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FN-SCAN®
User's Guide

Experimental
Nonlinear Vibro-Modulation Testing System

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1. GENERAL INFORMATION

1.1 . General Description

The FN-SCAN® is an **experimenta**l portable nondestructive Structural health Monitoring (SHM) and NonDestructive Testing and Evaluation (NDT&E) system utilizing patented (U.S.Patent # 6,301,967 and other patent pending) Vibro-Modulation Testing technique (VMT). VMT allows for inspection and monitoring of structural integrity of metal, non-metal, and composite materials and structures, indicating the presence of contact-type defects such as cracks, debondings, delaminations, etc. This technique employs effect of nonlinear interaction of ultrasound (high frequency) and vibration (low frequency) in the presence of defects. Vibration changes contact area within the defect effectively modulating phase and amplitude of an ultrasonic signal passing through this varying contact interface. The major advantages of VMT include:

- Material independence
- Applicability to structures with complicated geometry
- Real time processing
- Interface with simple data output for pass/failed inspection

In the present configuration FN-SCAN® does not allow for localization of the defect; it is only indicates its presence and severity or absence.

1.2. Safety and Use

WARNING: FN-SCAN® **is an experimental system and supposed to be used ONLY for experimental validation of VMT. FN-SCAN® should not be used for actual inspections without proper certification.**

WARNING: Dangerous voltages, capable of causing death, are present in this electronic system. Use extreme caution whenever the instrument covers are removed.

The FN-SCAN® system components such as power amplifier and Digital Data Acquisition (DAQ) should only be connected via a three-wire power cord to an AC power source 220V having a line frequency of 60 or 50 Hz. Always use an outlet which has a properly connected protective ground.

Operating
The FN-SCAN® system can be operated outdoors if protected from the elements.
The system must not be turned on until all cables are connected. Make sure that all cables are connected properly and firmly. Protect all cables from mechanical damage.

Installing other components
Installing any other hardware or software components to the FN-SCAN® system which are not part of it as this is likely to damage the system.

2. SYSTEM DESCRIPTION: Configuration, Connections, and Installation

FN-SCAN® system consists of the following major components:

- System control, signal generation, processing, and storage housed in Ruggedized laptop computer (Panasonic Toughbook 54 Prime 14" Core i5 7300U 8 GB RAM) with proprietary   FN-SCAN® v4.0 software
- Ultrasonic Power Amplifier: Trek, Inc.2100HF-L-CE
- Data Acquisition USB board: National Instrument NI 6366
- Two ultrasonic transducers: Mistras, F15A, 100 -450 kHz
- Ultrasonic preamplifier/filter: Mistras 0/20/40 dB single-ended/differential AST preamplifier with a 2/4/6 series filter
- 3D accelerometer: Digi-Key, model 4030-002-120

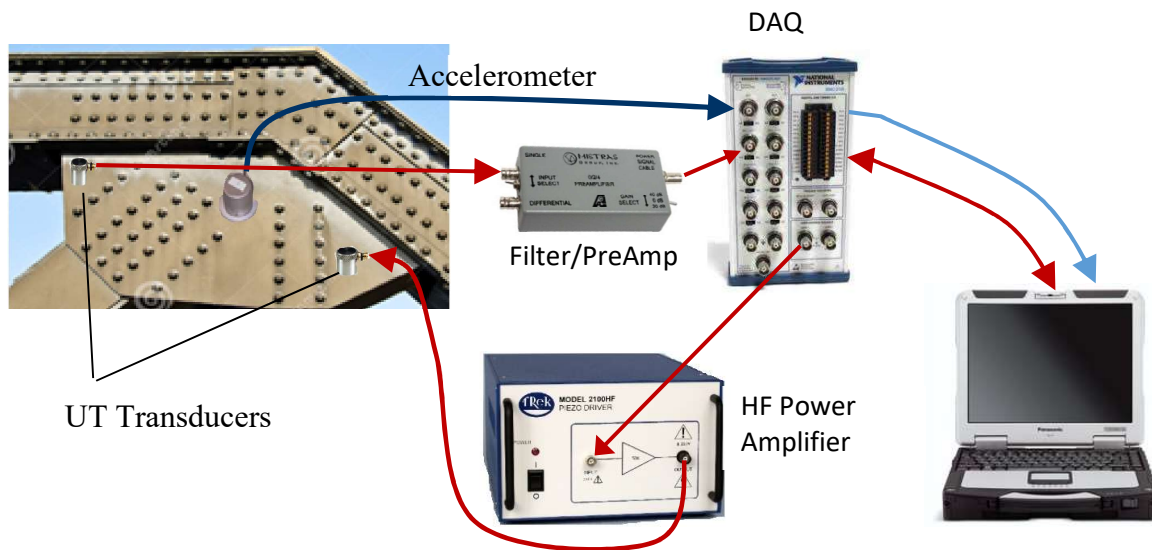**FN-SCAN®** connection diagram is shown in the Fig.2.1

Fig.2.1. **FN-SCAN®** system components and connection diagram

Accelerometer and UT transducers Installation.

