



Lecture 4: Frequency Response of Viscoously Damped Structures

1. Learning Objectives
 2. Frequency Response Function for SDOF Systems
 3. Representation of Frequency Response Function
 4. Estimation of Frequency Response Function
 5. Half-Power Method for Determining Damping Factor
 6. Hands-on Experiment Project
 7. Test Setup and Equipment
 8. Users Manual of NI-LabVIEW VI Program
 9. Reference
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Learning Objectives

Learning Objectives

- ❑ **Objective 1:** Understand characteristics of frequency response functions (FRF) of SDOF system.
 - ❑ **Objective 2:** Represent the FRF in various forms.
 - ❑ **Objective 3:** Estimate the FRF from experimental measurements.
 - ❑ **Objective 4:** Determine the damping factor from FRF by using the half-power method.
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Frequency Response Function of SDOF System

- Complex Frequency Response Function of a SDOF system
 - It is typically simpler to consider the frequency response function (FRF) in the complex domain
 - Consider the E.O.M of $m\ddot{u} + c\dot{u} + ku = p(t)$ ----- (1)

$$m\ddot{u}_R + c\dot{u}_R + ku_R = p_0 \cos \Omega t$$
$$+ (\ddot{u}_I + \dot{u}_I + u_I = p_0 \sin \Omega t) \times i \text{ ----- (2)}$$

$$m\ddot{\bar{u}} + c\dot{\bar{u}} + k\bar{u} = p_0 e^{i\Omega t} \text{ ----- (3)}$$

- Then, the general response takes the form

$$\bar{u}(t) = \bar{U} e^{i\Omega t} = u_R + i u_I \text{ ----- (4)}$$

where $\bar{U} = U e^{-i\alpha}$ is complex amplitude

- If the input takes a $\cos(\Omega t)$ form, the response is a real part of $u(t)$. If the input takes a $\sin(\Omega t)$ form, then the response is an imaginary part of $u(t)$.

- Substituting Eq. (4) into the E.O.M, Eq. (1),

$$\dot{\bar{u}}(t) = i\Omega \bar{U} e^{i\Omega t}$$

$$\ddot{\bar{u}}(t) = -\Omega^2 \bar{U} e^{i\Omega t}$$

$$-m\Omega^2 \bar{U} e^{i\Omega t} + i\Omega c \bar{U} e^{i\Omega t} + k \bar{U} e^{i\Omega t} = p_0 e^{i\Omega t}$$

$$(-m\Omega^2 + i\Omega c + k) \bar{U} e^{i\Omega t} = p_0 e^{i\Omega t} \quad \text{-----} \quad (5)$$

$$\bar{U} = \frac{p_0}{k - m\Omega^2 + i\Omega c}$$

$$\text{setting } U_0 = \frac{p_0}{k}$$

$$\bar{H}_0(\Omega) = \frac{\bar{U}}{U_0} = \frac{1}{\left(1 - \frac{m}{k} \Omega^2\right) + i \frac{c\Omega}{k}}$$

$$\text{using } c = \zeta c_{cr} = \zeta 2\sqrt{mk}$$

$$= \frac{1}{\left(1 - \frac{\Omega^2}{\omega_n^2}\right) + i2\zeta \frac{\Omega}{\omega_n}}$$

$$\text{setting } r = \frac{\Omega}{\omega_n} \quad \text{-----} \quad (6)$$

- Therefore, the complex frequency response function is as follows

$$\bar{U} = Ue^{-i\alpha} \rightarrow \boxed{\bar{H}_0(\Omega) = \frac{\bar{U}}{U_0} = \frac{1}{(1-r^2) + i(2\zeta r)}} \quad (7)$$

- The complex FRF contains both magnitude and phase angle information of the steady state response of structures.

$$\bar{H}_0(\Omega) = \underbrace{\frac{1-r^2}{(1-r^2)^2 + (2\zeta r)^2}}_{\text{Real part}} + i \underbrace{\frac{-2\zeta r}{(1-r^2)^2 + (2\zeta r)^2}}_{\text{Imaginary part}} \quad (8)$$

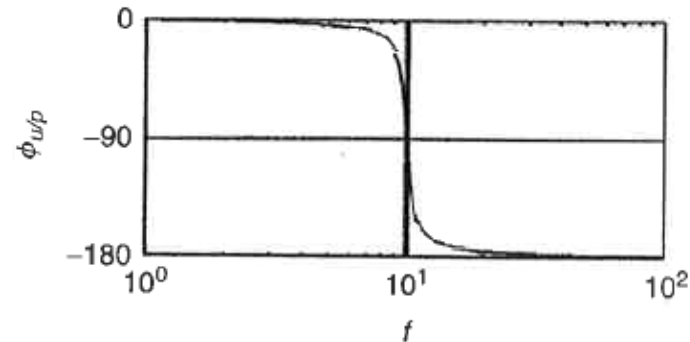
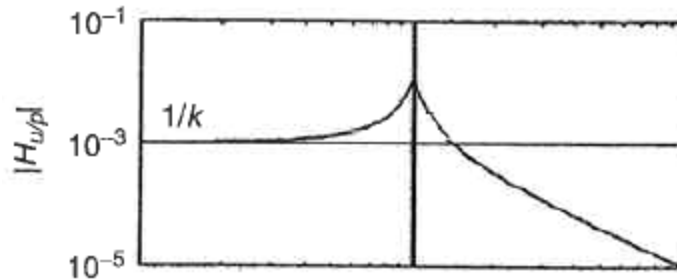
$$H_0(r) = |\bar{H}_0(\Omega)| = \frac{1}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}} \quad (\text{magnitude}) \quad (9)$$

$$\tan \alpha(r) = \frac{2\zeta r}{1-r^2} \quad (\text{phase angle}) \quad (10)$$

Note

$$\begin{aligned} \bar{A} &= A_R + iA_I \\ A &= \sqrt{A_R^2 + A_I^2} \\ \alpha &= \tan^{-1} \left(\frac{A_I}{A_R} \right) \end{aligned}$$

- Plotting the magnitude and phase angle of the complex FRF of *displacement* output per unit force input



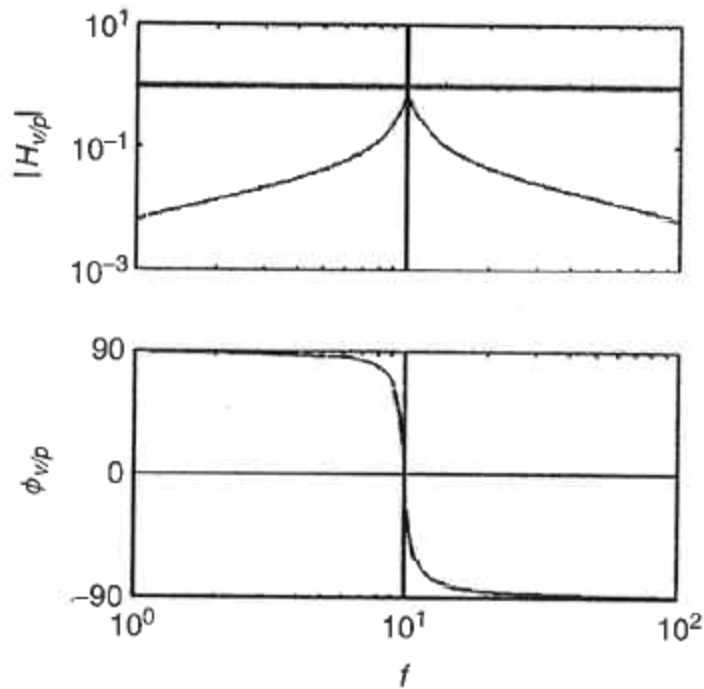
- Eq. (7) is the complex FRF of *displacement* output per unit force input. It is also called as *receptance FRF*.
- Then, the *mobility* FRF (i.e. *velocity* output per unit force input)

$$\bar{H}_{v/p}(\Omega) = i\Omega \frac{1/k}{(1-r^2) + i(2\zeta r)} \quad \text{since } \bar{v}(t) = i\Omega \bar{U} e^{i\Omega t} \quad \text{-----} \quad (11)$$

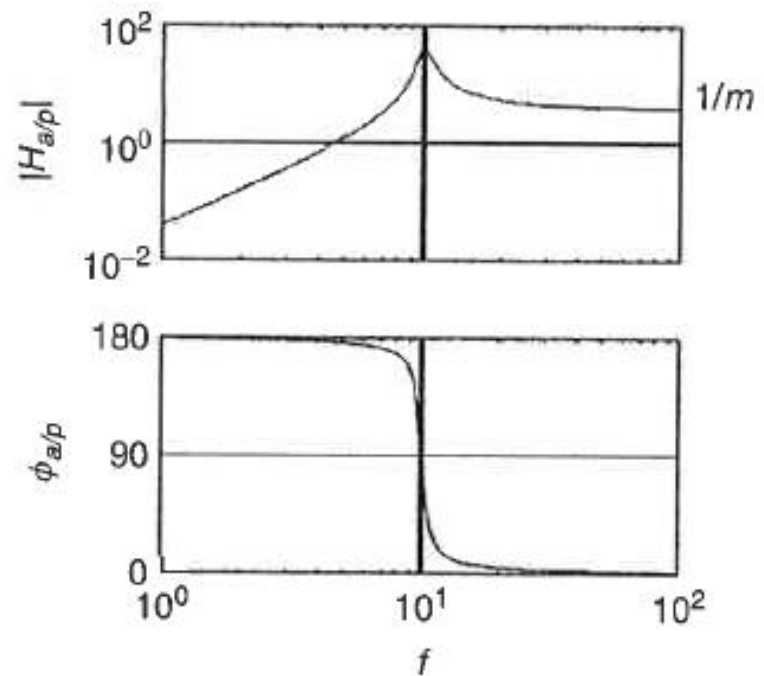
- Then, the *accelerance* FRF (i.e. *acceleration* output per unit force input)

$$\bar{H}_{a/p}(\Omega) = -\Omega^2 \frac{1/k}{(1-r^2) + i(2\zeta r)} \quad \text{since } \bar{a}(t) = -\Omega^2 \bar{U} e^{i\Omega t} \quad \text{-----} \quad (12)$$

