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Automated impact device with non-synchronous impacts: a practical solution for modal testing during operation

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Key word: Auto impact device; Frequency response function; Impact-synchronous time averaging; Manual impact hammer; Phase synchronization

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Impact-Synchronous Modal Analysis (ISMA)

- Allows analysis to be performed during operation like Operational Modal Analysis (OMA)
- Information of input forces in the transfer functions is available
- Integrated with Impact-Synchronous Time Averaging technique prior to performing the Fast Fourier Transformation (FFT) operation
- Use the modal extraction techniques commonly used in Experimental Modal Analysis (EMA)
- Current device using manual impact hammer

Rahman AGA, Ong ZC and Ismail Z. (2011) Effectiveness of Impact-Synchronous Time Averaging in determination of dynamic characteristics of a rotor dynamic system. Measurement 44: 34-45.

Rahman AGA, Ong ZC and Ismail Z. (2011) Enhancement of coherence functions using time signals in Modal Analysis. Measurement 44: 2112-2123.

Rahman, A. G. A., et al. (2013). Impact-Synchronous Modal Analysis (ISMA)- An Attempt to Find an Alternative. Paper presented at the 5th International Operational Modal Analysis Conference, Guimarães - Portugal.

Problem Statement

- Lack of control of the distribution of the phase angle of the disturbance at the impact instances has limited the effectiveness of ISMA, i.e., the harmonic could potentially have the same phase angle in different time blocks

- Simulation and experimental studies showed that the effectiveness of ISMA is enhanced when the phases of the impacts are not synchronized with the phase of the periodic response of the cyclic load

- Avoiding the phase synchronization effect is rarely achievable with the current manual impact hammer due to the lack of control on the impact timing

Ong ZC, Lim HC, Khoo SY, et al., 2017. Assessment of the phase synchronization effect in modal testing during operation. Journal of Zhejiang University-Science A (Applied Physics & Engineering), 18(2):92-105.

Control of auto impact device

Parameters for generating non-synchronous impacts

- frequency (f) or period (T) of the square wave
- sampling rate (SR)
- block size (BS)
- duty cycle (DC)
- time of response block (t_{block})
- number of cycles in a time block (n)
- length of time for active pulse (t_{pulse})
- time difference (Δt)
- number of blocks for active pulse (N)
- solenoid 'ON' time (t_{on})
- impact interval (T_{impact})
- impact frequency (f_{impact})

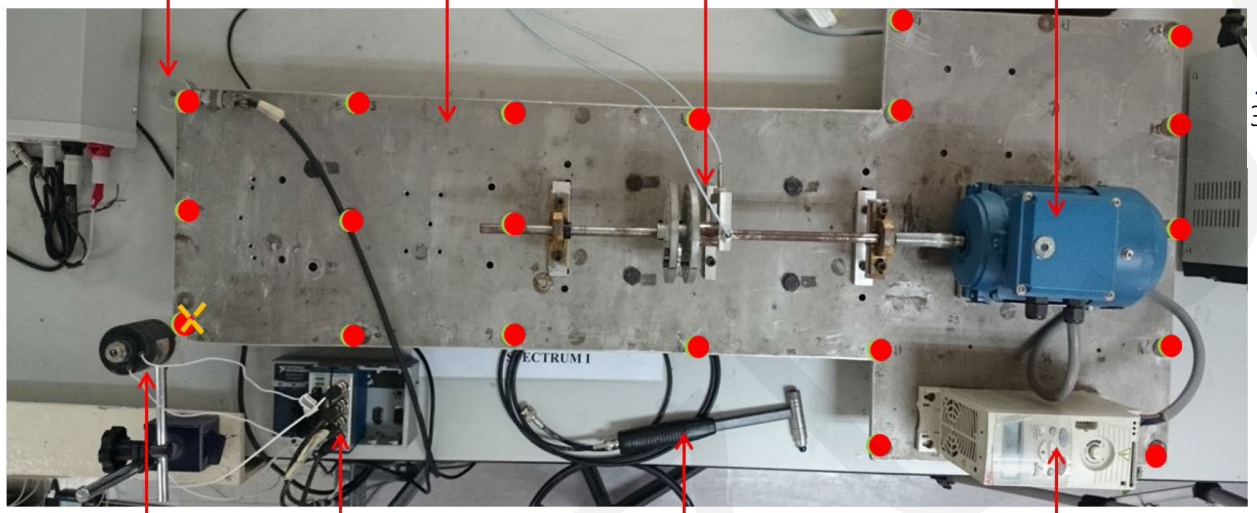
$$T_{\text{impact}} = [\frac{T}{\Delta t}] \bullet t_{\text{block}}$$

