University of New Hampshire
Department of Mechanical Engineering

ME 747 – Lab # 3
(29 Sept 2017)

Velocity and Position Sensors: LVT and LVDT Characterization, Parameter Identification

Purpose:

In this lab, you will use a position and velocity transducer to investigate the properties of a distributed parameter mass-spring-damper system.

A linear velocity transducer (LVT) produces a voltage proportional to the velocity of a permanent magnet core moving through a coil. The linear variable differential transformer (LVDT) produces a sine wave whose amplitude varies proportionally with the location of an iron core between its primary and secondary windings. The frequency of the sine wave depends on the frequency of the excitation signal. Further information by the manufacturer of the model E-500 LVDT you are using in lab is provided at the end of this document.

Note: Numbered questions are lab work, lettered questions are for the write-up. You should make sure that you have all necessary data to answer these questions.

1 Linear Velocity Transducer (LVT)

1. The LVT setup consists of the LVT core shaft, a weight, and the LVT cylinder. Sketch the setup. Note that this is a self-generating device that needs no power. The shaft, with the weight, has a mass of 75 grams.

2. Place a piece of foam under the core shaft of the LVT. Release the shaft, recording the height it is dropped (between 1-2 in), allowing it to oscillate ***on the foam*** (try not to bounce the shaft off the foam). Observe the oscillation on the scope, using the trigger position on the scope to obtain the complete output response. Sketch and save this data. Remember that the output curve is a voltage representing velocity and not position.

a) Plot the LVT output voltage vs. time curve.

b) From your observations of the LVT output voltage curve, describe the motion of the mass:
   i) during free fall
   ii) during initial impact with the foam
   iii) as it bounces off the foam

c) Describe the physical significance of:
   i) the first three zero crossings of your LVT output voltage
   ii) the first minimum and maximum voltage points

d) According to your free response curve, at approximately what time does the mass stop bouncing off the foam and remain in contact with the foam?

e) From the initial slope of the curve, given that the acceleration due to gravity is 386 in/sec^2, determine the sensitivity of the LVT, $e_o/\dot{x}$, volts/(in/sec).

f) Using the LVT output, and its sensitivity, make a plot of the core velocity (in/sec) and position (in) versus time.

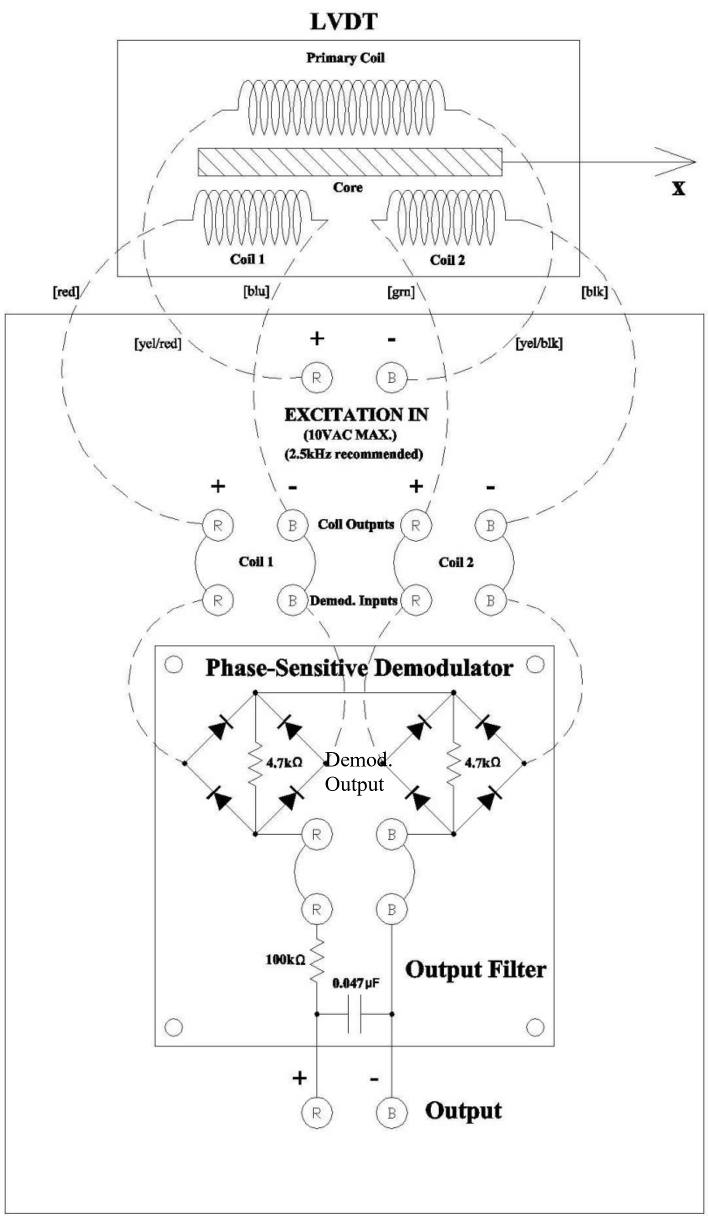
g) Determine the following parameters for the foam-mass system:
   i) damping ratio ζ, ii) damped natural frequency ω_d (rad/sec), iii) spring constant k (lb_f/in)