- Plotting the magnitude and phase angle of the mobility and accelerance FRFs



Mobility FRF and Phase Angle



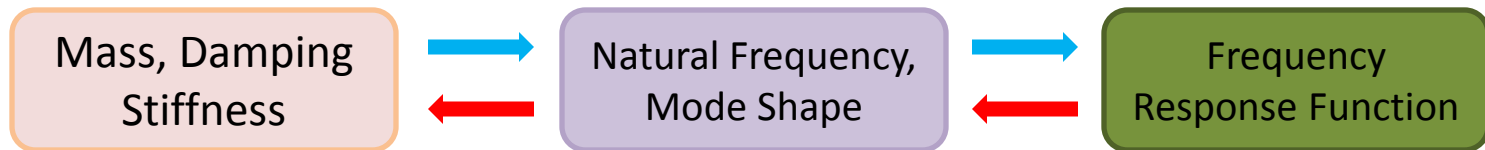
Accelerance FRF and Phase Angle

Summary of Types of FRF

□ Summarizing the types of FRF

Definition		Terminology
$\frac{\text{Displacement}}{\text{Force}}$	$\bar{H}_{u/p}(\Omega) = \frac{1/k}{(1-r^2) + i(2\zeta r)}$	Receptance Dynamic Flexibility
$\frac{\text{Velocity}}{\text{Force}}$	$\bar{H}_{v/p}(\Omega) = i\Omega \frac{1/k}{(1-r^2) + i(2\zeta r)}$	Mobility
$\frac{\text{Acceleration}}{\text{Force}}$	$\bar{H}_{a/p}(\Omega) = -\Omega^2 \frac{1/k}{(1-r^2) + i(2\zeta r)}$	Inertance Accelerance

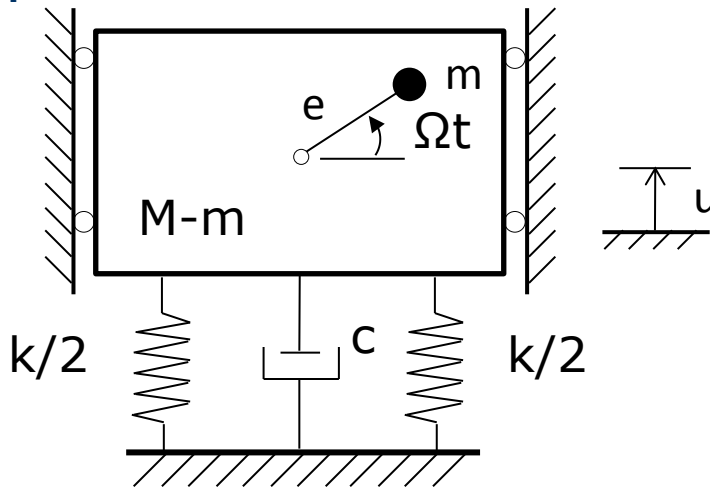
□ Procedures for dynamic analysis



→ Theoretical analysis

← Experimental analysis

- ❑ Imbalance in rotating machines is a common source of vibration excitation. Such a situation is illustrated in the following figure. Let $M-m$ be the mass of the machine alone and let m be the mass of the rotating imbalance, which rotates at speed Ω rad/s at eccentricity e .
- ❑ Q1) Derive the equation of motion for vertical motion, $u(t)$ of the machine
- ❑ Q2) Use the complex frequency response method to derive an expression for the amplitude of the steady-state response of this system, expressed in the non-dimensional form MU/me , and plot the FRF.



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Representation of Frequency Response Function

Bode Plot (Magnitude and Phase)

- ❑ The magnitude of the FRF is generally very large near the resonance. Thus, the curve for magnitude of the FRF is frequently plotted to logarithmic scale.
- ❑ Looking at the receptance FRF, when $r \ll 1$, phase angle of the displacement is 0° . On the contrary, when $r \gg 1$, the phase angle of the displacement will be 180° .
- ❑ At resonance, the phase angle becomes 90° . The phase angle can be checked with the following equation.

$$\bar{H}_{u/p}(\Omega) = \frac{1/k}{(1-r^2) + i(2\zeta r)}$$

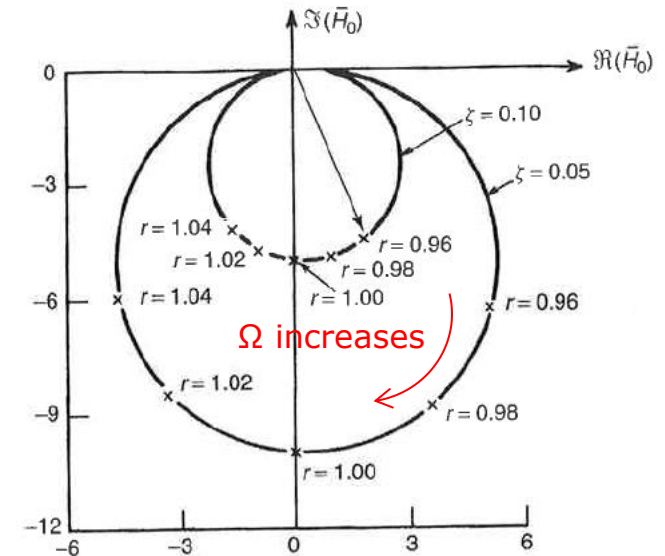
- ❑ In case of mobility FRF and accelerance FRF, the phase increases by 90° sequentially because it is multiplied by $i\Omega$ and $(i\Omega)^2$.

- From the mobility FRF

$$\bar{H}_{v/p}(\Omega) = i\Omega \frac{1/k}{(1-r^2) + i(2\zeta r)}$$

- Modifying this equation,

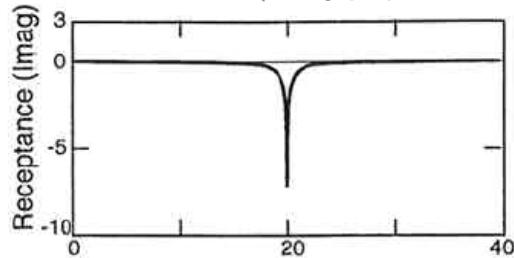
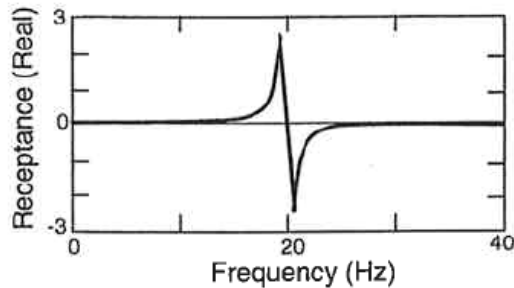
$$\left[\text{Re}(\bar{H}_{v/p}) - \frac{1}{4m\zeta\omega_n} \right]^2 + [\text{Im}(\bar{H}_{v/p})]^2 = \left(\frac{1}{4m\zeta\omega_n} \right)^2$$



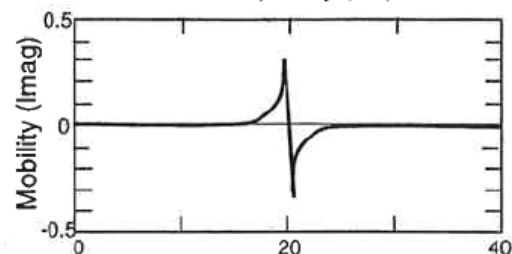
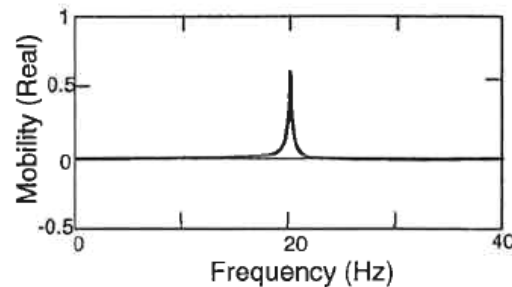
- Thus, if the FRF is plotted on the complex plane, it becomes a circle.
- Only mobility FRF of viscously damped structure makes the circle.
- Nyquist plots are used for extracting modal parameters.

Real-Imaginary Plot

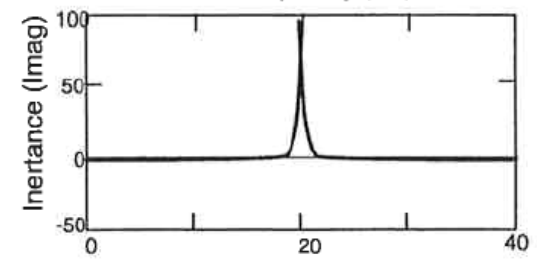
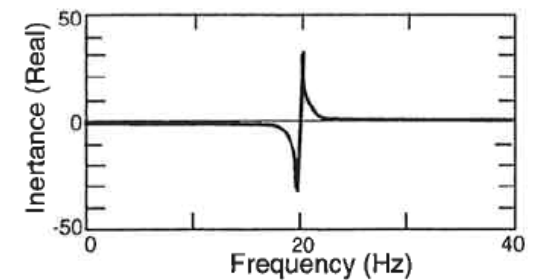
- ❑ The real and imaginary parts of the complex FRF can be plotted versus excitation frequency (Ω)
- ❑ Near the resonance, either real or imaginary part changes its sign and the other has max (or minimum) value.



Receptance FRF



Mobility FRF



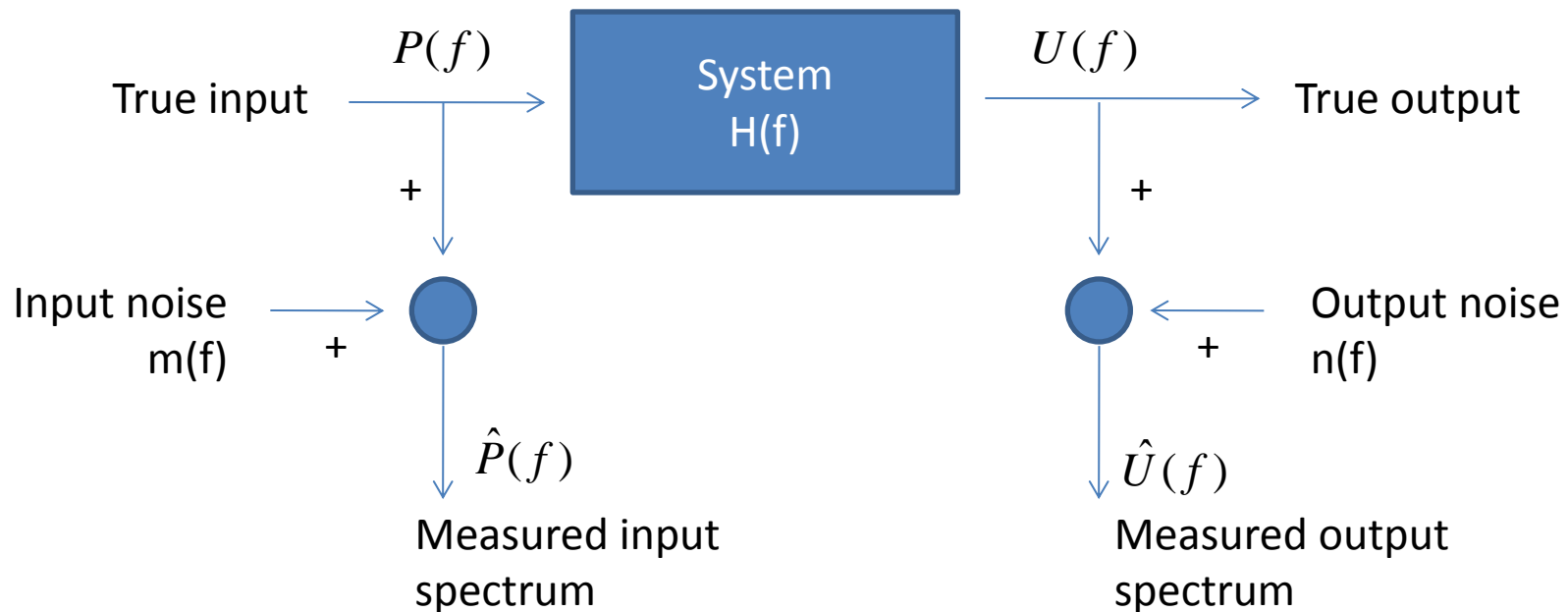
Accelerance FRF

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Estimation of Frequency Response Function

- Considering a single-input-single-output FRF, $H(f)$...

$$U(f) = H(f)P(f)$$



- How to calculate FRFs from noisy input and output signals ?