Accelerometer and transducers must be install to enable good acoustic coupling with structure under test. Accelerometer can be attached to the structure using screws or magnets. Special care should take for installation of the UT transducers. Besides good acoustic coupling, the interface between the transducers and the surface of the structure should not introduce contact-type nonlinearity, i.e.

should be no dry contact between transducers and the surface. The best coupling without nonlinearity is glue (such as fast setting epoxy glue) to the exposed metal surface of the structure (paint must be removed).

3. SYSTEM OPERATION

All operation of the system and all its components are fully controlled via FN-SCAN® interface software. FN-SCAN® has four mode of operations and respective displays: Oscilloscope, Spectrum Analyzing (SA) mode, N-Scan and FN-Scan modes.

3.1 Start-up

To make measurements with the FN-SCAN® proceed as follows:

1. Attach accelerometer and UT transducers to the structure under test.
2. Connect the system according to the diagram in Fig.2.1.
3. Turn ON all system devices.
4. On the laptop Desktop screen double-click the short-cut icon FN-Scan.

The FN-SCAN® program starts and the Application Display, Fig.3.1, appears. The display has soft buttons and control tabs, which set and control FN-SCAN® system operation.
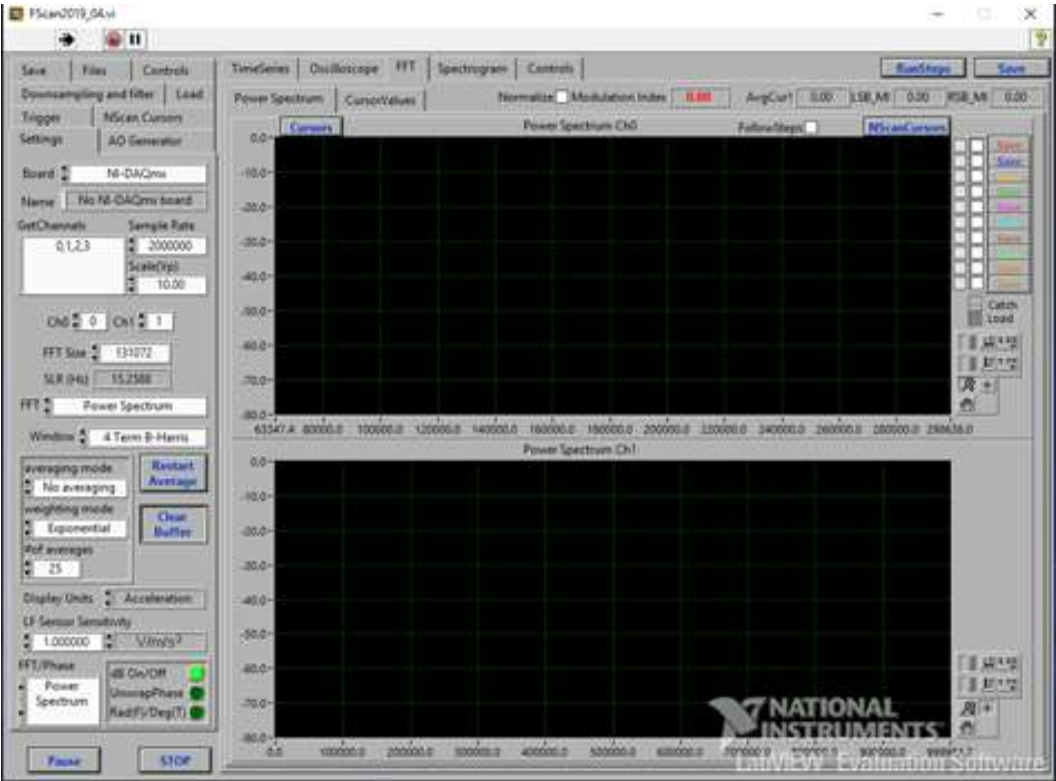

Fig.3.1. FN-SCAN® Application Display

3.2. Application Display

FN-SCAN® has a multiple displays ![TimeSeries Oscilloscope FFT Spectrogram Controls] which can be switch on using tabs above the signal screens.