h) What is the average force of impact on the foam when the shaft just hits the foam?

2 Linear Variable Differential Transformer (LVDT)

2.1 LVDT Characteristics

A circuit diagram for the LVDT system and set up is shown in the figure below. This schematic also incorporates a full-wave demodulation circuit and a low pass filter.



The LVDT setup consists of a spring-beam and mass attached to the iron core of the LVDT. Manufacturers specifications (attached, for E500 series) state that the LVDT excitations signal (sine wave) should be at a frequency of 2.5kHz. The outputs available are ± Coil 1 and ± Coil 2.

1. Sketch the LVDT setup and all connections. Use the function generator to create a 6V amplitude (12V p-p) sine wave with a frequency of 2.5 kHz. Connect this signal to the LVDT input labeled EXCITATION IN, and check the signal amplitude with the scope.

2. Connect the coil 1 output of your LVDT to scope channel 0 and coil 2 to scope channel 1. Displace the LVDT core and observe both coil outputs at the following core positions: i) above null, ii) below null, and iii) at null. Do NOT displace the LVDT core more than 1/4" in either direction! (Note that exact core displacements need not be measured at this time.) Sketch and save/export your results (in an Excel file) for all three plots.

3. Increase the input voltage to an amplitude of ± 10V (20V p-p) at 2.5kHz (check amplitude with scope). To better understand the LVDT output, a full wave phase-sensitive demodulator is implemented (shown in LVDT diagram). Using this circuit, it is possible to determine if the core is moving in a positive displacement region or a negative displacement region. A low-pass filter, also shown in the LVDT figure, can be used across the output of the demodulated signal to filter out the high frequency carrier and obtain a signal proportional to displacement.

4. Connect the output of the filter (FILTERED OUTPUT) to scope channel 0. Connect the output of the demodulator circuit ("Demod. Output", prior to the low pass filter) to scope channel 1. Displace the core in both positive and negative directions, sketching and saving the demodulated and filtered data for each direction. Also observe and sketch the output signals when the core is at null (or in the null region). Now, displace and release the beam and observe both output signals as the beam vibrates.

5. Observe and sketch the scope frequency plot of the demodulated signal (channel 1) with the beam not moving. Using FREQ at the top of the scope screen, set the number of data points to 75K (use HORZ button), the time scale to 0.5 sec, and the frequency scale to 4.9 – 5.1 kHz (use FFT config at the top of screen).

6. Observe and sketch the scope frequency plot of the demodulated signal (channel 1) with the beam moving. Keep the same FREQ setup as in 5. Now, start a single time trace and deflect (and release) the beam so it can vibrate. Sketch the frequency plot of the beam vibrating, making sure you indicate the dominant signal frequencies.

a) Plot and describe the output of coil 1 and coil 2 (before and after amplitude modulation) as the displacement of the core varies.

b) Plot and describe your observations of the output voltage after amplitude demodulation, but before the filter.

c) Plot and describe your observations of the output signal with the filter.