- Let's define "auto-power spectrum" of time domain signal $a(t)$ and the "cross-power spectrum" of time domain signals $a(t)$ and $b(t)$ as

$$G_{AA} = A(f)A^*(f)$$

$$G_{AB} = A(f)B^*(f) \quad G_{AB} = A(f)B^*(f)$$

Where $A(f)$ and $B(f)$ are the Fourier transforms of signals $a(t)$ and $b(t)$

$$A(f) = \int_{-\infty}^{+\infty} a(t)e^{-2\pi ft} dt \quad B(f) = \int_{-\infty}^{+\infty} b(t)e^{-2\pi ft} dt$$

- Then

$$U(f)P^*(f) = H(f)P(f)P^*(f) \quad \text{OR}$$

$$U(f)U^*(f) = H(f)P(f)U^*(f)$$

$$H(f) = \frac{G_{UP}}{G_{PP}} \quad \text{OR} \quad H(f) = \frac{G_{UU}}{G_{PU}}$$

Note: the auto-power spectrum is a real function of frequency. But the cross-power spectrum is a complex function that carries both magnitude and phase information.

- To minimize the noise, the averaged spectra need to be computed from different segments $(\cdot)_n$ of the time-domain signals

$$\tilde{G}_{AA} = \frac{1}{N_{avg}} \sum_{n=1}^{N_{avg}} A_n(f) A_n^*(f)$$

$$\tilde{G}_{AB} = \frac{1}{N_{avg}} \sum_{n=1}^{N_{avg}} A_n(f) B_n^*(f)$$

- If input and output noises $m(t)$ and $n(t)$ are not correlated with each other and with the true input or output signals

$$\tilde{G}_{UP} = \frac{1}{N_{avg}} \sum_{n=1}^{N_{avg}} (U + n(f))_n (P + m(f))_n^* \quad \text{---} > G_{UP}$$

$$\tilde{G}_{\hat{U}\hat{U}} = \frac{1}{N_{avg}} \sum_{n=1}^{N_{avg}} (U + n(f))_n (U + n(f))_n^* \quad \text{---} > G_{UU} + G_{NN}$$

$$\tilde{G}_{\hat{P}\hat{P}} = \frac{1}{N_{avg}} \sum_{n=1}^{N_{avg}} (P + m(f))_n (P + m(f))_n^* \quad \text{---} > G_{PP} + G_{MM}$$

- Finally, to minimize the noise, the averaged spectra need to be computed from different segments $(\cdot)_n$ of the time-domain signals

$$H_1 = \frac{\tilde{G}_{\hat{U}\hat{P}}}{\tilde{G}_{\hat{P}\hat{P}}} = H_0 \left(1 + \frac{1}{1 + G_{MM} / G_{PP}} \right)$$

$$H_2 = \frac{\tilde{G}_{\hat{U}\hat{U}}}{\tilde{G}_{\hat{P}\hat{U}}} = H_0 \left(1 + \frac{G_{NN}}{G_{UU}} \right)$$

$$H_v = \sqrt{H_1 H_2}$$

- Since $H_1 \leq H_0$, $H_1(f)$ is a lower bound to the true FRF. Note that H_1 is affected by the input noise $m(t)$. Thus, H_1 is poorest near resonance, where the input is small.
- Since $H_2 \geq H_0$, $H_2(f)$ is an upper bound to the true FRF. Note that H_2 is poorest near anti-resonance, where the output is small.
- $H_v(f)$ is the average of $H_1(f)$ and $H_2(f)$.

- The measure of the amount of the output that is due to the input signal is the ordinary coherence $\gamma^2(f)$
- It can be shown that $\gamma^2(f) \leq 1.0$, with $\gamma^2(f) = 1.0$ when there is no noise on the input or output.

$$\gamma^2(f) = \frac{H_1(f)}{H_2(f)}$$

5

Half-Power Method for Determining Damping Factor

- Unlike the logarithmic damping method, forced-vibration response using harmonic or non-harmonic excitation can be used to determine the damping factor.

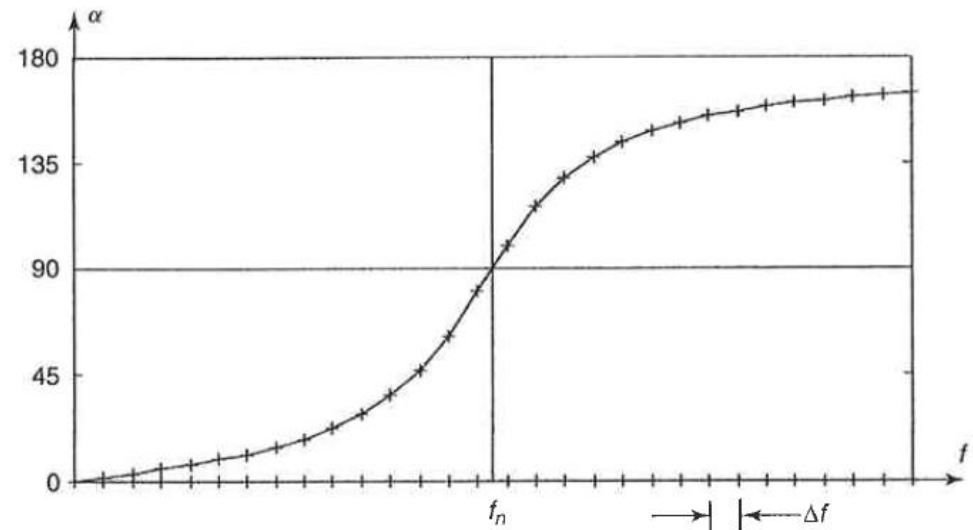
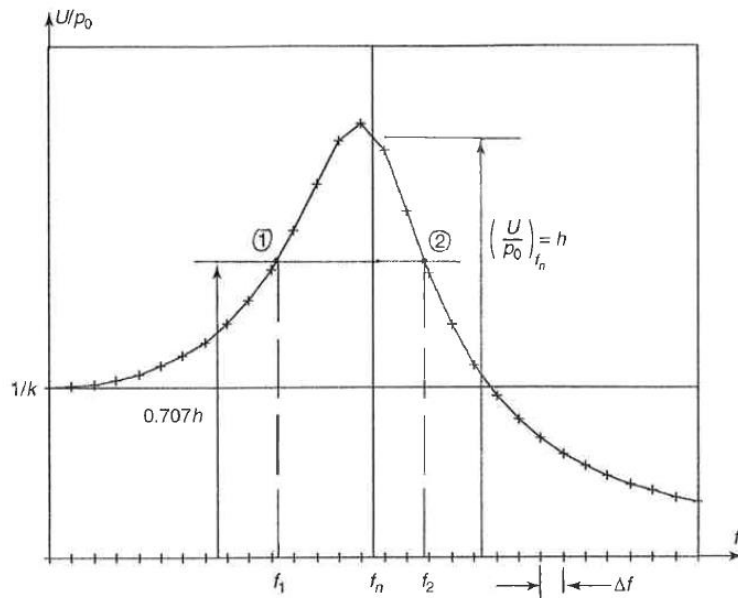
$$\left| \overline{H}_{u/p}(\Omega) \right| = \frac{U}{p_0} = \frac{1/k}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}}$$

$$\tan \alpha = \frac{2\zeta r}{1-r^2}$$

- The natural frequency of the SDOF system can be found
 - The response lags the input by 90°.
 - The response magnitude is at its maximum value.
 - The spacing on the Nyquist plot is a maximum.

Half-Power Method

- ❑ The half-power method is used in frequency domain.
- ❑ If we identify the points on the FRF that correspond to $1/\sqrt{2}$ x (resonant response amplitude) and call the frequency f_1 and f_2 , then these points theoretically occur at $r_i^2 = 1 \pm 2\zeta$.



□ Derivation)

$$\left(\frac{U}{p_0}\right)^2 = \frac{(1/k)^2}{(1-r^2)^2 + (2\zeta r)^2}$$

$$\frac{1}{2}\left(\frac{U}{p_0}\right)_{r=1}^2 = \frac{1}{2}\left(\frac{1/k}{2\zeta}\right)^2 = \frac{(1/k)^2}{(1-r_i^2)^2 + (2\zeta r_i)^2}$$

$$r_i^4 - 2(1-2\zeta^2)r_i^2 + (1-8\zeta^2) = 0$$

$$r_i^2 = (1-2\zeta^2) \pm 2\zeta\sqrt{1+\zeta^2}$$

$$r_i^2 = 1 \pm 2\zeta$$

□ Using a binomial expansion,

$$r_i = (1+2\zeta)^{1/2} = 1 + \frac{1}{2}(2\zeta) + \dots$$

$$r_i = (1-2\zeta)^{1/2} = 1 - \frac{1}{2}(2\zeta) + \dots$$

$$r_2 - r_1 = 2\zeta \quad \text{for } \zeta \ll 1$$

$$\zeta = \frac{1}{2} \frac{f_2 - f_1}{f_n}$$

- ❑ The procedure is as follows:
 - ❑ Determine the undamped natural frequency f_n (Hertz), by one of the methods described above and then determine the resonant response amplitude $(U / p_0)_{r=1}$.
 - ❑ Note the points on the response amplitude curve where the amplitude is $(1/\sqrt{2})(U / p_0)_{r=1}$. Call the corresponding frequencies (in hertz) f_1 and f_2 .
 - ❑ Then use the equation to determine the damping factor.

$$\zeta = \frac{1}{2} \frac{f_2 - f_1}{f_n}$$

- ❑ Note that the accuracy with which ζ is determined depends on the frequency resolution in the original frequency response data.

