The Basic Physics of a Shake Table

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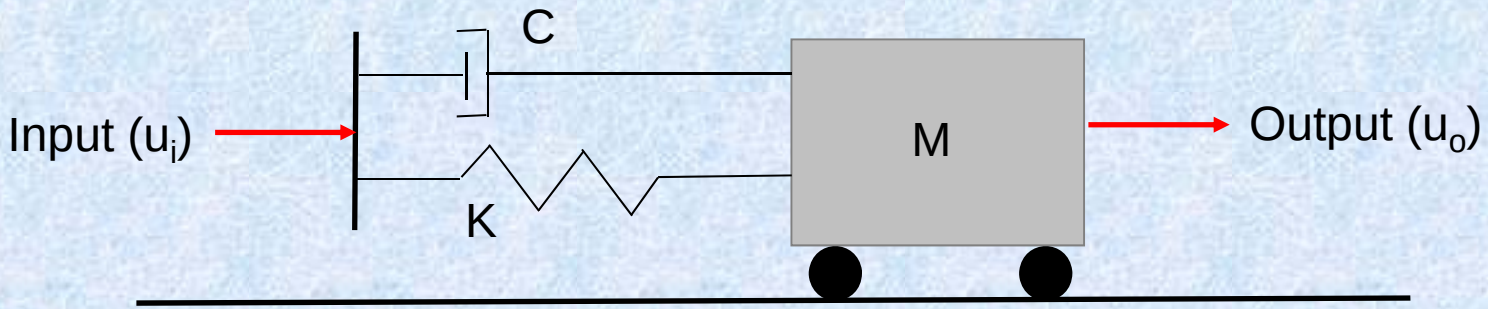
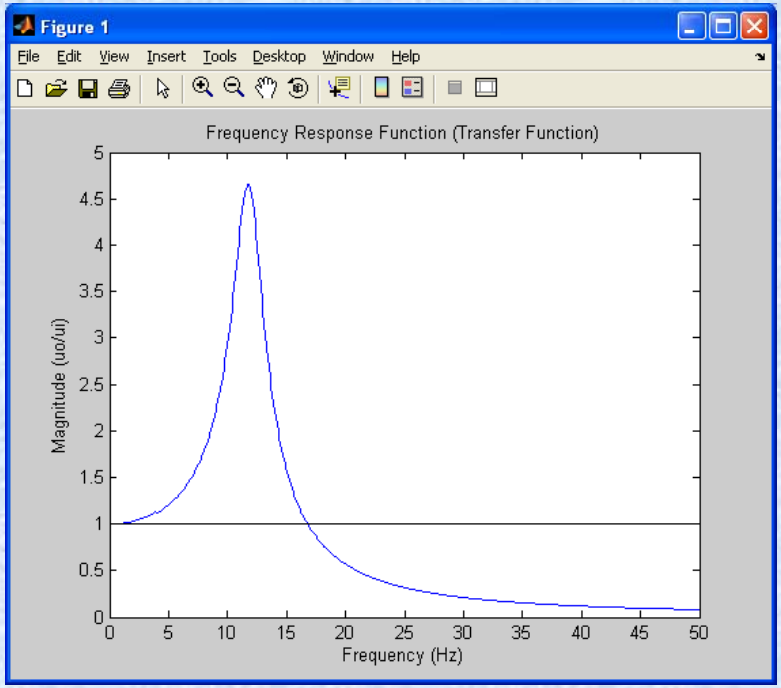
The classic spring-mass-damper



1. Apply a constant amplitude input (u_i open loop) at varying frequencies.
2. Measure the output (u_o) at each input frequency
3. Plot (u_o/u_i versus frequency)



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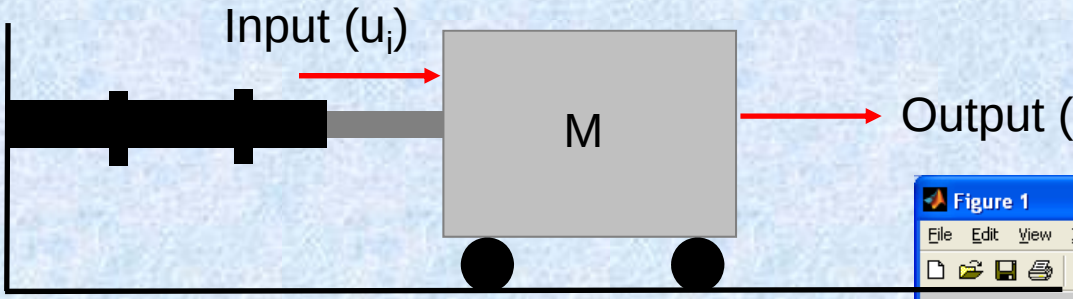
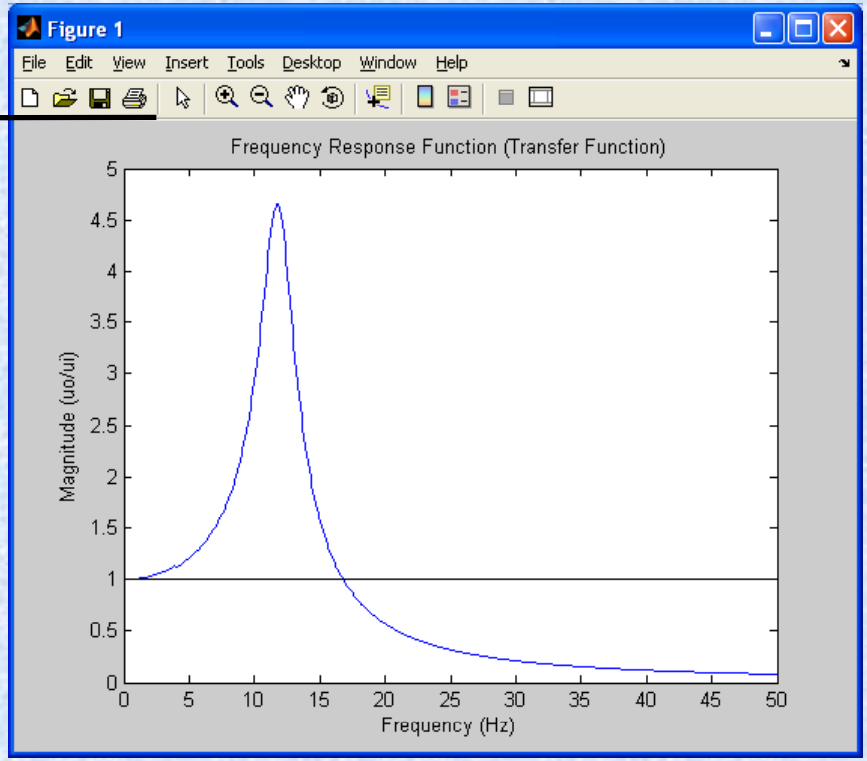
Replace spring/damper with an actuator