3.2.1. Oscilloscope Mode

There are two ocsilloscope screens activated by tabs **TimeSeries** and **Oscilloscope** situated above the signal screen.

- TimeSeries shows an oscillograms of the acquired signals in the DAQ buffer.

- Oscilloscope shows oscillograms of the acquired signal in predefined time interval defined by the "ScopeTime" box situated to left of the screen, Fig.3.2.2.

- TimeSeries shows an oscillogram of the acquired signals in the DAQ buffer.

- Oscilloscope shows oscillograms of the acquired signal in predefined time interval defined by the "ScopeTime" box situated to left of the screen, Fig.3.2.2.

Fig.3.2.2. Oscilloscope display.

3.2.2. Spectrum Analyzing (SA) Mode

SA mode is an auxiliary mode for analyzing vibration frequency response of a structure under test. Fig.3.2.3, shows **Power Spectrum** of received signals as well as post processed data such as Modulation Indexes vs Frequency Scan using tab **CursorValues**

The displayed spectrum could be zoomed in or out using ![zoom buttons] soft buttons. The button ![zoom button] can be used to undo previously changed zoom (undo only the last change). The axis scales can also be changed by clicking on first/last scale number and manually typing a desirable number.

Standard spectrum averaging (arithmetic, exponential, and peak) can also be used in SA mode by choosing the respective options in the dial boxes: No Average and Number of averaging 100 located in tab **Average** in **Settings** panel, Fig. 3.2.3. LF averaging cannot be used if N-Scan mode is activated.

The displayed spectrum can be captured and saved as a separate Excel file by using soft button **Save**.
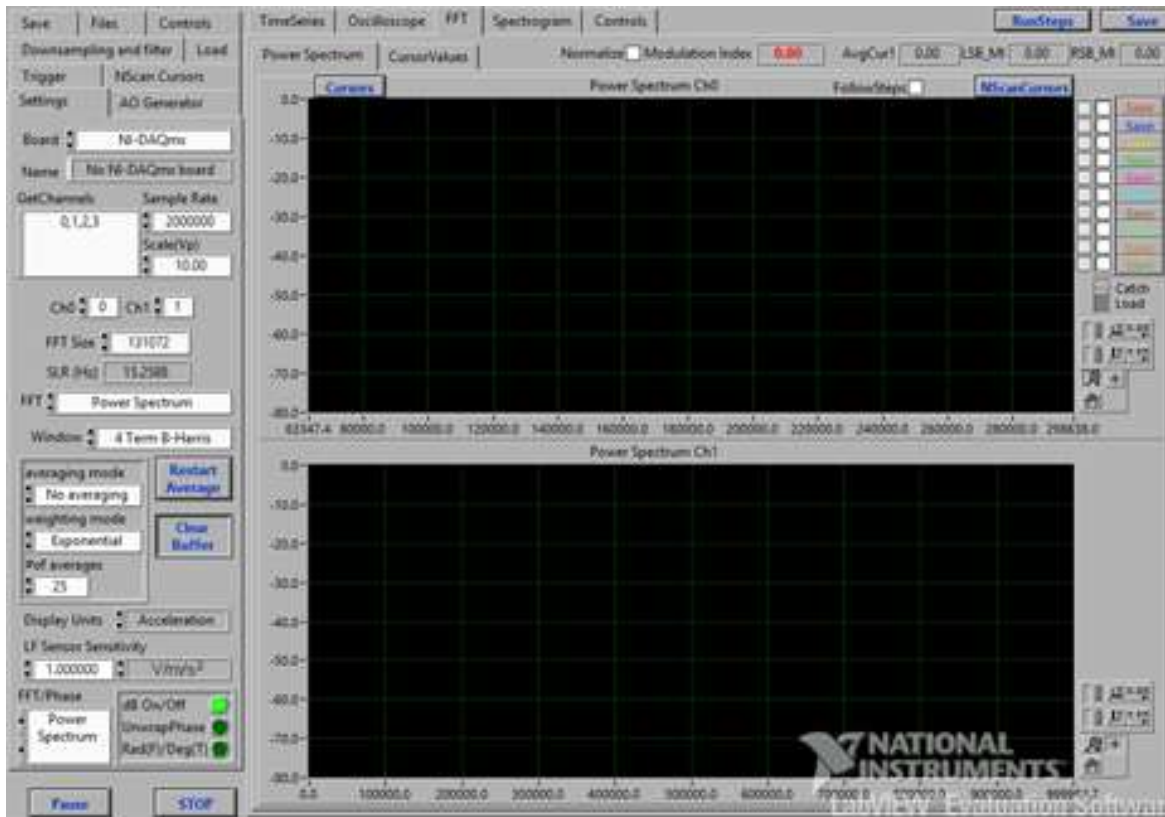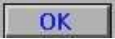

Fig.3.2.3. Power Spectrum Display.