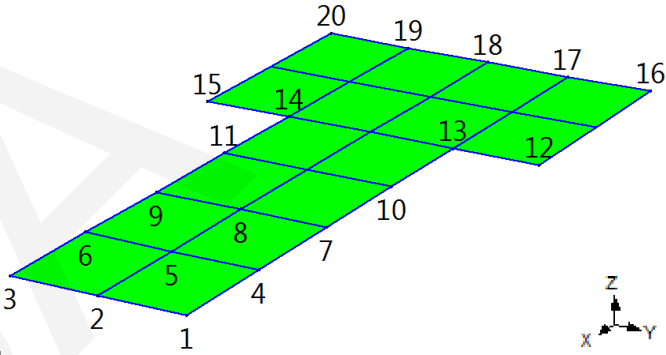
$$f_{\text{impact}} = \frac{1}{T_{\text{impact}}}$$

*The parameters to be manipulated to get different impact profiles are the BS, SR, DC and f or T of square wave

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Methodology





- Sampling rate = 2048 samples/sec
- Block size = 4096
- Motor frequency = 20 Hz
- Number of averages = 20
- Roving accelerometer approach
- Fixed excitation at Point 1

Methodology

Random impacts excitation, $T_{random\ impact}$

$$T_{random\ impact} = \frac{1}{f_{multiple}} + (pseudo\ random\ number \times \frac{1}{f_{cyclic\ load}})$$

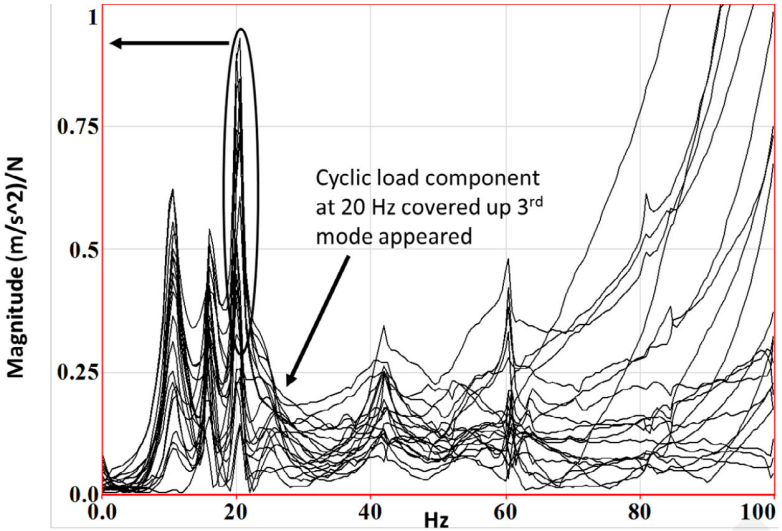
$f_{multiple}$= multiple of cyclic load frequency
$f_{cyclic\ load}$= cyclic load frequency

Non-synchronous impact excitation

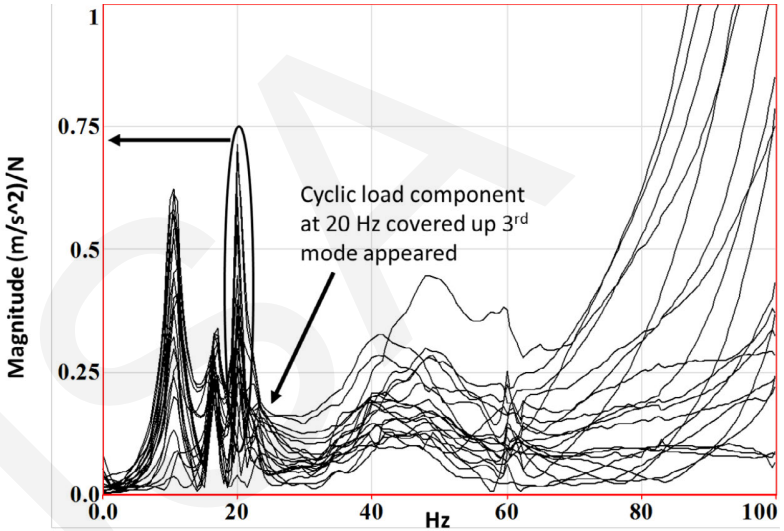
Input signal to DAQ	Sampling Rate (SR): 50,000 samples/s
	Block Size (BS): 1024 samples
	Duty Cycle (DS): 0.5%
	Frequency (*f*): 97.78 Hz
Output response of auto impact device	Impact interval = 0.1239 Hz