2.2 LVDT System Calibration

1. Weigh the plastic bucket which will be used to hold weights for calibration.

2. Connect the filtered LVDT output to the NI oscilloscope. Calibrate the LVDT by hanging the plastic bucket and placing various weights (up to 500g) in the bucket and recording the corresponding LVDT outputs from the filter.

3. Remove the bucket and all weights. Calibrate the LVDT again, inputting varying deflections of the beam (up to the same limit of deflection as obtained with the weights) with the micrometer set up, and measuring the corresponding LVDT outputs from the filter. Be sure that the micrometer is directly centered on the beam and over the LVDT rod during this calibration.

4. With the micrometer out of the way, deflect the beam a small amount and release it, capturing the response on the scope. Make sure you record enough data to be able to calculate the parameters of an under-damped second order response. Sketch and save this data.

a) Plot LVDT output voltage vs. weight. Plot LVDT output voltage vs. displacement. Comment on the linearity of the curves and the range of linearity of the LVDT.

b) Determine the beam spring constant k.

c) Determine the LVDT system sensitivity in V/in.

d) Find the damping ratio ζ, the damped natural frequency ω_d , and the undamped natural frequency ω_n of the first mode of vibration (part 4).

e) Find the effective mass M of the system (part 4).

f) Using Matlab, make a Bode plot of the first order filter used on the output of the LVDT signal. Does this filter have any effect on the LVDT output for the given mass-damper-spring system? Explain.

2.3 LVDT Frequency Response

1. Use the Lab View Signal Express (LV-SE) to obtain a Bode plot of $E_o(j\omega)/E_i(j\omega)$ for the LVDT (See the attached document Mike Deleon 10/23/14). Sketch the experimental frequency response and note the bandwidth and amplitude ratios/slopes. Save/export your data (in Excel).

a) Use the experimental Bode plot to find (approximate) the two break point frequencies. Recall that a model of the LVDT (homework 4) yielded the following transfer function.

$$\frac{E_{o\,(j\omega)}}{E_i(j\omega)} = \frac{2\,R_m\,K_m\,x\,s\,/\,((R_m+\;2R_s)R_p)}{\left(\frac{L_p}{R_p}\,s+1\right)\,(\frac{2L_o}{R_m\,+\,2\,R_s}s\;+\;1)}$$

b) Using the break frequencies from a) and the above transfer function, find the inductances L_p and L_0. Use the spec sheet for the E-500 LVDT for resistance values. Assume the measurement resistance is a mega ohm. What is the usable bandwidth of the LVDT based on your experimental Bode plot?

c) For the flat (usable) portion of the Bode plot, what is the theoretical sensitivity of the LVDT (give a symbolic expression)? Using this expression and your experimental Bode plot, assuming that x=0.1 in, find the gain term K_m.

d) Use Matlab to make a theoretical Bode plot of $E_o(j\omega)/E_i(j\omega)$ using the transfer function derived from the homework problem, and the values of L_p, L_0, and K_m found in parts b) and c). Assume x=0.1 in.

e) Compare the experimental and theoretical frequency responses.