6

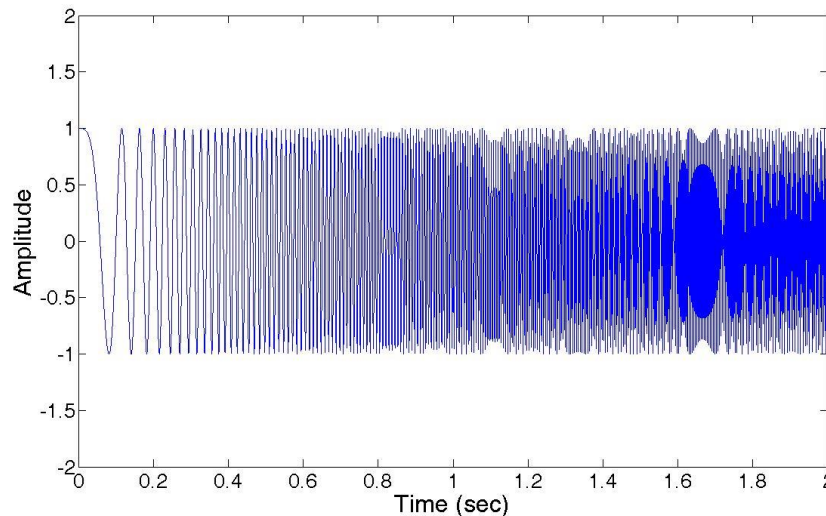
Hands-on Experiment Project

Problem Statement (1)

- ❑ **Conduct a fast sweep sine test** using a beam structure and measure dynamic response.
- ❑ **Determine the undamped natural frequency and the damping factor from the measured FRF** acquired by the provided NI-LabVIEW VI program.
- ❑ Instead of measuring the displacements, measure accelerations. Thus, the FRF will represent the ratio of acceleration to input force. **Show that you can still determine the damping factor from the accelerance FRF.**
- ❑ Note that the tested structure is a beam. Thus, you will observe multiple peaks in the accelerance FRF. Choose the first peak corresponding to the first mode.
- ❑ The tested beam is a fixed-fixed carbon steel beam.

Problem Statement (2)

- ❑ Excitation method: **Fast sine sweep (Periodic chirp signals)**
- ❑ The fast sine sweep excitation method sweeps from low to high frequencies multiple times during FFT process.
- ❑ Unlike the single frequency excitation, the structure does not show steady state response.
- ❑ However, it can reduce the number of ensemble averaging because it has clear frequency spectrum.
- ❑ It also allows us to observe any nonlinear effect on the FRF by narrowing the frequency range.



Guides for Reports

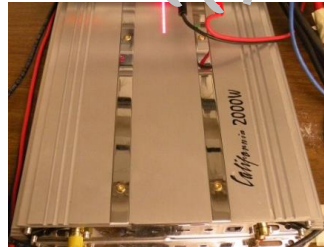
- ❑ Write a full report using the instructions provided in class. Organize your report into sections (e.g. Introduction, Procedures, Results, Discussion, Summary, References). Write concisely and clearly.
 - ❑ Include the following: (1) A schematic diagram and description of the test equipment. (2) Derivation of the damping factor from half-power method based on the accelerance FRF. (3) Plots of the time-domain vibration response data measured from the experiment. (4) Plots of the FRF computed by the NI-LabVIEW VI program. (5) The undamped natural frequency and the damping factor.
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7

Test Setup and Equipment

Test Setup and Procedures (1)

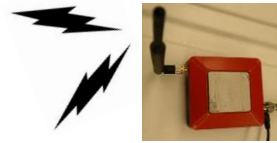
Power Supply(MPJA 14604PS)



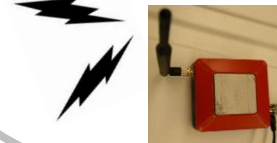
Amplifier(AP2000)



MSP-100



Output acc.



Input force



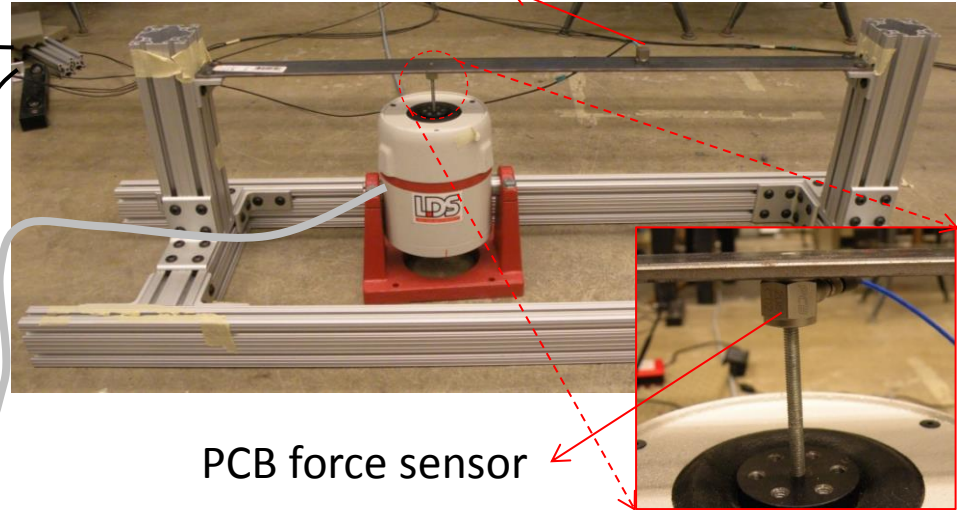
Connector Block (SCB68)



NI PXI 6733

NI-PXI 8105 in NI-PXI 1042

Accelerometer with magnetic mount



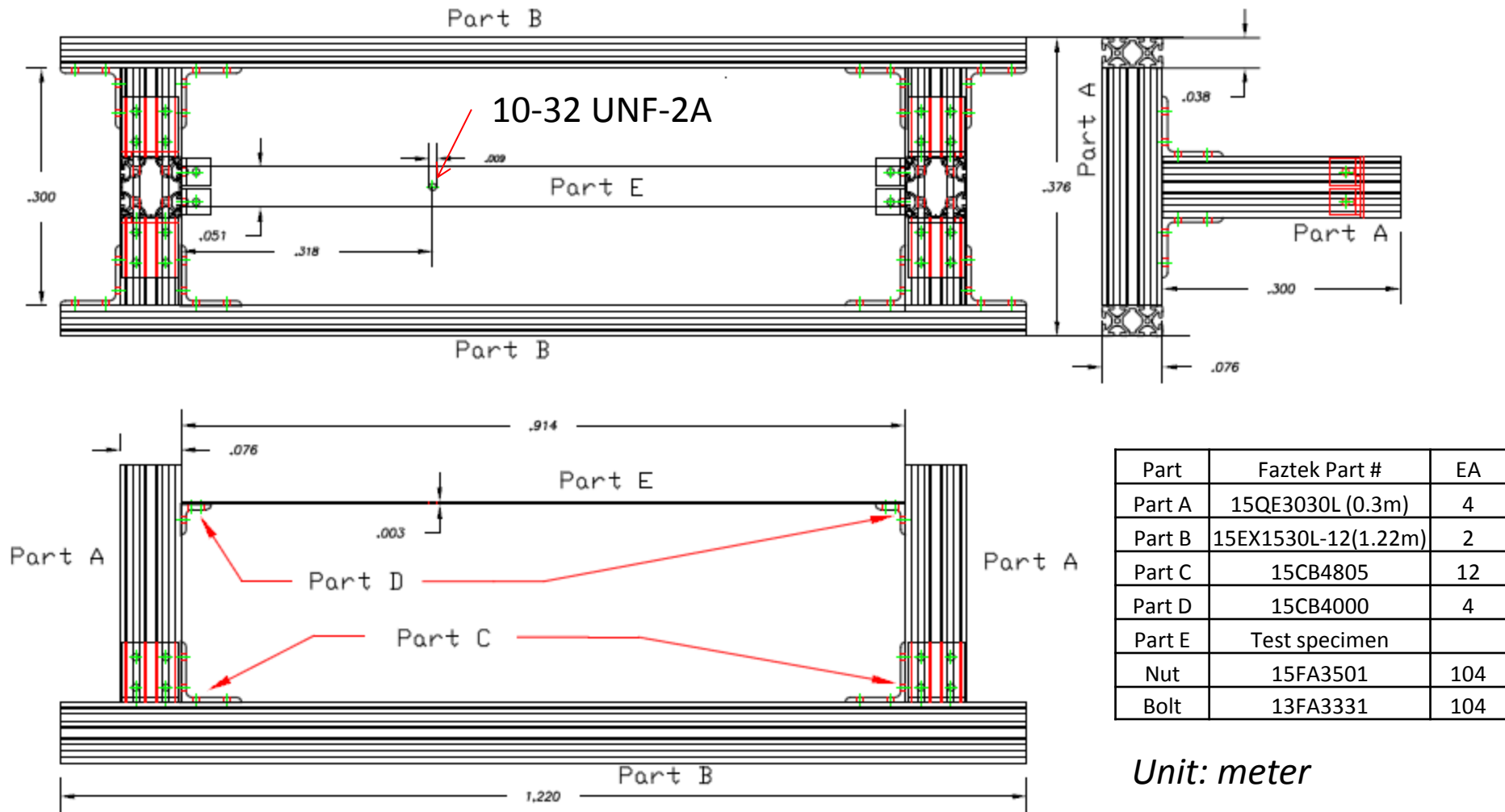
PCB force sensor



Test Setup and Procedures (2)

- ❑ Step1 Turn on power supply.
- ❑ Step2 Generate excitation signals using NI-LabVIEW and send them through analog output board(NI-PXI 6733).
- ❑ Step3 Under the vibration excitation, proceed the test.

Test Structure- Drawing



- ❑ Agilent 33250A (For function generator based test)
 - ❑ Amplifier (California AP2000 2000W)
 - ❑ Power Supply (MPJA 14604PS)
 - ❑ NI-PXI 8105 Controller
 - ❑ NI-PXI 6733 (For NI analog out signal generator based test)
 - ❑ 68-Pin Connector Block (SCB68)
 - ❑ ICP type Dytran triaxial accelerometer (3093B1)
 - ❑ ICP type PCB force sensor (208C02)
 - ❑ One-channel AnyLogger (Korea Maintenance Co., LTD): AnyLoggerS-V/ICP.
 - ❑ NI-LabVIEW 8.6
-

Specification



- ☐ 320 watts RMS x 2 at 4 ohms
- ☐ 480 watts RMS x 2 at 2 ohms
- ☐ 960 watts RMS x 1 bridged output at 4 ohms
- ☐ 4-ohm stable in bridged mode
- ☐ Stereo or bridged mono output
- ☐ Tri-way capable (Tri-Way Crossover required)
- ☐ Dual power supply for stability at high volumes
- ☐ Fuse rating: 25A x 4
- ☐ Requires 4-gauge power and ground leads and a 100-amp fuse
- ☐ Wiring and hardware not included with amplifier
- ☐ Variable low-pass filters (50-250 Hz, 12 dB/octave)
- ☐ Variable bass boost (0-12 dB) at 45 Hz
- ☐ Variable subsonic filter (20-50 Hz)
- ☐ Preamp-level inputs (speaker-level to preamp-level adapter included)
- ☐ Preamp outputs
- ☐ Wired bass level remote control
- ☐ 24-1/4"W x 2"H x 10-1/4"D