As any spectrum analyzer, FN-SCAN has the options to set the sampling rate and the FFT size, as well as FFT window. This can be done using **Settings** panel on the left to the screen.

LF frequency response of the structure can be obtained using ambient struural vibrations, impact excitation of the structure, external shaker, or utilizing FN-Scan generator using tab **Generators** on the left panel. This tab allows for setting LF generator amplitude, Start Frequency, Frequency Step, and Number of steps. If this option is chosen, only Peak averaging is allowed, so the frequency response can be captured as the generator is step-sweeping through the frequency range. The generator is activated by clinking on button [Start] located at the left top of the screen.

3.2.3. N-Scan Testing Mode

N-Scan testing mode is the original testing mode is used then external low frequency excitation is available and can be controlled by the FN-Scan system. Typically, it is used in the laboratory settings.

The N-Scan testing mode is set in **Settings** panel and is activated by pressing soft button [OK] and than button [Start] at the left top of the Screen.

The N-Scan testing mode operates as following:

-   The generated ultrasonic signal is step-swept in the specified frequency range, with the specified frequency step, Δf, (the range and the step are set using Tab **Generators** (in **N-Scan Settings Panel**), so at each step, n, the frequency is changing according to $f_n = f_0 + n*\Delta f$, where n = 0, 1, 2, …N-1, N is the total number of steps set in dial box [Number of steps | 100].

-   The low frequency vibration is set (using **Generators** setting tab) with the fixed frequency, F, (usually it is one of the resonance frequencies of the structure under test).

-   The cursors are automatically set to frequencies $f_{\pm c} = f_n \pm c*F$, where c = 0, 1, 2, … C. (1+2C) is the total number of cursors, which is set in **Cursors** setting tab.

-   At each frequency step, N-SCAN acquires and processes the received ultrasonic signal.[16] The signal spectrum magnitudes, $A_{\pm c}$, at cursor's frequencies, $f_{\pm c}$, are displayed on the upper portion of the Application Display as function of the frequency step, n.

-   At each frequency step, N-Scan calculates the modulation indexes for each cursor. For example $M_{-1}(n) = A_{-1}/A_0$ for cursor # 2, $M_{+1}(n) = A_{+1}/A_0$ for cursor #3, etc.
-   If LF Channel is used and connected to vibration sensor measuring LF vibration amplitude A_F, and the option **Normalize** is chosen in the tab **Settings** N-Scan calculates the normalized modulation indexes as $M_{-1Norm}(n) = A_{-1}/A_0 A_F$, $M_{+1Norm}(n) = A_{+1}/A_0 A_F$, and etc. for each cursor frequency.

-   N-Scan testing mode allows for Arithmetic and Peak averaging of data at each frequency step. The averaging type and the number measurements to average at each HF frequency is set in Tab **Average** for **HF Channel** (in **Settings**). Note, if HF Channel average is activated, LF Channel average is not allowed.

Each calculated Modulation Index is arithmetically averaged across the scanned frequency range and the results can be saved in excel file.

An averaged Modulation Index for second and first cursor's frequencies $M_{sum}(n) = \frac{1}{2}(M_{-1}(n) + M_{+1}(n))$, is also averaged across the scanned frequency range is displayed (in dB scale) at the top of the Screen as Modulation Index 0.000 . As practice showed, this value is the most commonly used for the structural integrity evaluation and in most applications is used as a sole description of structural damage.

Nevertheless, the measurements at the other cursor frequencies could be saved as Excel files for the record keeping and post-processing.

As a rule, the Modulation Index first is determined for a control (no defect) structure to establish a baseline for the given structure. Appreciable increase of the Modulation Index (usually over 3 dB) over the established baseline indicates the presence of a defect in a structure under test: the greater the increase, the greater the defect.

If the baseline cannot be established, N-SCAN can be used for periodic or continuous monitoring: any increase in the Modulation Index during the monitoring may indicate the development and accumulation of damage.

3.2.4. FN-Scan Testing Mode

FN-Scan testing mode specifically developed for field-testing using intermittent ambient vibrations of the structure under test. In this mode, the system monitors ambient vibration using 3D accelerometer. FN-Scan operation is triggered if one of the monitored accelerometer signal exceeds the predetermined trigger level (threshold) for the predetermined time duration (all set in **Trigger** panel). The minimum threshold duration is 0.1 second and can be increase by 0.1sec increment. Once the trigger is activated, the system generates muti-sine HF ultrasonic signals, capture and store all LF and HF signal for the following processing.