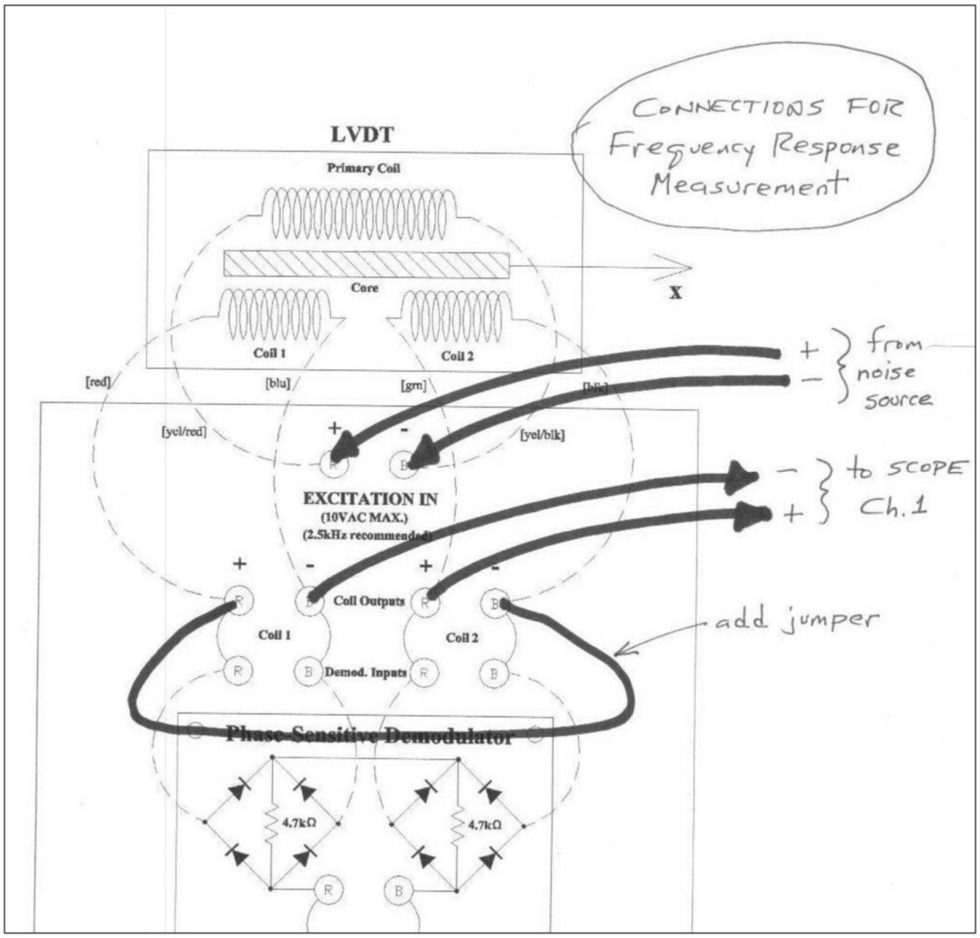
f) Filtering can cause problems in accuracy of the output signal when the core is moving. Why or why not?

g) Discuss the effect of lowering the excitation frequency to the LVDT. Use the Bode plots to draw conclusions.

LabView Signal Express (LV-SE) for LVDT

M.H. deLeon, (Oct 23, 2014

For Part 2.3:



LVDT Lab Set Up for Frequency Response

1. Exit the the ScopeSoft program, turn off the function generator (FGEN), and open LV- SE template file "Lab06_FreqResp_DAQnn " in the "LabViewSE Templates" folder on the desktop, where nn corresponds to your DAQ and NI frame number. Refer to the figure above and the description below for setting up the wiring.

2. Connect the DAQ output channel ao0 (noise source) from DAQ pins 12 (+) and 14 (-) to the LVDT primary coil input ("EXCITATION IN"). Also use a BNC tee connector to monitor this signal in Ch.0 of the 'Scope digitizer.

3. Connect a banana jumper from the Coil 1 (+) output to the Coil 2 (-) output. Connect a banana jumper from the Coil 1 (-) output AND the Coil 2 (+) output, via a BNC adapter, to Ch.1 of the 'Scope digitizer. Pay careful attention to polarity.

4. 5. Use the micrometer to displace the core (beam) down by approx. 1/8in (0.10-0.12in) and set it there. Click on the "Run" button in LV-SE to initiate the frequency response measurement. LV-SE will execute a number of averaging cycles and generate frequency response plots. When it stops, hit "Stop".