1. K is the “oil column stiffness”
2. C is the actuator damping
3. M is the table mass
4. Plot (u_o/u_i versus frequency)



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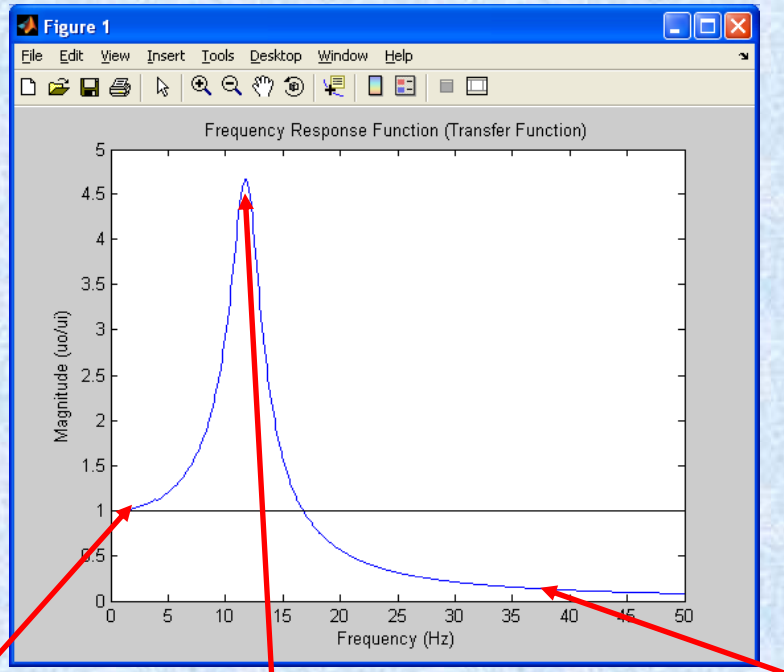
What can we infer from this plot?



Output = Input

Good!

Output >> Input

Not Good!

Output << Input

Not Good!

But I'm running Open Loop

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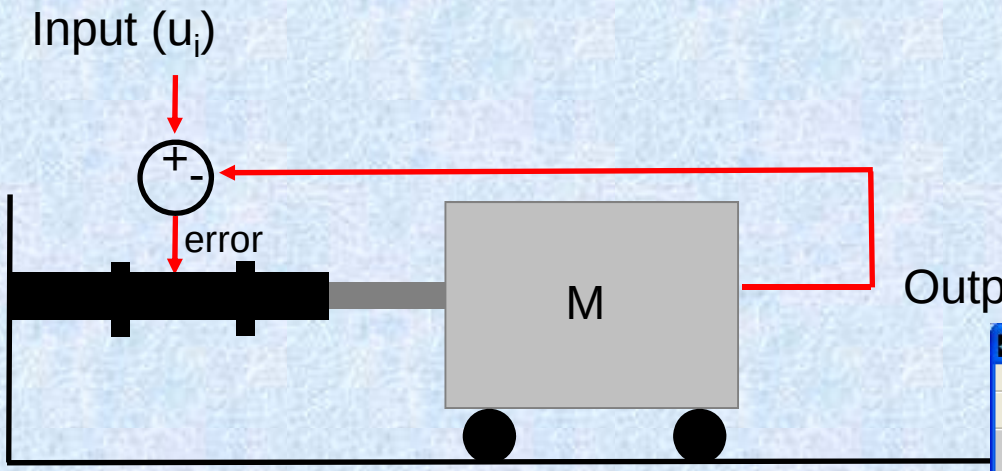
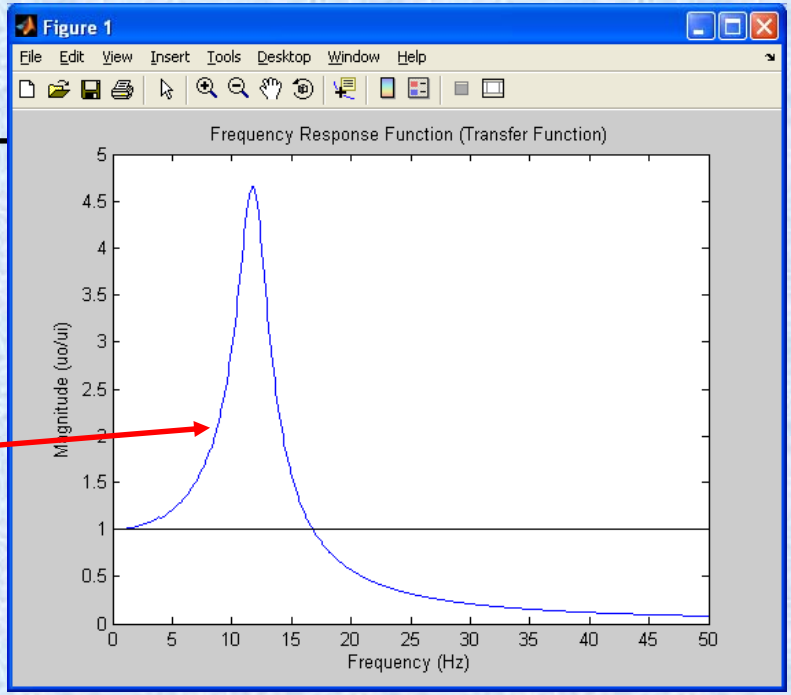
Let's run in Closed Loop



But I still get this response

Why?



