scheme of the MVMS, using the Wi-Fi Router

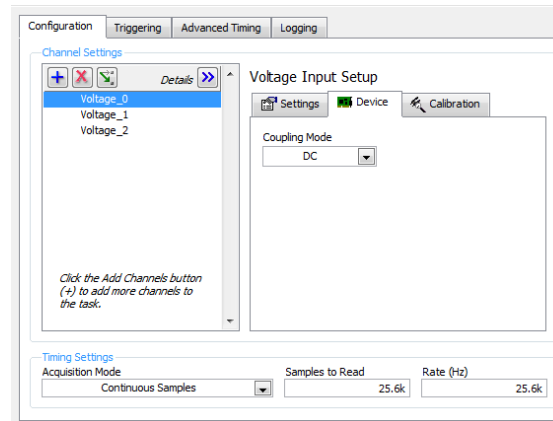


Fig.2 Channel setting in MAX for MVMS

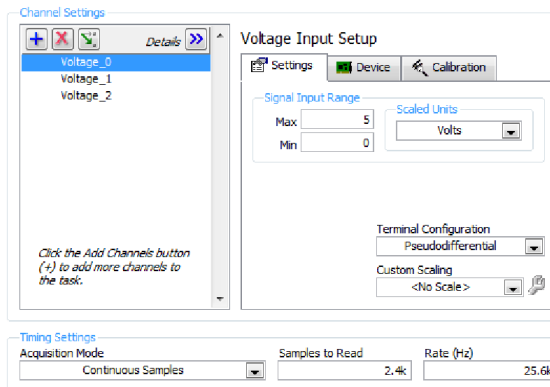


Fig.3 Channel setting in the DAQ assistant

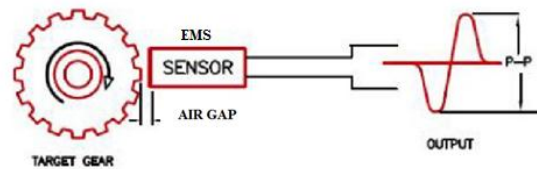


Fig.5 Operation principle of the Electro-Magnetic Sensors, using in the MVMS



Fig.4 Express data processing and monitoring measurement vibrations on D-G set 110 kW using MVMS, experiment regime N=1500 rpm, I=100A (Load)

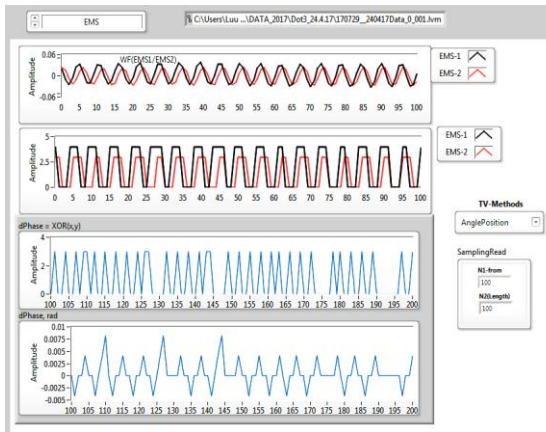


Fig.6 Data processing of the EMS₁ and EMS₂ for torsional deformation of the immediate shaft of the D-G set 110 kW using MVMS

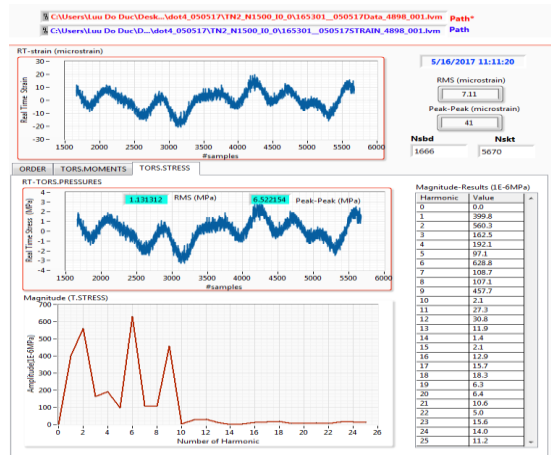


Fig.7 Results of data processing of the torsional stress on the immediate shaft of the D-G set 110 kW using MVMS

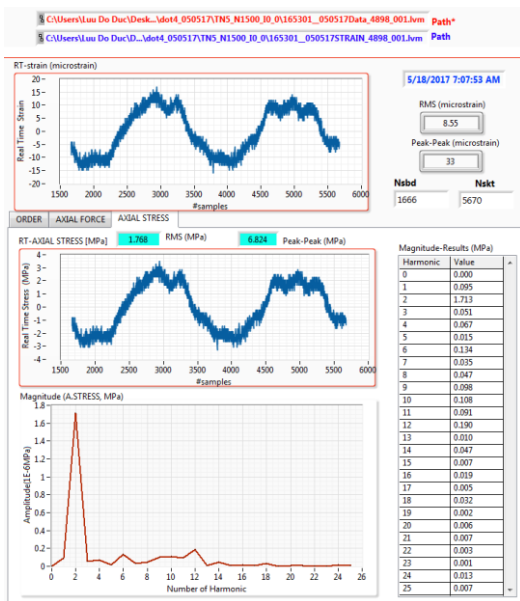


Fig.8 Results of data processing of the axial stress on the immediate shaft of the D-G set 110 kW using MVMS

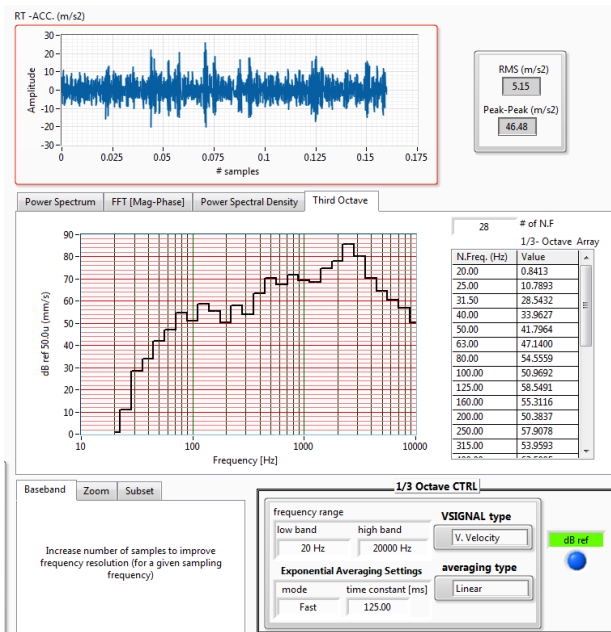


Fig.9 Results of data processing of accelerations on the D-G set 110 kW using MVMS