Specification



- ☐ Input voltage : 110-127 AC
- ☐ Output voltage : 0-30 DC
- ☐ Current : 0-10 A
- ☐ Voltage regulation
 - ☐ CV $\square 1 \times 10^{-4} + 3 \text{mV}$
 - ☐ CC $\square 2 \times 10^{-3} + 6 \text{mA}$
- ☐ Load regulation
 - ☐ CV $\square 5 \times 10^{-4} + 3 \text{mV}$
 - ☐ CC $\square 5 \times 10^{-4} + 6 \text{mA}$
- ☐ Ripple & noise
 - ☐ CV $< 1.5 \text{mVrms}$
 - ☐ CC $< 10 \text{mArms}$
- ☐ Protection : current limiting
- ☐ Voltage indication accuracy : $1\% + 1 \text{d}$
- ☐ Current indication accuracy : $1\% + 1 \text{d}$
- ☐ Ambient temperature : $0 \sim 40^\circ\text{C}$
- ☐ Humidity: $< 90\%$

Specification

- ❑ Intel Core Duo Processor T2500(2.0 GHz dual core)
- ❑ 512 MB (1 x 512 MB DIMM) dual channel 667 MHz DDR2 RAM standard, 4 GB (2 x 2 GB DIMMs) maximum
- ❑ Integrated I/O
 - ❑ 10/100/1000BASE-TX Ethernet
 - ❑ 4 Hi-Speed USB ports
 - ❑ ExpressCard/34 slot
 - ❑ DVI-I video connector
 - ❑ GPIB (IEEE 488) controller
 - ❑ RS232 serial port
 - ❑ IEEE 1284 ECP/EPP parallel port
 - ❑ Integrated hard drive
- ❑ Internal PXI trigger bus routing
- ❑ Watchdog timer Software
- ❑ Hard drive-based recovery image PXI System



Specification

- ❑ 8 high-speed digital I/O lines; two 24-bit counters; digital triggering
- ❑ Onboard or external update clock PXI trigger bus for synchronization with DAQ motion, and vision products
- ❑ NI DAQmx driver with configuration utility to simplify configuration and measurement
- ❑ Superior integration: LabVIEW, LabVIEW Real-Time, LabWindows™/CVI, and Measurement Studio for VB
- ❑ 1MS/s, 16-Bit, 8 Channels



68-Pin Connector Block (SCB68)

Specification



- ☐ Number of channels : 8 differential, 16 single-ended
- ☐ Accuracy : $\pm 1.0^{\circ}\text{C}$ over a 0° to 110°C range
- ☐ Output : $10\text{ mV}/^{\circ}\text{C}$
- ☐ I/O connectors One 68-pin male SCSI connector
- ☐ Temperature : 0° to 70°C
- ☐ Relative humidity : 5% to 90% non-condensing
- ☐ Temperature : -55° to 125°C
- ☐ Relative humidity : 5% to 90% non-condensing

Dytran Accelerometer (3093B1)



Model 3093B1 Dytran Triaxial Accelerometer

Specification	Value	Unit
Weight	13.5	Grams
Size(Height x Width x Depth)	0.54 x 0.59 x 0.59	Inch
Sensitivity	100	mV/G
Ranges	+/-50	G
Frequency Response	2 to 5000	Hz
Equivalent Electrical Noise	0.007	G, RMS
Linearity	1	% F.S.
Temp. Range	-60 ~ +250	°F
Supply Current Range each axis	2 to 20	mA
Supply Voltage Range each axis	+18 to +30	VDC
Output impedance	100	OHMS

Specification of Force Sensor



Force Sensor (PCB 208C02)

Specification	Value	Unit
Weight	22.7	Grams
Size(Hex x Height x Sensing Surface)	15.88 x15.88 x 15.7	mm
Sensitivity	11241	mV/kN
Ranges	± 0.4448	kN
Linearity	Below 1	% F.S.
Temp. Range	-54 to +121	°C
Supply Current Range each axis	2 to 20	mA
Supply Voltage Range each axis	30	VDC
Output impedance	Below 100	OHMS



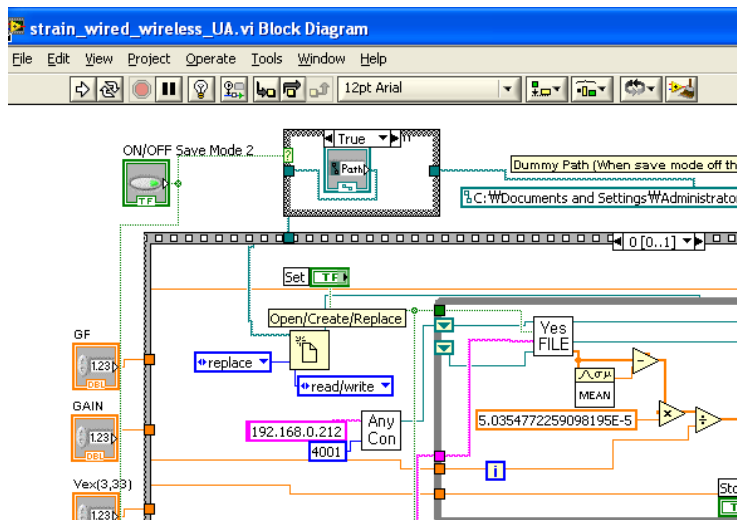
AnyLoggerS-V/ICP for acceleration transmitter
AnyLoggerS-B for strain transmitter

Specification

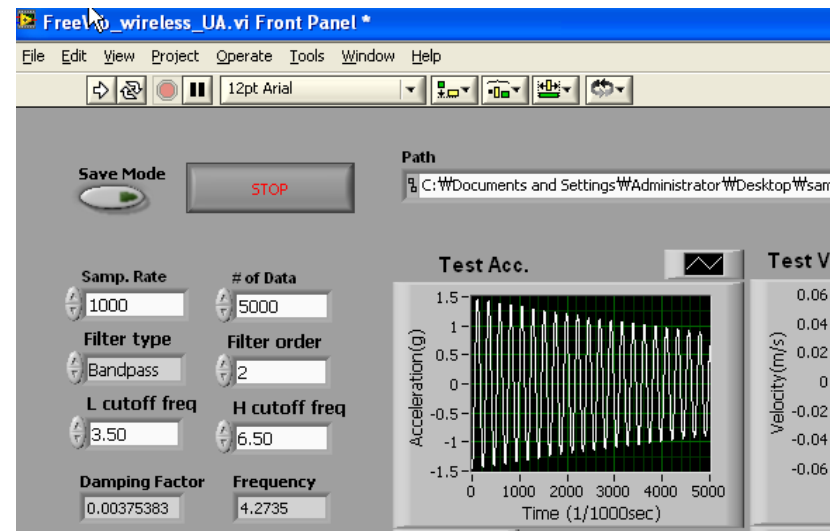
Contents	AnyLoggerS-V/ICP	AnyLoggerS-B
Support Num. of Channel	1	1
Input Voltage Range	-5 ~ 5V	0 ~ 3V
Gain	1,2,5,10,20,50,100	50,100,250,500,1000,2500,5000
Programmable	10~1000Hz (10,20,50,100,200,500,1000)	10 ~ 1000Hz
Lower Pass Filter		10,20,50,100,200,500,1000
Prog. Offset	0 ~ 5V(12Bit)	0 ~ 3.3V(12Bit)
Max Sampling Rate	1000Hz	1000Hz
Exciting Voltage	24V(Only ICP Type)	3.3V±0.5%
Connector	BNC Connector	4Pin Circular Connector
SIM Usage	No	Yes
Power Consumption (w/o sensor)	150mA	100mA(w/o SIM)
Internal Battery	Li-ion Rechargeable 1500mAh x 2EA(Serial)	Li-ion Rechargeable 1500mAh x 2EA(Serial)
Ext. Power Requirement	5V	5V
Operation Temperature	-10 ~ 80℃	-10 ~ 80℃
Sync. Accuracy	< 10ms	< 10ms
Dimension	800 x 973 x 353	800 x 883 x 353
Weight	210g	210g
ADC Resolution	Differential 16Bit	Differential 16Bit
Measurement Accuracy	F.S. 0.1%	F.S. 0.1%
Sensor Connectivity	Voltage or ICP source	Bridge type sensor
Signal Ripple	Depends on Gain	Depends on Gain
Communication	Bluetooth v1.2 class1 18dBm(w/o ant.)	Bluetooth v1.2 class1 18dBm(w/o ant.)
Radio Frequency Range	2.402 ~ 2.480GHz	2.402 ~ 2.480GHz
Transmission Method	FHSS(freq. Hopping Spread Spectrum)	FHSS
Modulation Method	GFSK(Gaussian-filtered Freq. Shift Keying)	GFSK
Approvals	MIC, FCC, CE	MIC, FCC, CE

❑ LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language that uses icons instead of lines of text to create applications.

❑ In contrast to text-based programming languages, where instructions determine the order of program execution, LabVIEW uses dataflow programming, where the flow of data through the nodes on the block diagram determines the execution order of the VIs and functions. VIs, or virtual instrument, are LabVIEW programs that imitate physical instruments.