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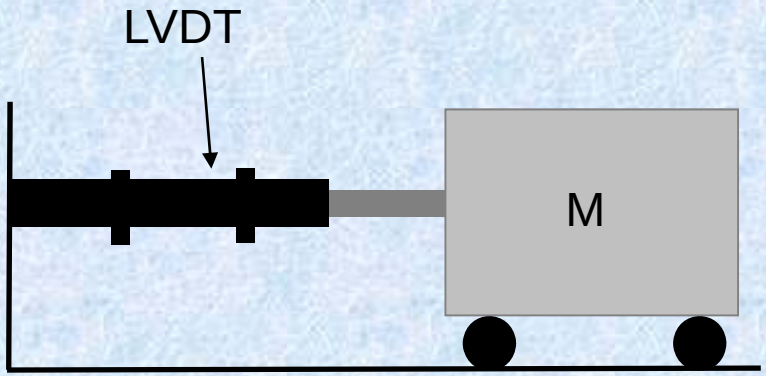
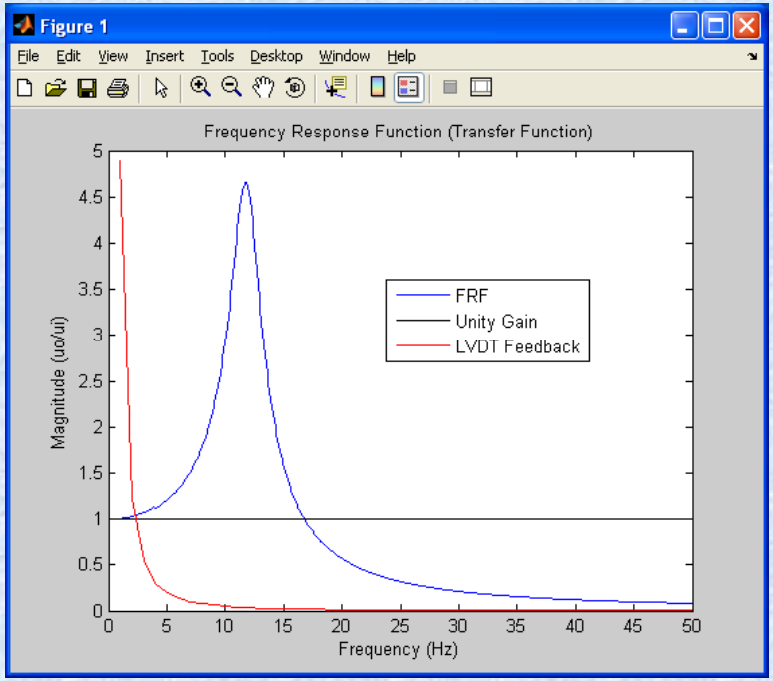
One reason: look at Act. LVDT





1. Apply a constant “0.5 g” sine wave at various frequencies
2. Measure table displacement
3. Remember, we are still closing the loop with displacement
4. Conclusion: LVDT feedback is very small at higher frequencies.

Other reasons: delay, phase, velocity feedback

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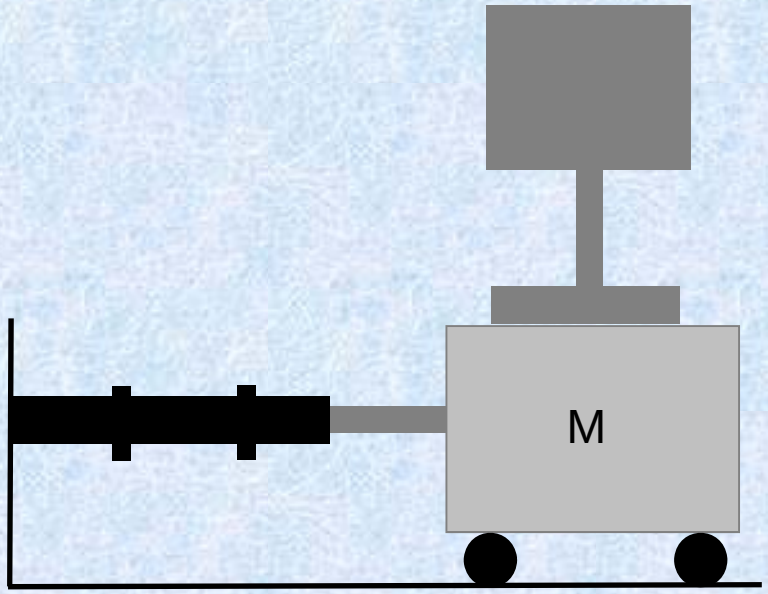
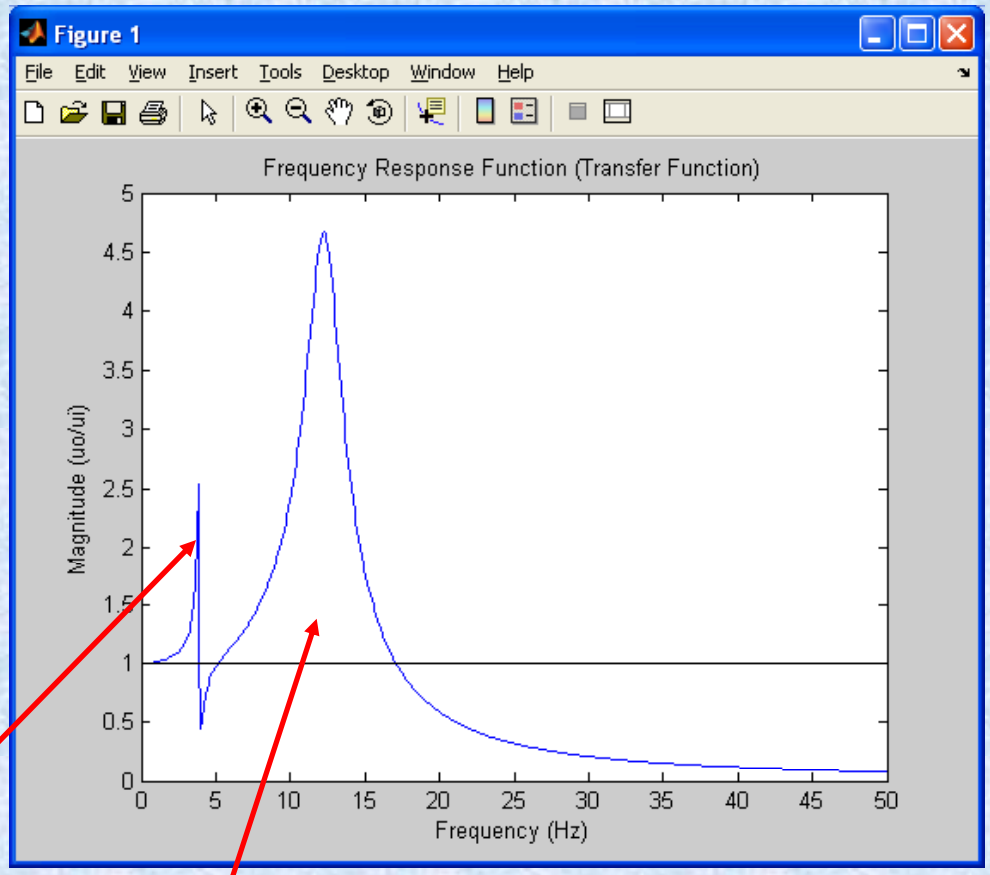
Now add a specimen on the table