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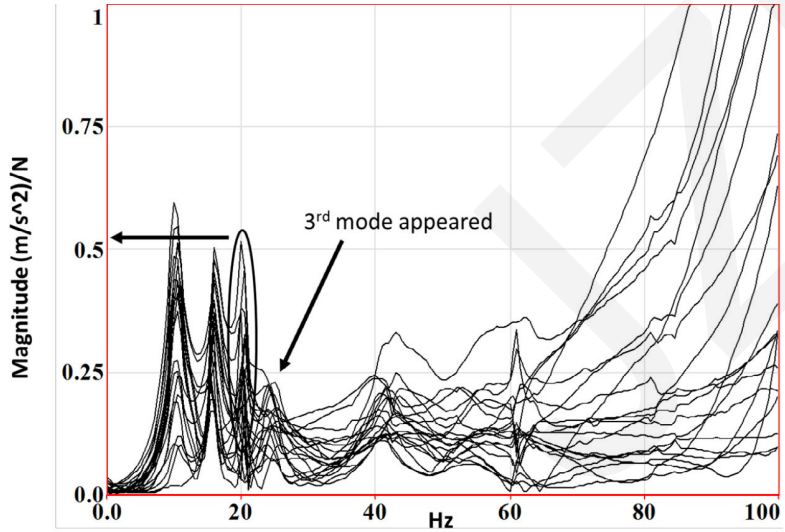
Results (FRFs Estimation)