Technical Paper

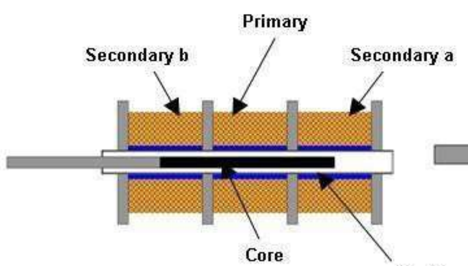
The LVDT: construction and principle of operation

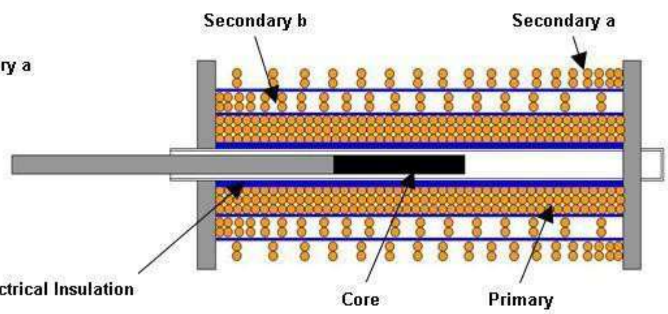
Introduction

An LVDT, or *Linear Variable Differential Transformer*, is an absolute displacement transducer that converts a linear displacement or position from a mechanical reference (or *zero*) into a proportional electrical signal containing phase (for direction) and amplitude information (for distance). The LVDT operation does not require electrical contact between the moving part (probe or core rod assembly) and the transformer, but rather relies on electromagnetic coupling; this and the fact that they operate without any built-in electronic circuitry are the primary reasons why LVDTs have been widely used in applications where long life and high reliability under severe environments are a required, such Military/Aerospace applications.

Construction

The LVDT consists of a primary coil (of magnet wire) wound over the whole length of a non-ferromagnetic bore liner (or spool tube) or a cylindrical, non-conductive material (usually a plastic or ceramic material) coil form or bobbin. Two secondary coils are wound on top of the primary coil for “long stroke” LVDTs (i.e. for actuator main RAM) or each side of the primary coil for “Short stroke” LVDTs (i.e. for electro-hydraulic servo-valve or EHSV). The two secondary windings are typically connected in “opposite series” (Differential). A ferromagnetic core, which length is a fraction of the coil assembly length, magnetically couples the primary to the secondary winding turns that are located along the length of the core.





LVDT cross-section, short stroke

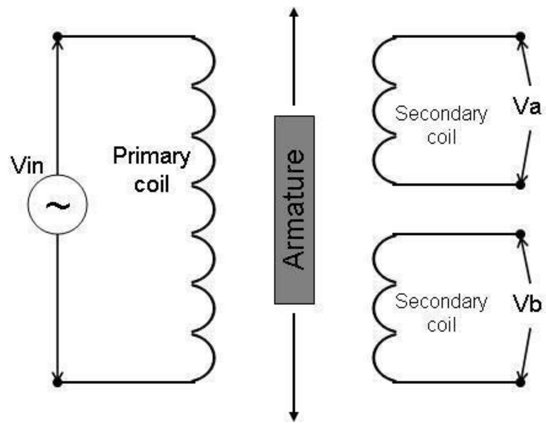
LVDT cross-section, long stroke

Even though the secondary windings of the long stroke LVDT are shown on top of each other, with insulation between them, on the above cross section, Measurement Specialties actually winds them both at the same time using custom designed, dual carriage computerized winding machines. This method saves manufacturing time and also creates secondary windings with symmetrical capacitance distribution and therefore allows meeting customer specifications more easily.

Principles of operation

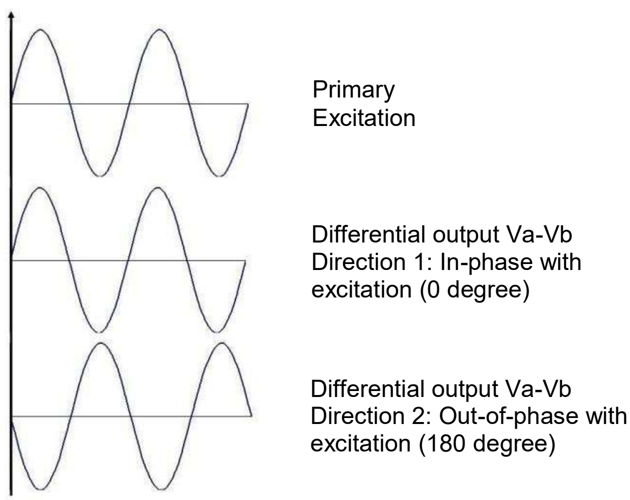
When the primary coil is excited with a sine wave voltage (Vin excitation), it generate a variable magnetic field which, concentrated by the core, induces the secondary sine wave voltages. While the secondary windings are designed so that the differential output voltage (Va-Vb) is proportional to the core position from null, the (Va-Vb) phase shift with reference to the excitation (close to 0 degree or close to 180 degrees depending on the direction) determines the direction away from the mechanical zero position. The zero position, called Null Position, is defined as the core position where the phase angle of the (Va-Vb) differential output is 90 degrees.