Specimen

Oil Column

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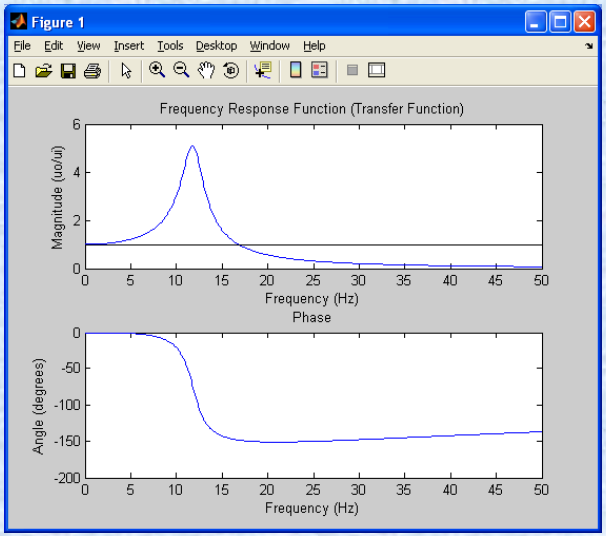
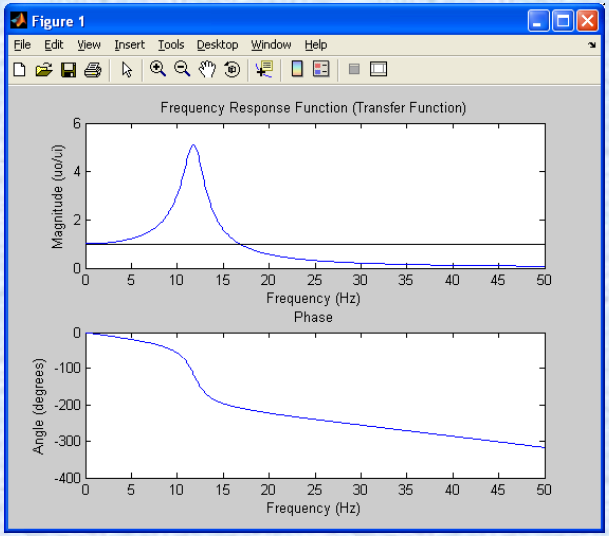
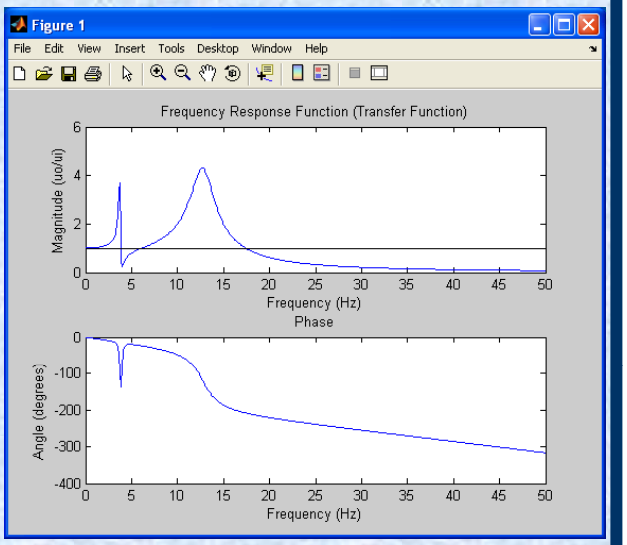
What about delay (phase)?



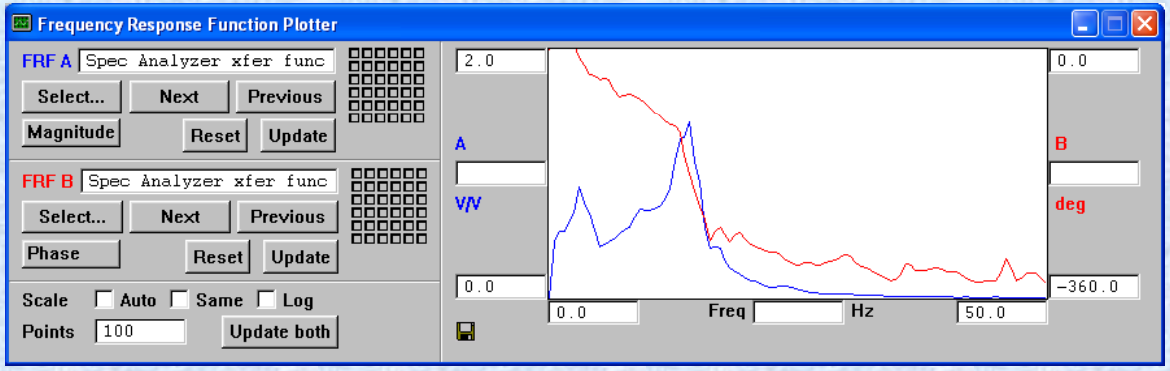
Open loop



Closed loop phase



Closed loop phase with specimen



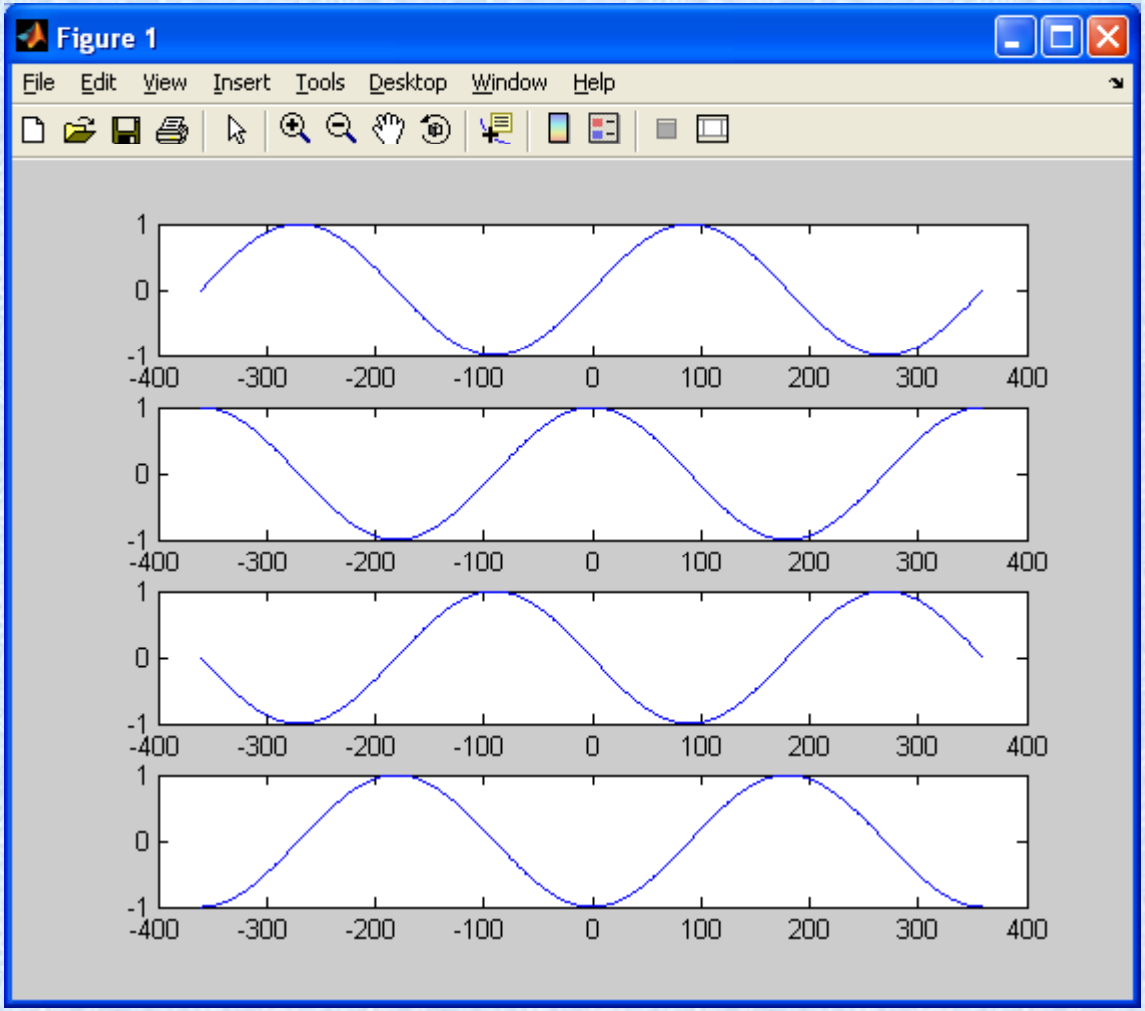
What can we do?