Manual impact hammer



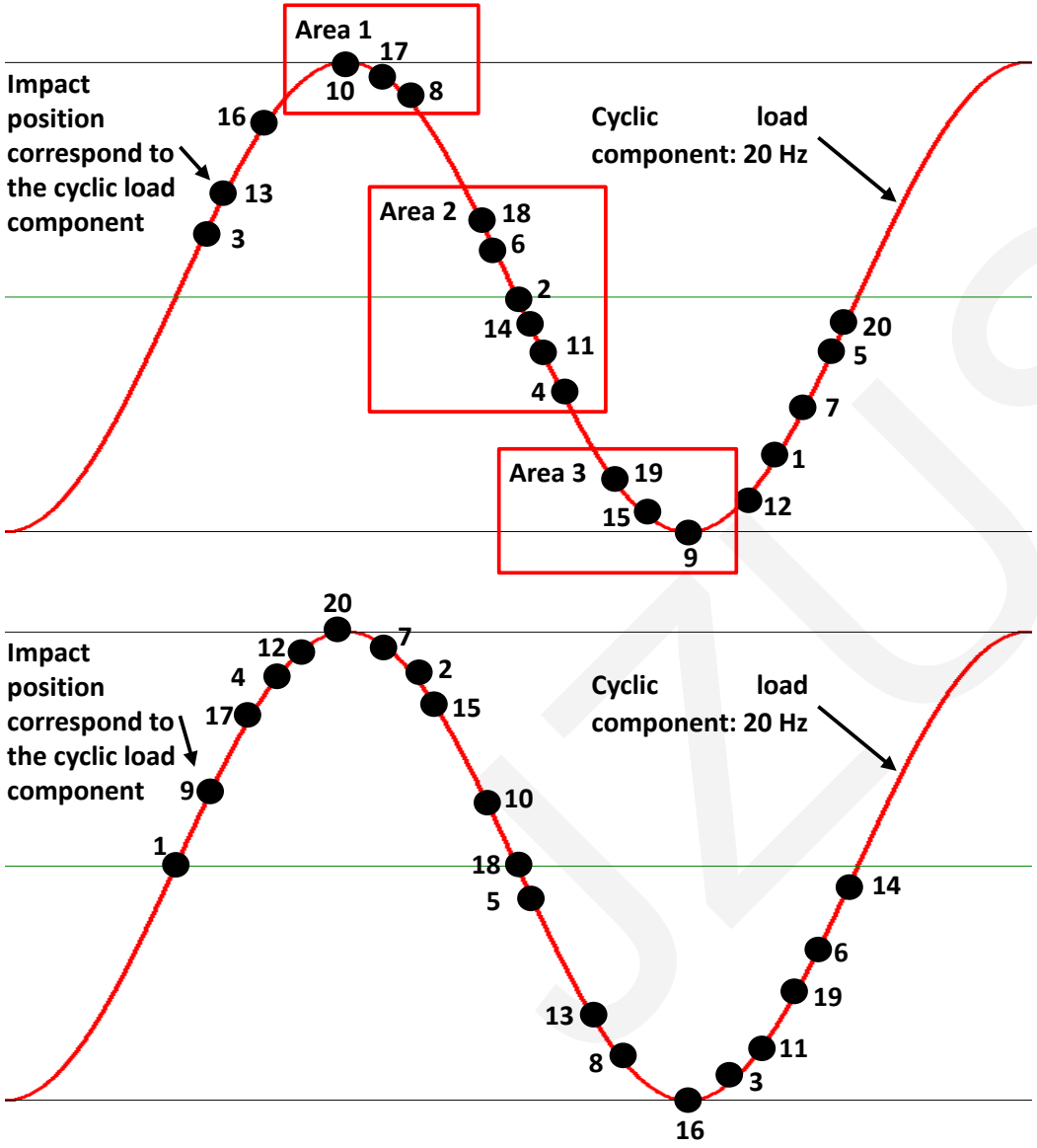
Auto impact device with random impacts



Auto impact device with non-synchronous impacts

- A significant decrease of the cyclic load component at 20 Hz, of 45 % compared to using a manual impact hammer, is observed
- Third natural mode appeared for FRFs estimation using auto impact device with non-synchronous impacts

Results (FRFs Estimation)



Auto impact device with random impacts

20 impacts applied at each measurement point tend to be concentrated or closely spaced within certain areas and not equally distributed

Auto impact device with non-synchronous impacts

20 impacts applied at each measurement point are equally over the periodic response from cyclic load

Results (Modal Parameters)

Benchmark measurement without the harmonic (BM)
ISTA using manual impact hammer (A)
ISTA using auto impact device with random impacts (B)
ISTA using auto impact device with non-synchronous impacts (C)

	Natural frequency (Hz)				Percentage of difference (%)			MAC		
Mode	BM	A	B	C	BM vs. A	BM vs. B	BM vs. C	BM vs. A	BM vs. B	BM vs. C
1	10.4	10.5	10.5	10.4	1.0	1.0	0.0	0.922	0.899	0.925
2	15.9	15.9	16.5	15.8	0.0	3.77	0.6	0.892	0.890	0.893
3	24.0	N/A	N/A	24.4	N/A	N/A	1.67	N/A	N/A	0.902

	Damping ratio				Percentage of difference (%)		
Mode	BM	A	B	C	BM vs. A	BM vs. B	BM vs. C
1	0.0832	0.0949	0.0935	0.0933	14.06	12.38	12.14
2	0.0448	0.0436	0.0499	0.044	2.68	11.38	1.79
3	0.0566	N/A	N/A	0.0495	N/A	N/A	12.54

In general, ISTA using auto impact device with non-synchronous impacts

- Percentage difference for natural frequency and damping ratio is the lowest
- MAC values for all natural modes are the highest

Conclusions

- First three natural modes are successfully determined for ISTA using using auto impact device with non-synchronous impacts

- All three modes achieve good correlation with benchmark EMA results with relatively low percentage of difference in natural frequency, of less than 2 %, 2 %-13 % in damping ratio, and MAC values between 0.89-0.92

Therefore, an auto impact device which applies non-synchronous impacts with respect to the phase of the harmonic disturbance is a viable option instead of a manual impact hammer to enhance the FRF estimation and modal extraction data