In order to utilize this mode, first HF ultrasonic multi-sin signals should set in tab **AO Generator**, Fig. 3.2.4. In multi-sine window the user can set an unlimited number of sinusoidal signals with chosen frequencies, amplitude and phase. All this frequencies will be generated simultaneously for the predetermined time interval set in **Trigger** panel.

Next, the trigger level and duration as well as HF signal generation duration must be set in **Trigger** panel, Fig.3.2.5. The **TriggerArray** indicates the triggering events for the set trigger duration – each square represents 0.1 sec interval. If the trigger signal exceed its trigger level at any given 0.1 sec interval, the respective square will light up showing I real time the triggering events. The FN-Scan generation and capturing will be activated if all squares within duration interval are lighted-up. At this point, all LF and HF signals will be captured and stored for the following up processing.
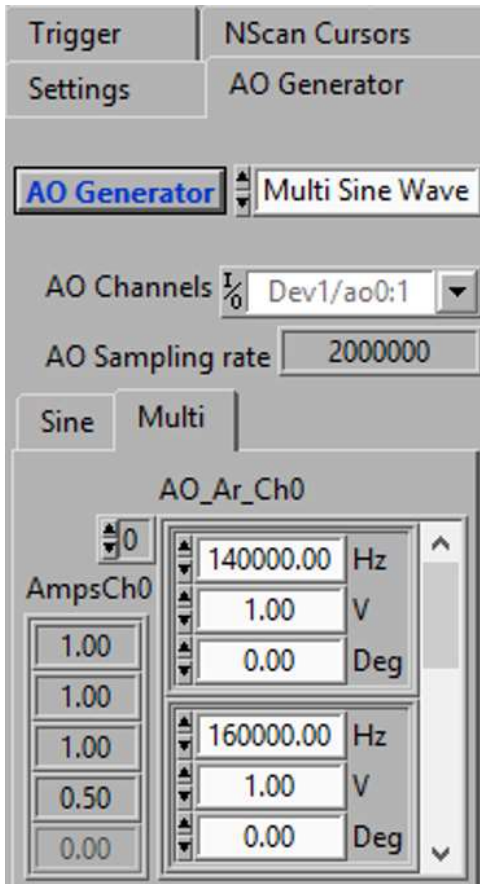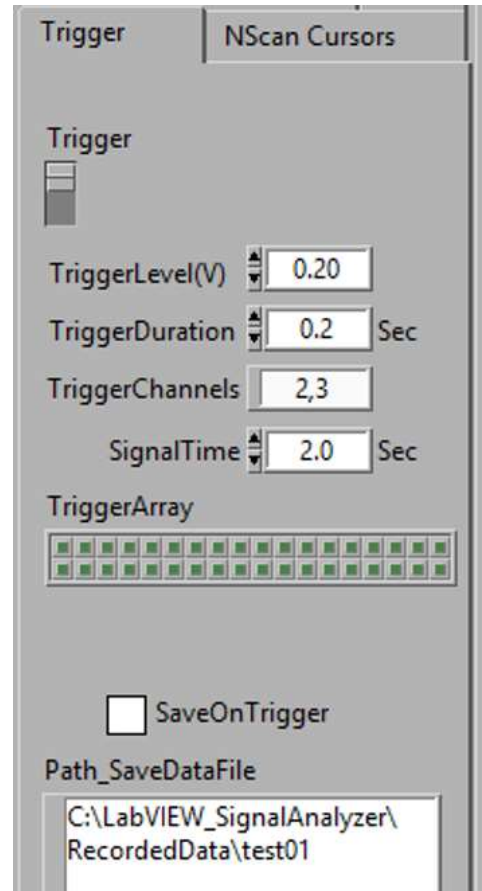
Fig. 3.2.4. FN-Scan multi-sine generator setting

Fig. 3.2.5. FN-Scan trigger setting

4. SIGNAL PROCESSING AND INTERPRETATION

Presently, the processing includes calculation of averaged MI indexes in established in proven N-Scan mode. FN-Scan mode has been developed for field testing using structure ambient vibrations. There are a number of processing algorithms have been developed for this mode of operation, however these algorithms are yet to be tested and validated under the real-life field conditions. Likely, these algorithms may need some corrections and then can be programmed and integrated into the FN-Scan software. Until that, the system allow for storage of the raw data for post-processing to test/modify/validate of all of the developed algorithms.