Displacement (D)

Velocity (V) = $d_t(D)$

Acceleration (A) = $d_t(V)$

Jerk (J) = $d_t(A)$



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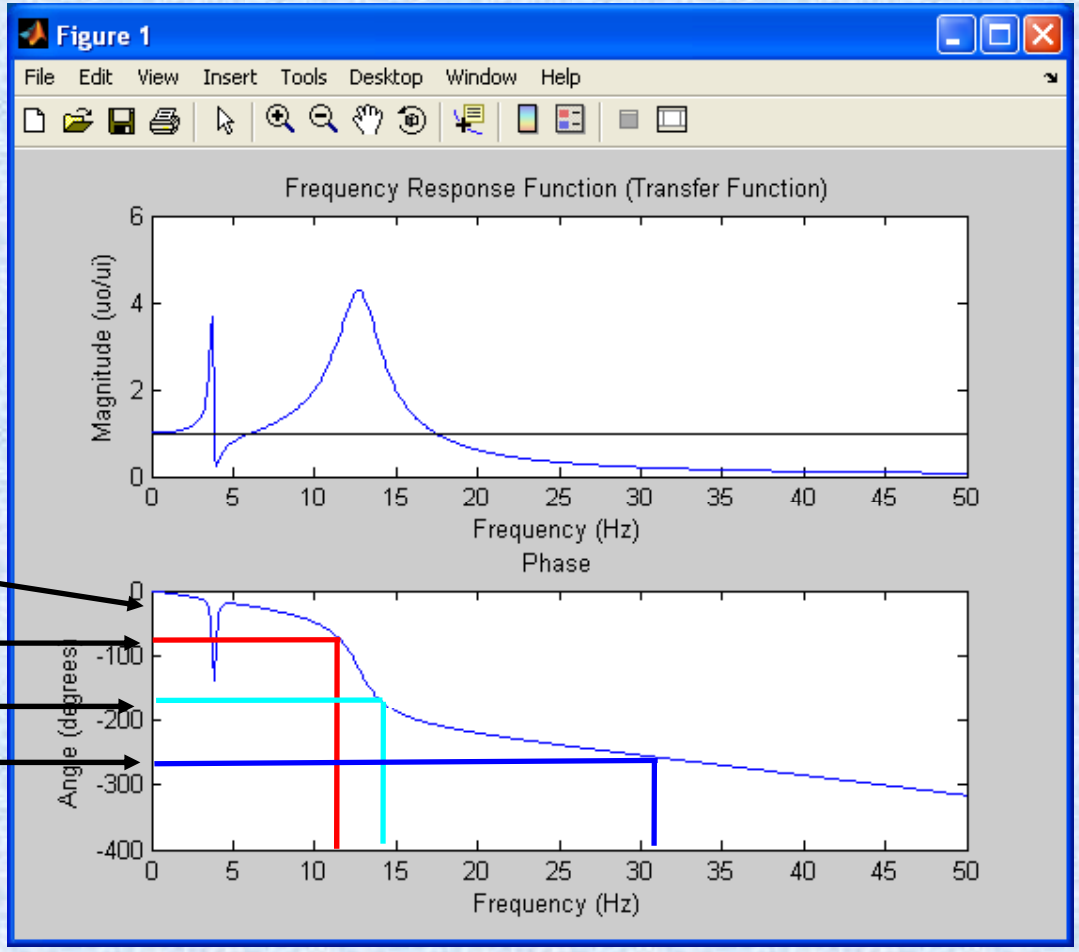
Feed Forward (Lead Terms)…