VI Block Diagram



Front Panel

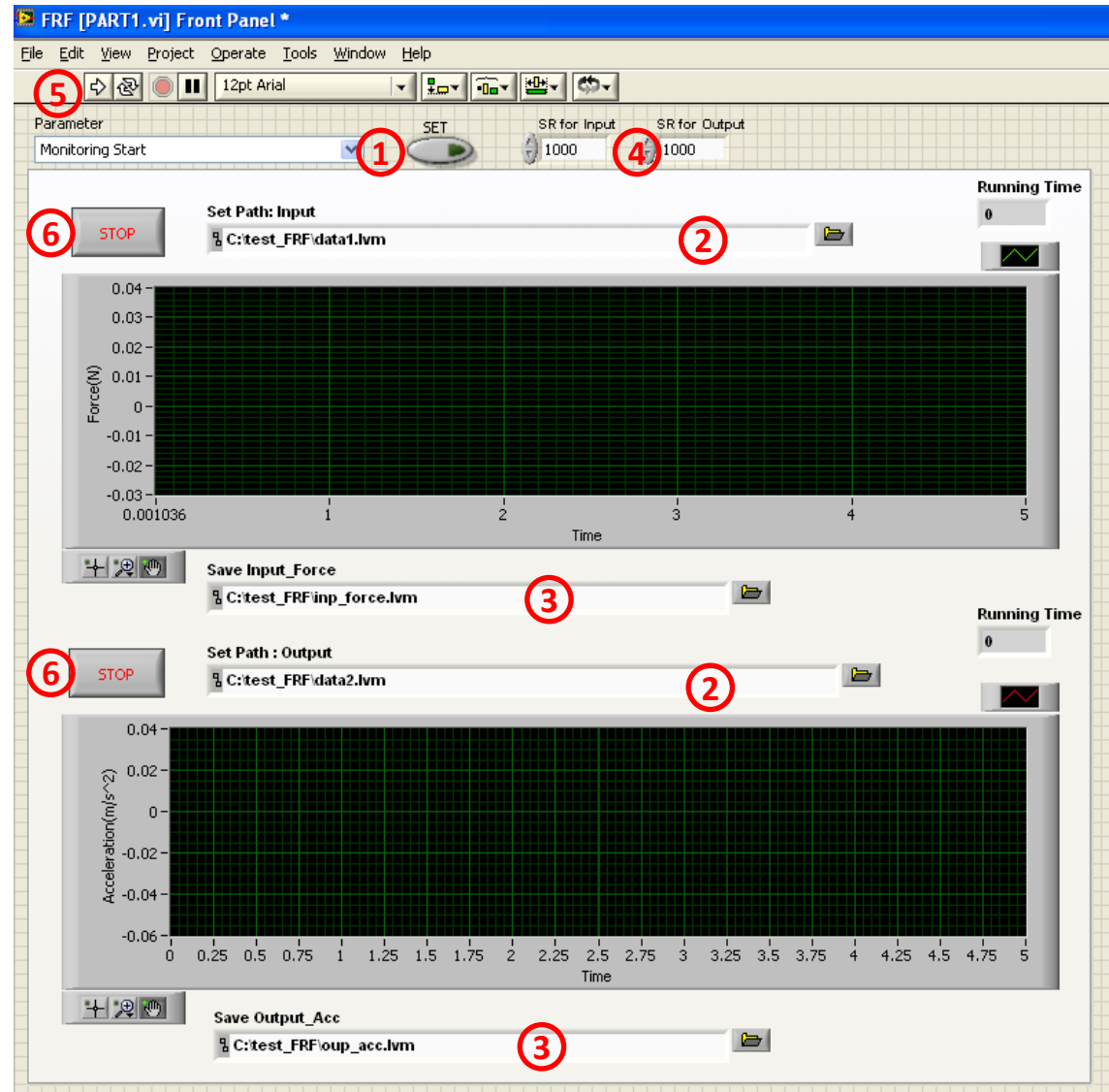
8

Users Manual of NI-LabVIEW VI Program

PART 1.VI

The part1.VI measures raw data and converts raw data to physical input forces and output accelerations and save.

- 1) **Set Parameter** – to “Monitoring Start” and click “Set”.
- 2) **Set Path** – Create empty files in “Path” where the original raw Acc. and force data will be saved.
- 3) **Set Path** – Create empty files in “Path” where the physical input force and output acc. data will be saved.
- 4) **Set Sampling Rate** – Default 1KHz for both input and output.
- 5) **Run**- Run the front panel while the structure is vibrating.
- 6) **Stop** –Users can control the amount of data.

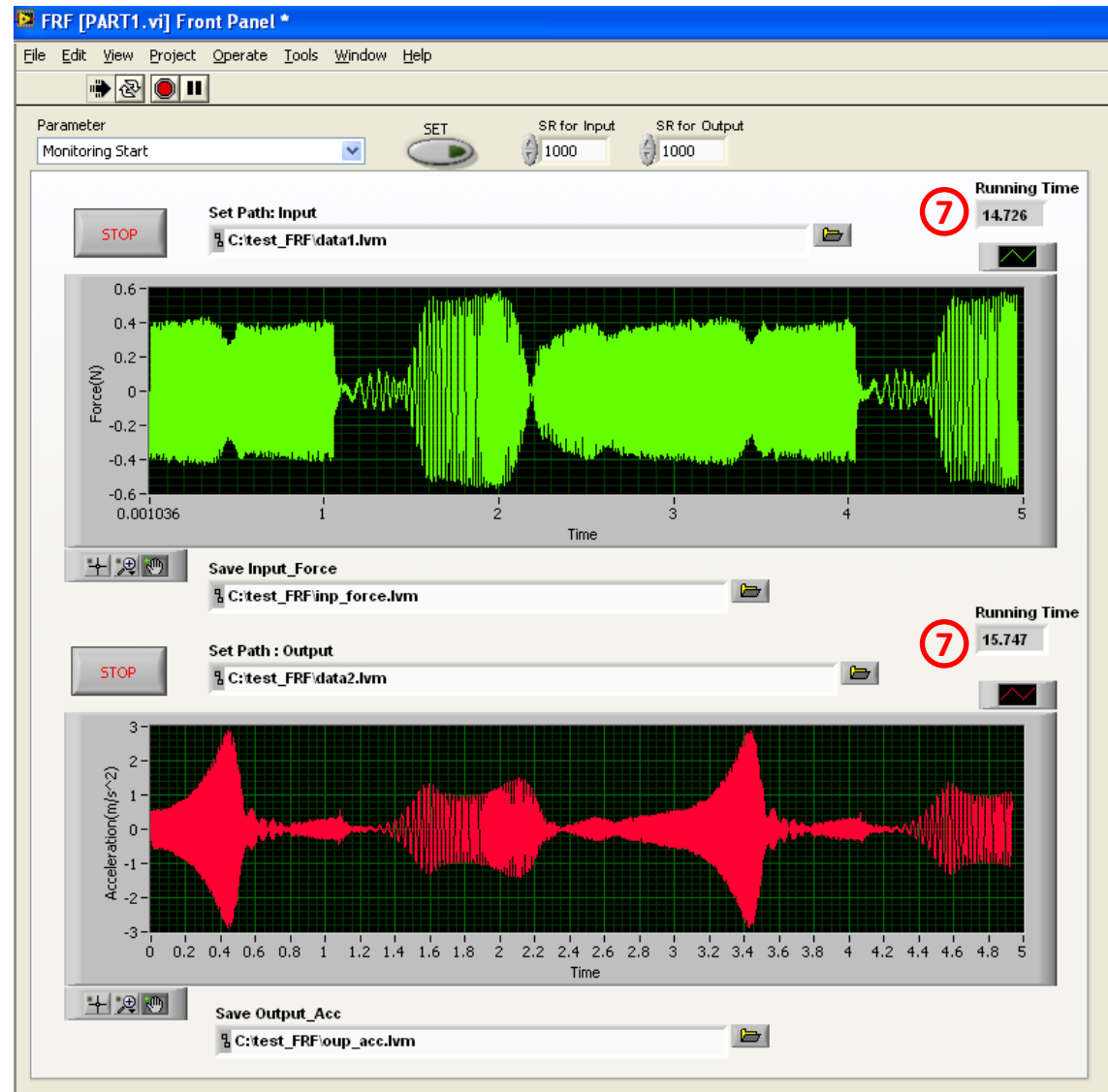


PART 1.VI

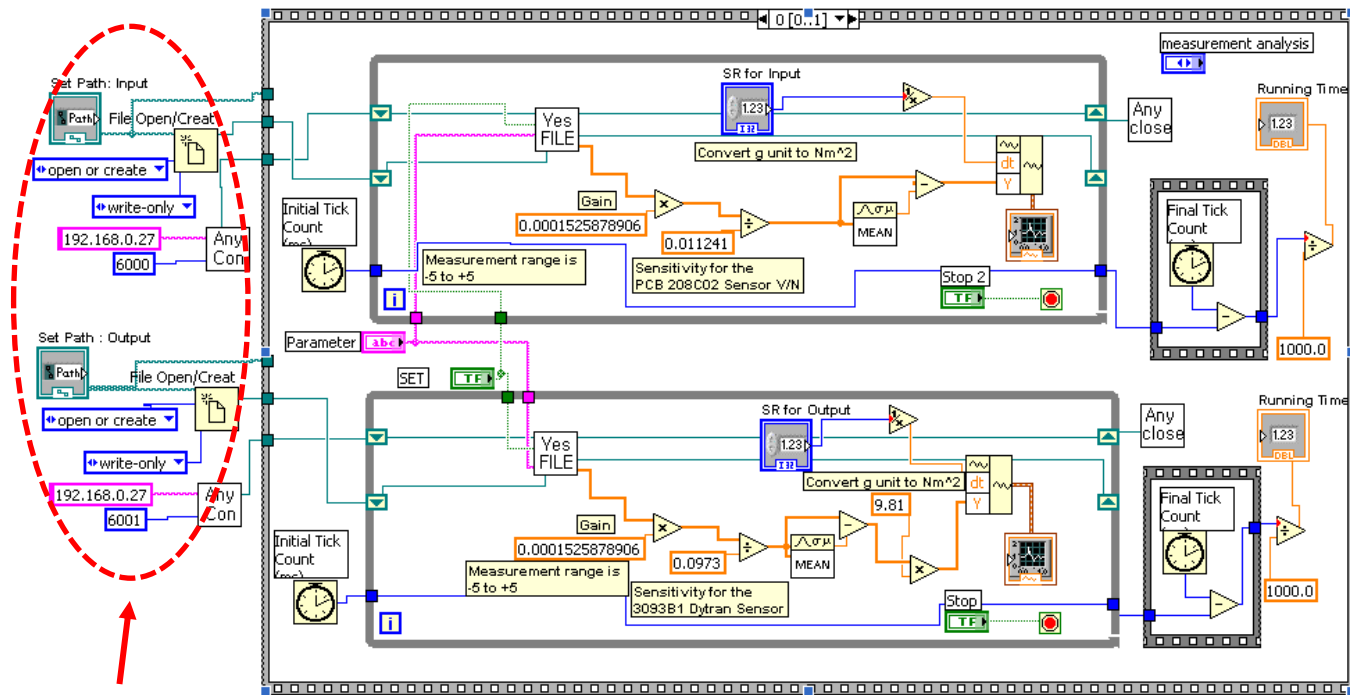
After acquiring raw data, the VI program automatically converts raw data to physical input force and output acceleration and save.

7) Running Time – it shows the time period for DAQ by AnyLogger ®.

Note : The number of input data does not need to be same as that of output data. The code automatically discards data that do not have samples corresponding to either input or output data. By taking samples from the beginning, it is assumed that sampling for input and output data are synchronized.