The LVDT: construction and principle of operation



LVDT Schematic

The differential output between the two secondary outputs (Va-Vb) when the core is at the mechanical zero (or Null Position) is called the Null Voltage; as the phase angle at null position is 90 degrees, the Null Voltage is a “quadrature” voltage. This residual voltage is due to the complex nature of the LVDT electrical model, which includes the parasitic capacitances of the windings. This complex nature also explains why the phase angle of (Va-Vb) is not exactly 0 degree or 180 degrees when the core is away from the Null Position.



LVDT waveforms

E Series – Economy Series AC LVDT

- **Economical**
- **Stroke ranges from ± 0.1 to ±2 inch**
- **AC operation, 50Hz to 10kHz**
- **Magnetically shielded case**
- **Available with imperial or metric core**

DESCRIPTION

The **E Series** of LVDTs is highly economical, satisfying numerous applications in which LVDT performance and reliability are desired, but where budgets are limited. With a linearity of just ±0.5% of full range (E 2000, ±1.0%), the E Series is suitable for most applications with moderate operating temperature environments. Housed in magnetic stainless steel for protection against electromagnetic and electrostatic interference, the E Series rugged construction is capable of resisting the shock and vibration of most industrial applications.

Like in most of our LVDTs, the E Series windings are vacuum impregnated with a specially formulated, high temperature, flexible resin, and the coil assembly is potted inside its housing with a two-component epoxy. This provides excellent protection against hostile environments such as high humidity, vibration and shock.

Measurement Specialties, Inc. (NASDAQ MEAS) offers many other types of sensors and signal conditioners. Data sheets can be downloaded from our web site at: http://www.meas-spec.com/datasheets.aspx

*MEAS acquired Schaevitz Sensors and the **Schaevitz**® trademark in 2000.*

FEATURES

- Customary LVDT performance
- AISI 400 Series stainless steel case
- Imperial or metric core

APPLICATIONS

- General industrial
- Moderate operating temperature environments
- Cost sensitive appli cations

PERFORMANCE SPECIFICATIONS

ELECTRICAL SPECIFICATIONS						
Parameter	**E 100**	**E 200**	**E 300**	**E 500**	**E 1000**	**E 2000**
Stroke range	±0.1 [±2.54]	±0.2 [±5.08]	±0.3 [±7.62]	±0.5 [±12.7]	±1 [±25.4]	±2 [±50.8]
Sensitivity, V/V/inch	2.40	1.57	1.20	0.68	0.76	0.46
Sensitivity, mV/V/mm	94.5	61.8	47.2	26.8	29.9	18.1
Output at stroke ends (*)	240mV/V	314mV/V	360mV/V	340mV/V	760mV/V	920mV/V
Non-linearity (maximum)	±0.5% of FR	±0.5% of FR	±0.5% of FR	±0.5% of FR	±0.5% of FR	±1.0% of FR
Phase shift	-3°	-5°	-8.5°	+6°	+4°	0°
Input impedance (PRI)	660Ω	970Ω	960Ω	408Ω	525Ω	585Ω
Output impedance (SEC)	960Ω	1010Ω	1005Ω	162Ω	690Ω	875Ω
Input voltage & frequency	3 VRMS @ 50Hz to 10kHz, sine wave					
Test input frequency	2.5kHz					
Null voltage (maximum)	1.0% of FSO					