Displacement

Velocity

Acceleration

Jerk

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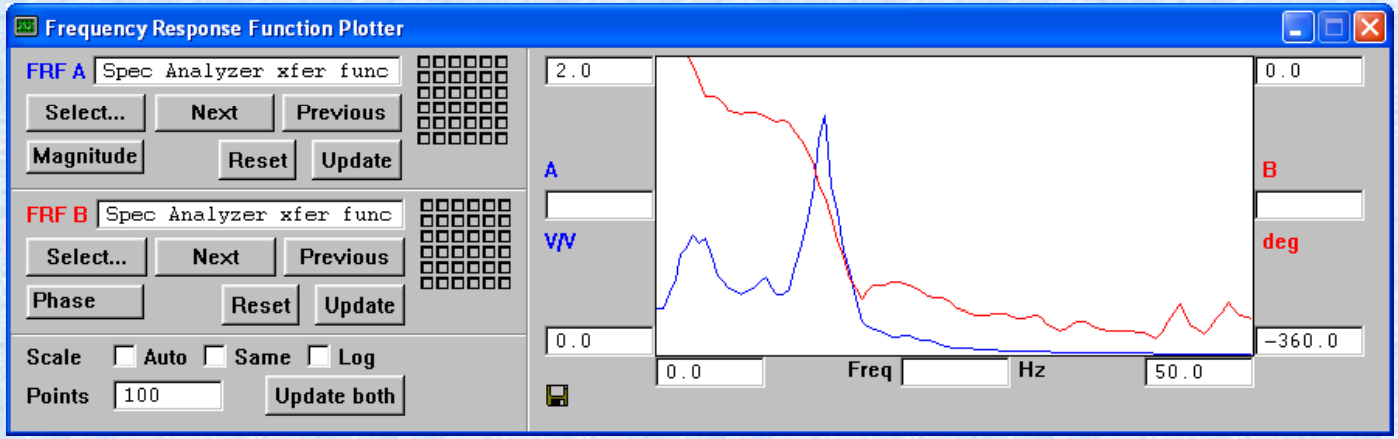
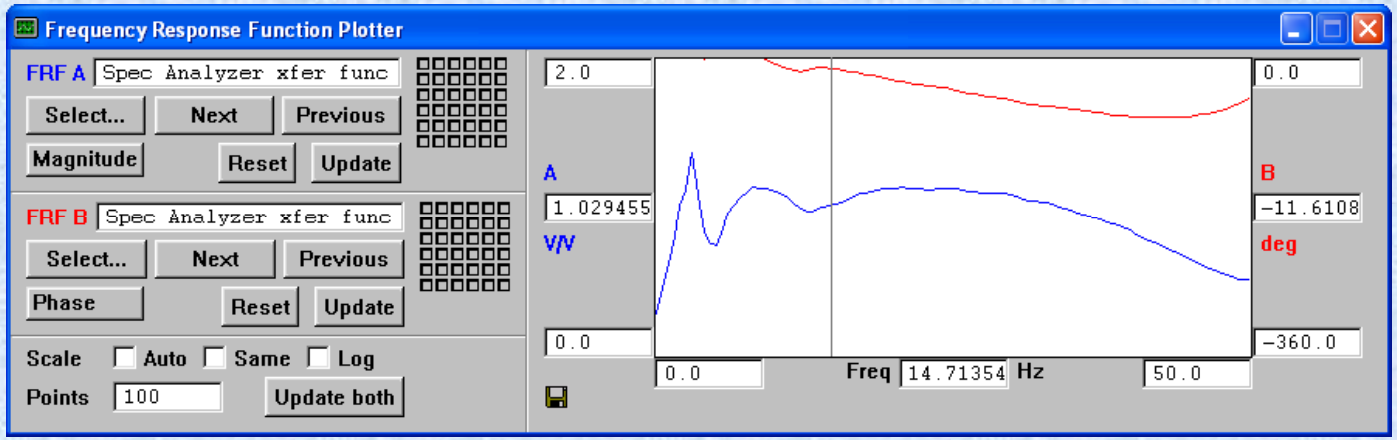
Results…



No forward terms



With forward terms

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But…

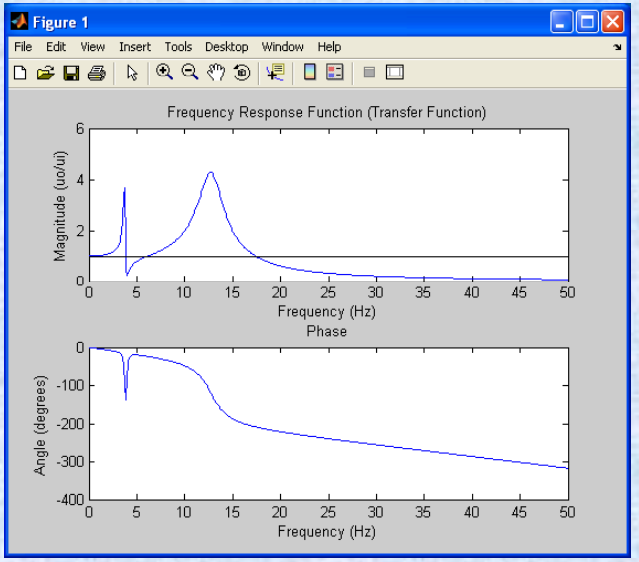
1. Forward Terms are NOT feedback terms
2. Phase and Gain problems still exist for **specimens** above and below oil-column frequency and the oil column itself

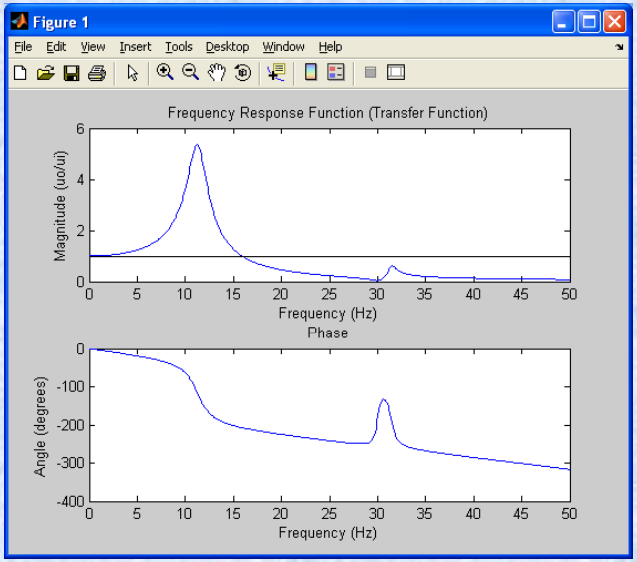
•We can adequately deal with specimens below oil column using notch filters (beware non-linear specimens) and compensation.

•Specimens above oil column are difficult due to phase matching and low system gain

•Oil column can be dealt with using delta-p stabilization

•Why are they called Seismic Tables and not Vibration Tables?





So how do we get D, V, A, and J?

Seismologist

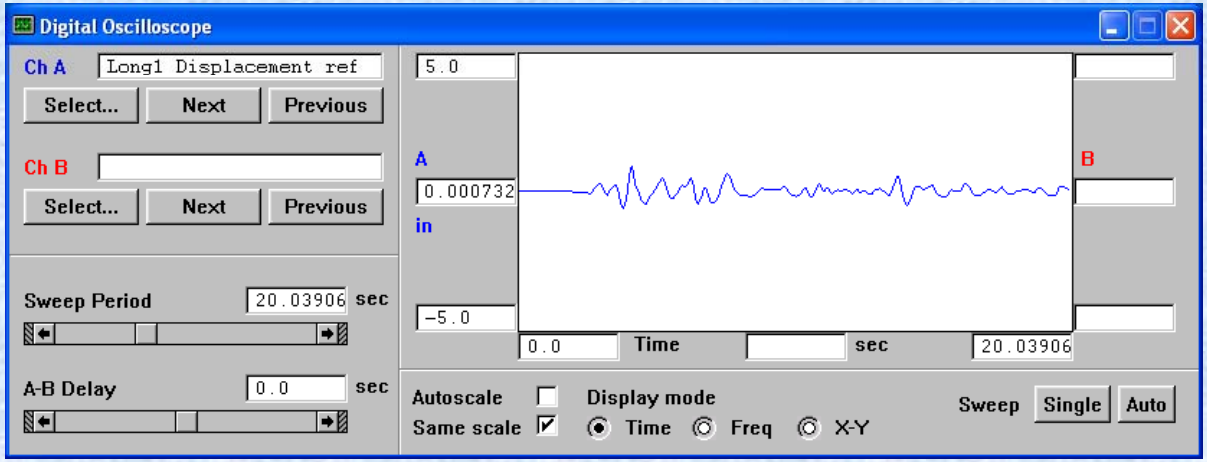
1. Records A from accelerometer
2. Pre-filter padding
3. Filtering
4. Integration
5. Baseline correction
6. Post filtering
7. “Experience”
8. Repeat?