PART 1.VI

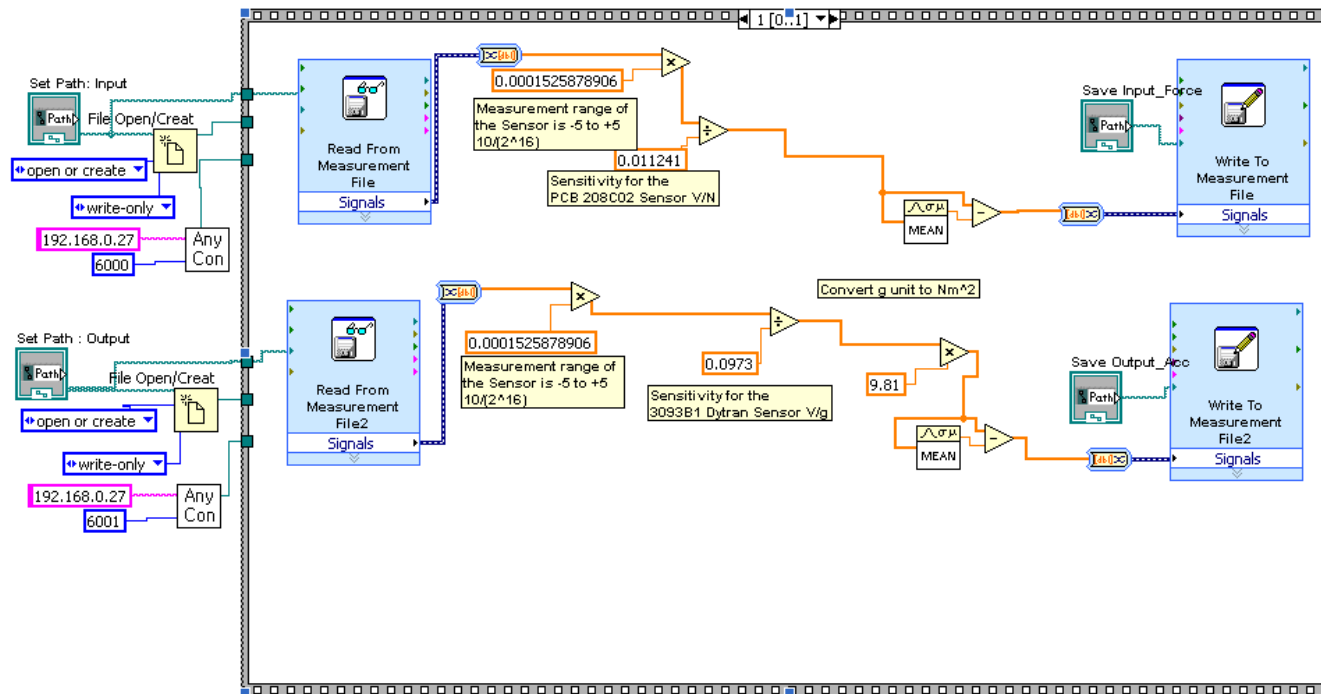


Set IP address and port number

The First Stack of Block Diagram of PART1.VI

- ❑ Two stack sequences were used for Part1.VI.
- ❑ At the first sequence, the program saves the raw data to the file in the given path.
- ❑ Users should define correct **IP address** and **port number** based on the equipment following the AnyLogger® manual.

PART 1.VI



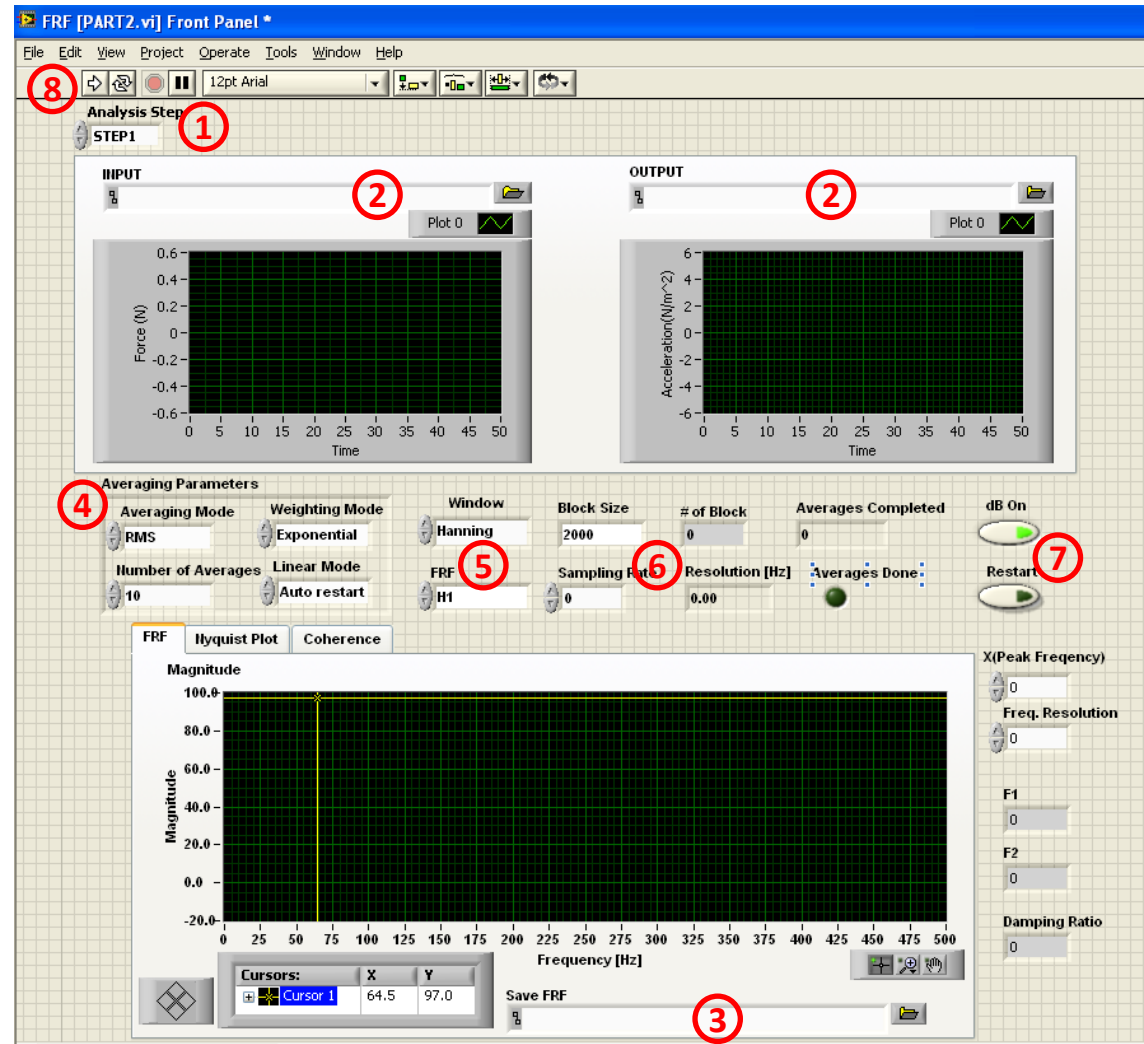
The Second Stack of Block Diagram of PART1.VI

- At the second sequence, the program reads the raw data from the file in the given path and converts to physical input force and output acceleration data and save as data file.

PART 2.VI

Part2.VI has two-step operation. In STEP1, it reads input excitation and output response signals and compute FRF and display it.

- 1) **Set Analysis Step**– to “STEP1”
- 2) **Set Path** – Set files which store the physical input and output data in “Path” .
- 3) **Set Path** – Create empty files in “Path” where the FRF magnitude will be saved.
- 4) **Average Parameter**– Users can set the Average Mode, the Number of Average, Weighting Mode, and Linear Mode.
- 5) **FRF Parameter**– Users can set the Window, and FRF Mode.
- 6) **FRF Parameter**– Users can set the Block (Window)Size and Sampling Rate.
- 7) **dB On and Restart**- dB On changes FRF magnitude to decibel unit. Users can click restart for restart averaging.
- 8) **Run**



FRF Parameters

☐ **averaging mode** specifies the averaging mode.

0	No averaging (default)
1	Vector averaging
2	RMS averaging

☐ **weighting mode** specifies the **weighting mode** for RMS and vector averaging.

0	Linear
1	Exponential (default)

☐ **number of averages** specifies the number of averages used for RMS and vector averaging.

☐ If **weighting mode** is exponential, the averaging process is continuous.

☐ If **weighting mode** is linear, the averaging process stops after this VI computes the selected **number of averages**.

☐ **linear mode** specifies the behavior of the averaging if you set the value of the **weighting mode** parameter to **Linear**. If you set **weighting mode** to **Exponential**, **linear mode** is ignored.

0	One shot —(default) Specifies that the averaging process stops once the value of number of averages is reached.
1	Auto restart —Specifies that the averaging process automatically restarts after the value of number of averages is reached.

FRF Parameters

- **window** specifies the time-domain window to use. The default is Hanning.

0	Rectangle
1	Hanning (default)
2	Hamming
3	Blackman-Harris
4	Exact Blackman
5	Blackman
6	Flat Top
7	Four Term Blackman-Harris
8	Seven Term Blackman-Harris
9	Low Sidelobe
11	Blackman Nuttall
30	Triangle
60	Kaiser
61	Dolph-Chebyshev
62	Gaussian

- **block size** specifies the number of data contained in each block.

- **FRF mode** specifies how to compute the frequency response function (FRF). **FRF mode** determines whether H1, H2, or H3 is computed when performing frequency response measurements. The default is H1.

* **Note FRF mode** only applies to RMS or vector averaging. **FRF mode** changes the result in RMS averaging but not in vector averaging. In vector averaging, $H1 = H2 = H3$.

0	H1 (default)
1	H2
2	H3

FRF Parameters

- ☐ **sampling rate** specifies the sampling rate of original input and output signal. For the FRF the sampling rate of input and output signal should be same.
- ☐ **# of block** specifies the number of blocks based on original signal and block size. The number of block is equivalent to the maximum number of average.
- ☐ **resolution** specifies the frequency resolution of FRF graph.
- ☐ **averages completed** returns the number of averages completed by the VI at that time.
- ☐ **averaging done** returns TRUE when **averages completed** is greater than or equal to the **number of averages** specified in **averaging parameters**. Otherwise, **averaging done** returns FALSE. **averaging done** is always TRUE if the selected **averaging mode** is No averaging.

Note : Users can refer more details about FRF VI program at the website of WWW.NI.COM

PART 2.VI

In STEP2, the damping factor is calculated by the half-power method.

9) Analysis Step –Select STEP2

10) Cursor: Users can move the cursor on the graph to find peak FRF magnitude and corresponding frequency.

11) Cursor controller Users can move the cursor to left or right direction by clicking the rectangular shape in order to find the maximum peak FRF magnitude and corresponding frequency.

12) Frequency and frequency resolution– Read X(frequency) and Resolution of frequency.