Shake Table (reference generator)

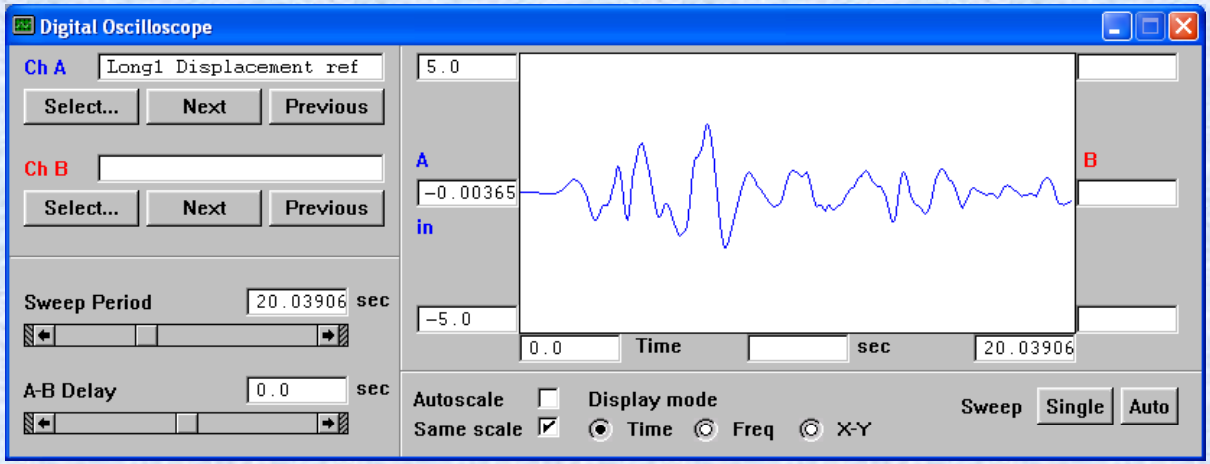
1. Gets A from student
2. High-pass filter
3. Integrate for V and D and differentiate for J



High Pass Filter
Calulate Displacement from Acceleration



Filter cut-in = 1Hz



Filter cut-in = 0.1Hz

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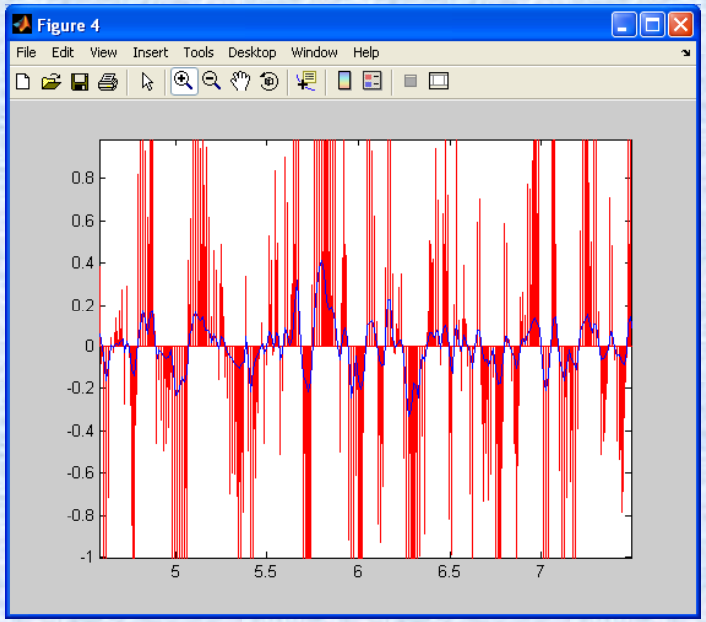
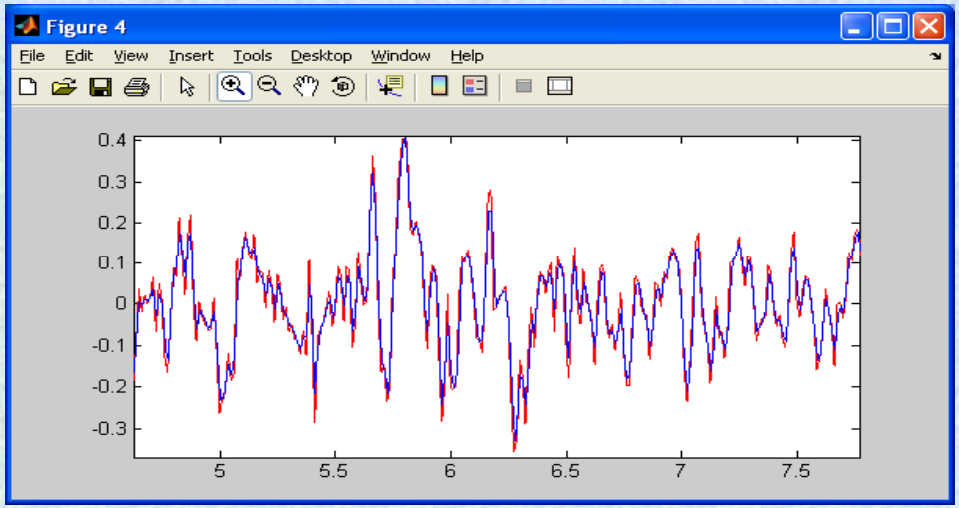
Differentiate Displacement to get Acceleration



Unconditioned

Conditioned



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Conclusions:

1. Shake tables and specimens can at a minimum be described by spring-mass dampers
2. Delay (phase) is partly from the shake table and partly from the controller-actuator-instrument control loop.
3. Delay (phase) can be dealt with up to a point
4. We haven't talked about
    1. Dealing with specimen resonance
    2. Shake table non-linearities
    3. External disturbances (coherence)
    4. Friction
    5. Mechanical resonances (bowstring)
    6. Multiple Tables (Multiple Tables with Actuators)