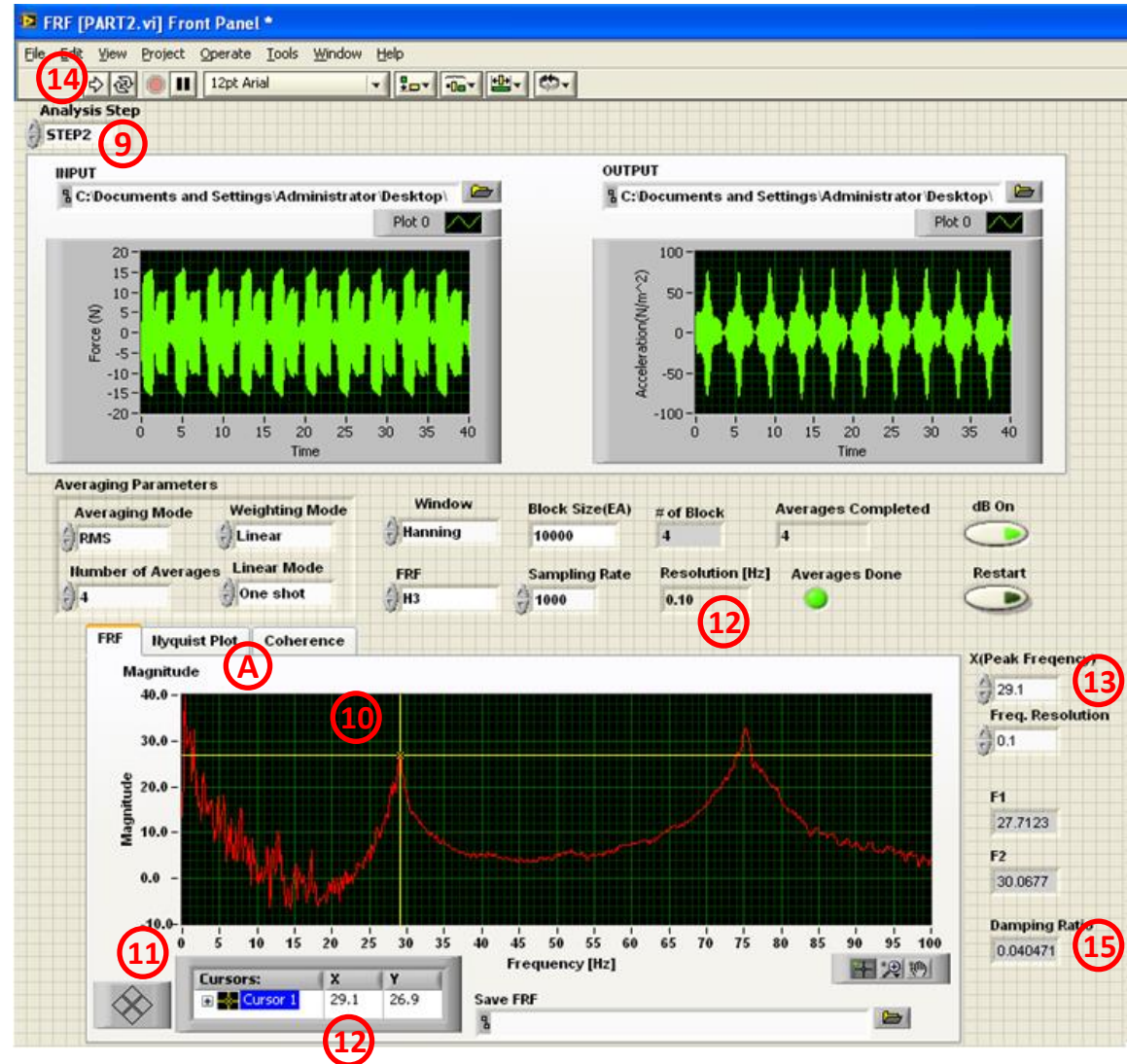
13) Input X and Resolution–Input those values for computing damping factor.

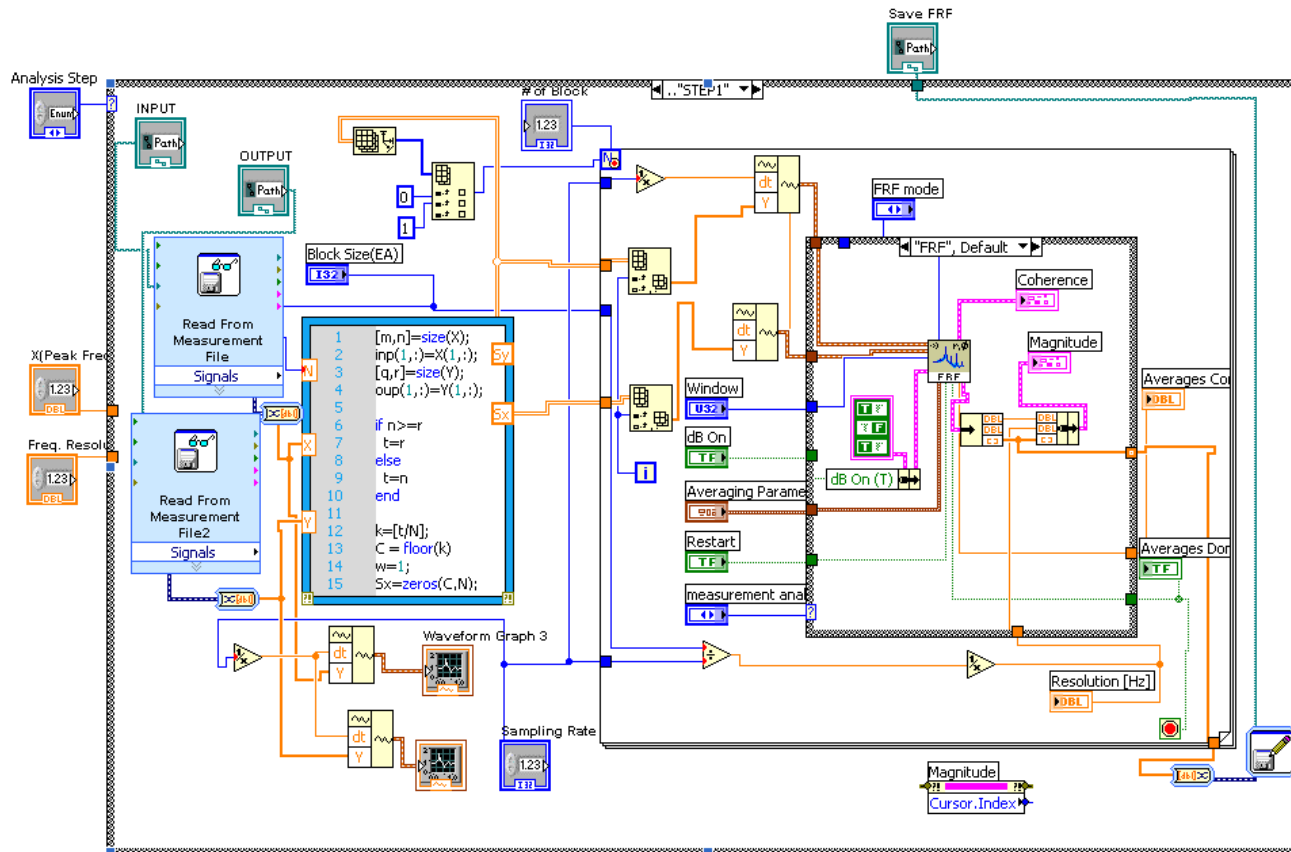
14) Run

15) Users can read the damping factor.

A) Plot changer – Users can also see the additional plots such as Nyquist plot and Coherence plot.

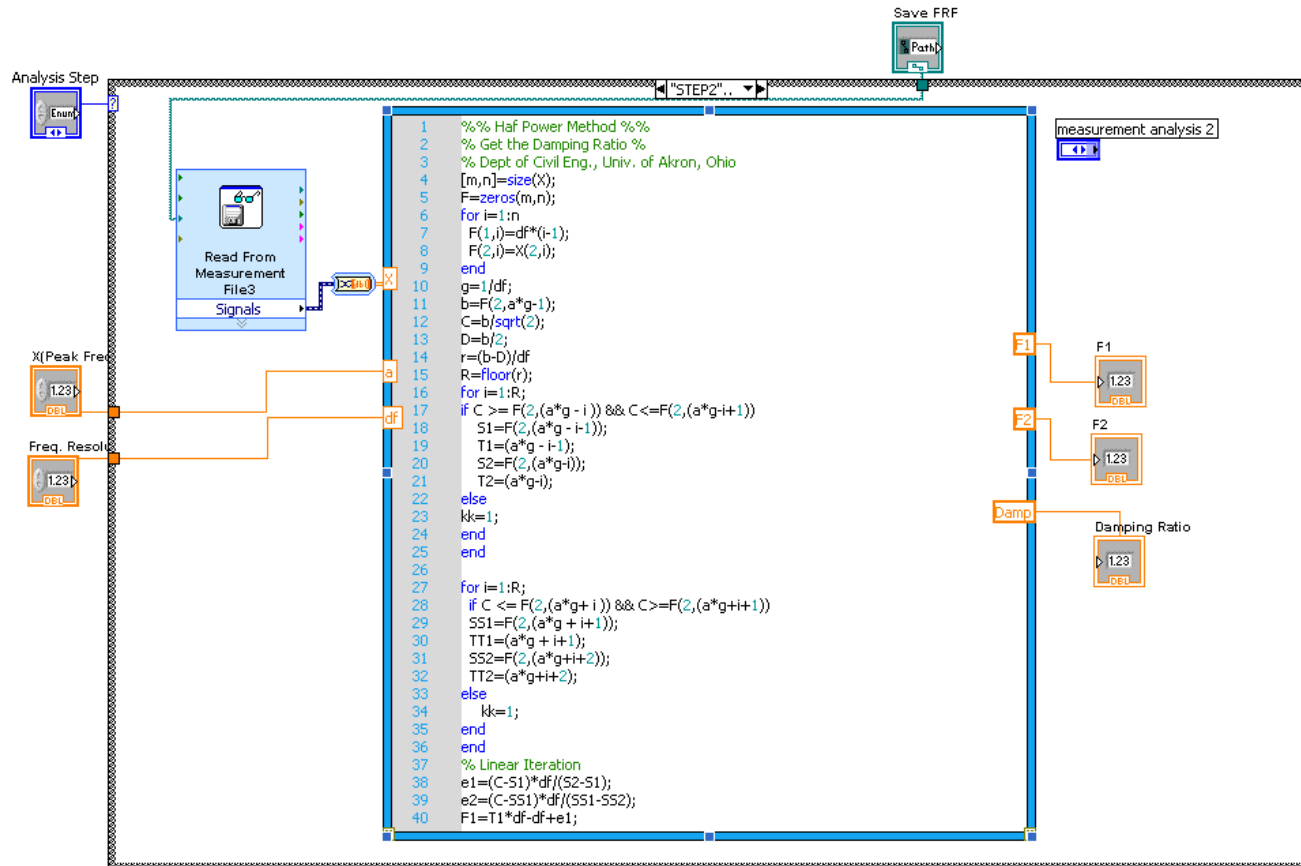
Note : Part2.VI does not save the data of Nyquist and coherence plots.





STEP1-The First Stack of Block Diagram of PART2.VI

- ❑ In STEP1 of case structure, the VI program reads physical input excitation and output response signals and compute FRF and display it.
- ❑ MATLAB script was used to divide the signals for the given FRF parameters (block size i.e. window size).



STEP2-The Second Stack of Block Diagram of PART2.VI

- ❑ In STEP2 of case structure, the VI program reads the peak value which is typed in by the user.
- ❑ MATLAB was used to calculate the damping factor based on the input.
- ❑ Half-power method was implemented in the MATLAB script to compute the damping factor.

9

References

References

- Roy R. Craig, Jr. and Andrew J. Kurdila, "Fundamentals of Structural Dynamics", 2nd Ed. Wiley