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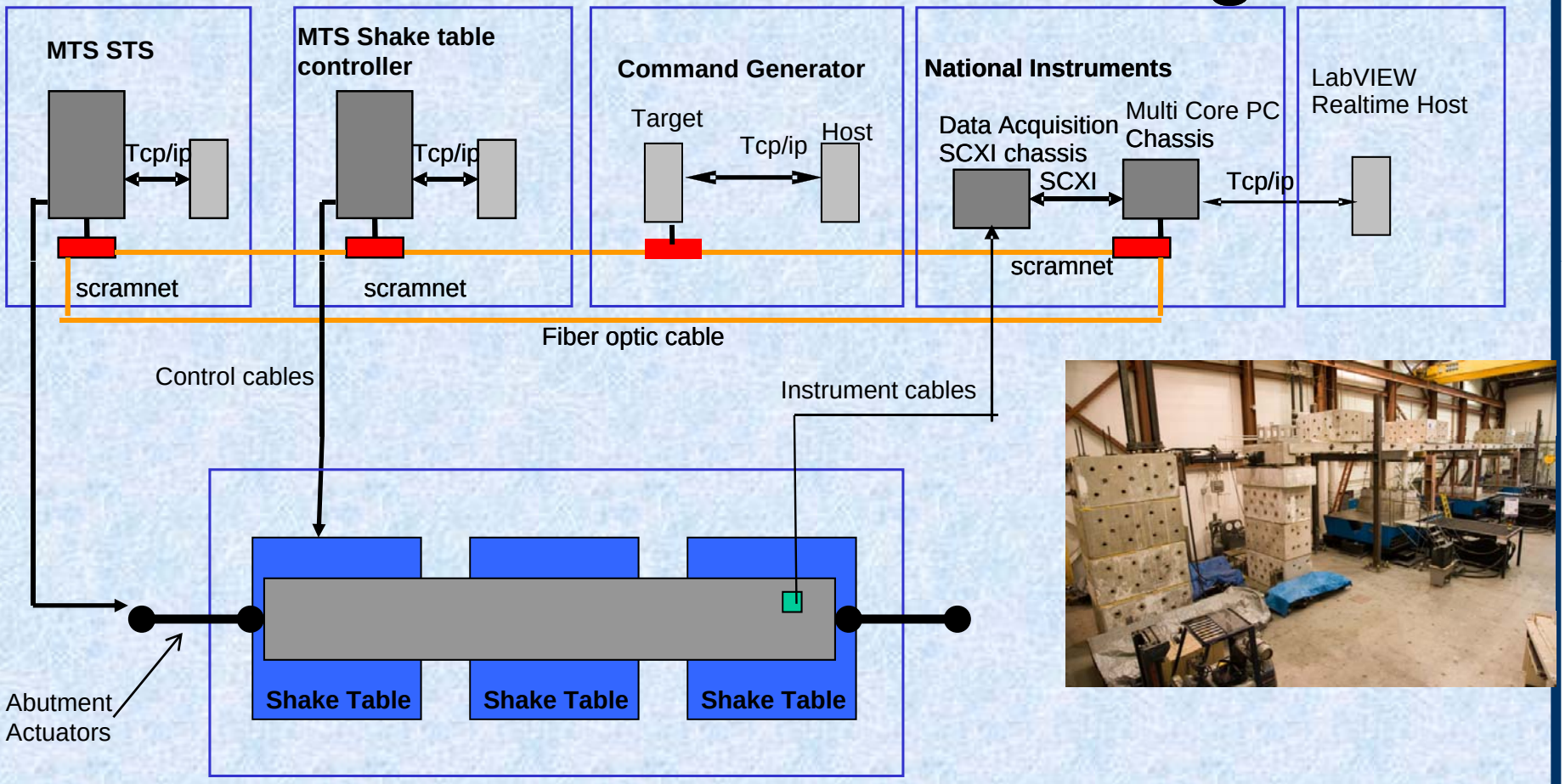
Please remember

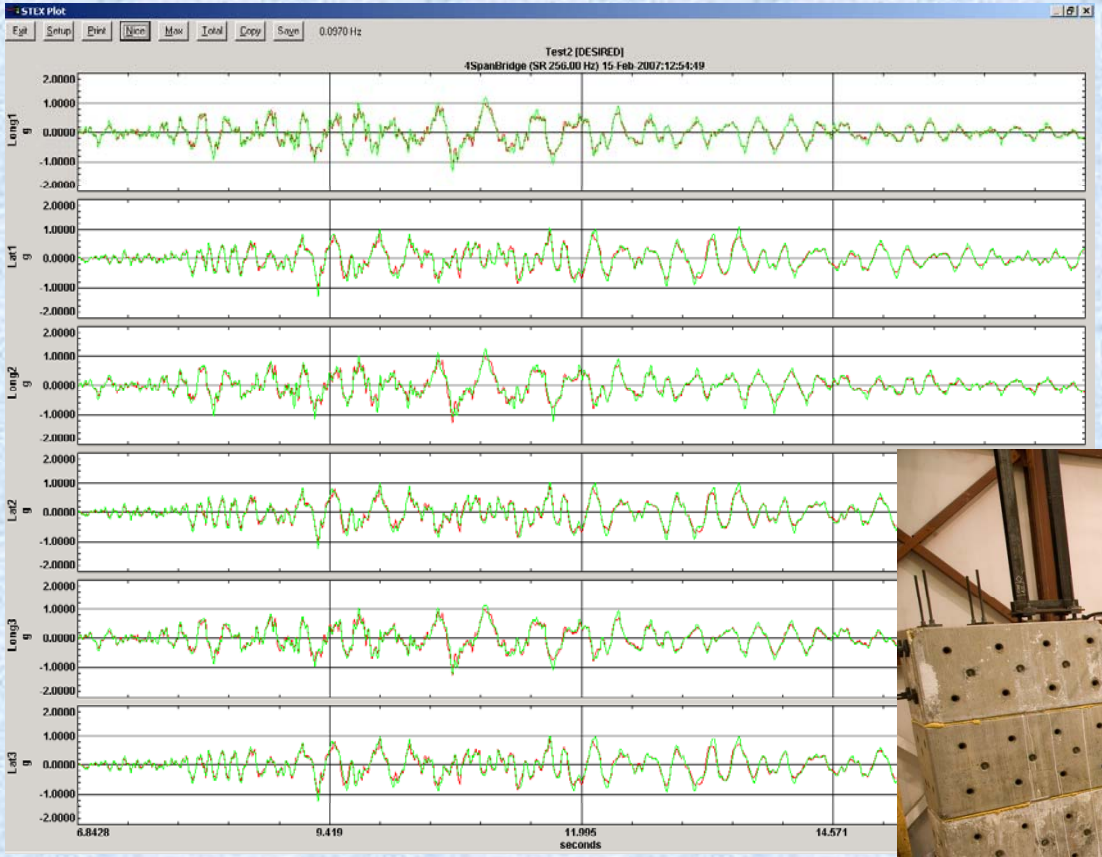
1. Every Shake Table performs differently
2. Every system has its limitations
3. We have a set of tools, and each test requires a different combination of these tools
4. There is no magic control algorithm that will solve all these challenges (MRAC, MCS, MFAC each work on a small subset of control problems)



3 UNR 4-span bridges
3 different control strategies



Thank you!



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