Chapter 9

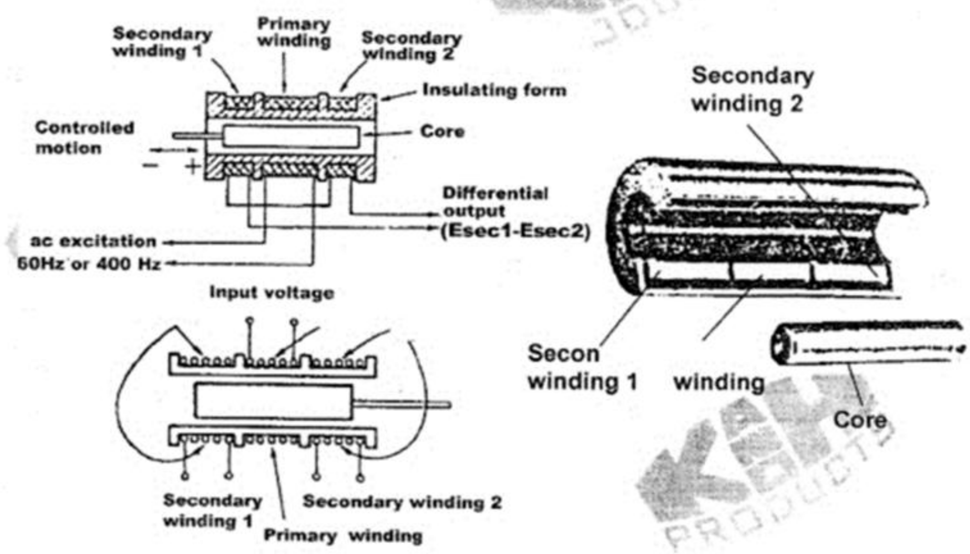
LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

9.1 OBJECTIVES

1. Study the construction of an LVDT.
2. Study the characteristic of an LVDT.
3. Study the signal conditioner for an LVDT.
4. Study the application of an LVDT.

9.2 DISCUSSION OF FUNDAMENTALS

The construction of a typical LVDT (linear variable differential transformer) is illustrated in Figure 9-1. Basically, it consists of a movable ferromagnetic core and three coils. The primary winding and the two secondary windings are wound over a hollow coil form made of a nonmagnetic and insulating material.



(a) construction (b) cross section

Figure 9-1. Construction of a typical LVDT

In most elementary connection, the secondaries are connected together at one of their two terminals as shown in Figure 9-2. When AC excitation is applied to the primary winding, and the core moves within the coil assembly, the coupling between the primary and each of the secondaries changes. As a result, magnitude of the output voltage; and the phase between the secondaries changes.

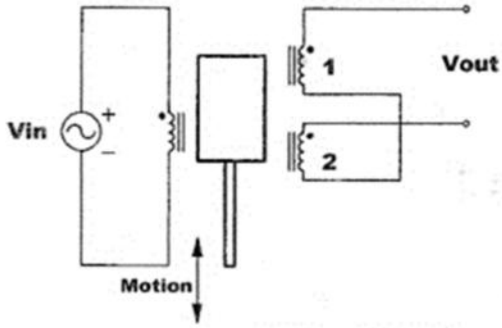
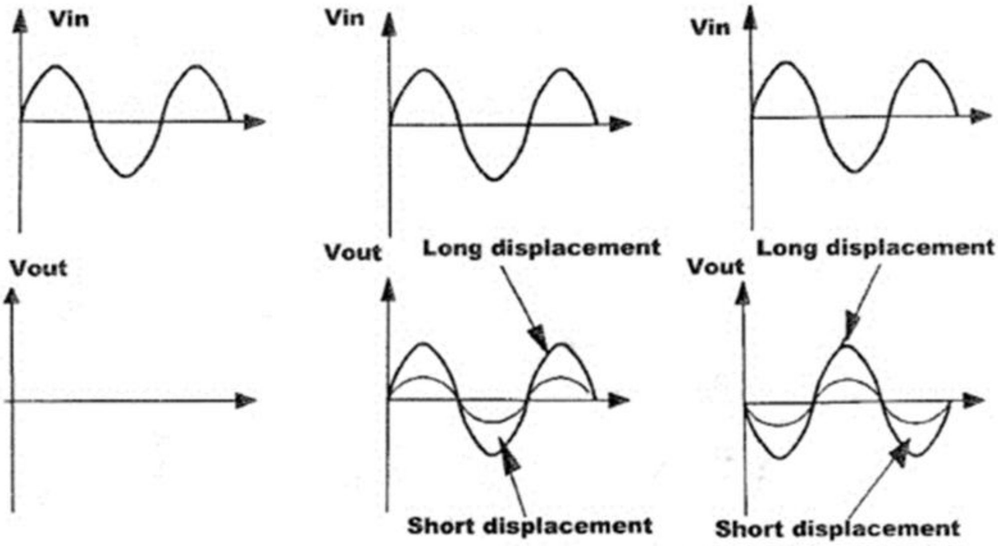


Figure 9-2. Operation of LVDT

If the core at the center, the magnetic flux induced in the secondaries are the same. Thus, the output voltage magnitude is zero as shown in Figure 9-3(a). If the core moves to the left hand in Figure 9-1 (or upward in Figure 9-2), the induced magnetic flux in the secondary winding 1 will be stronger than in the secondary winding 2, the output voltage is not zero and in phase with the input voltage, shown in Figure 9-3(b). Inversely, Figure 9-3(c) shows the output voltage and input voltage out phase by 180 degrees if the core moves to the right hand in Figure 9-1 (or downward in Figure9-2). Therefore, we have had a conclusion that the output voltage magnitude is proportional to the displacement of the core apart from the center, and the polarities are determined by moving directions of the core.



(a) core at center, Vout=0 (b) core move upward, voltages in phase (c) core move downward, voltages out of phase

Figure 9-3. Output voltage and phase

The above three operating situations are illustrated in Figure 9-4.

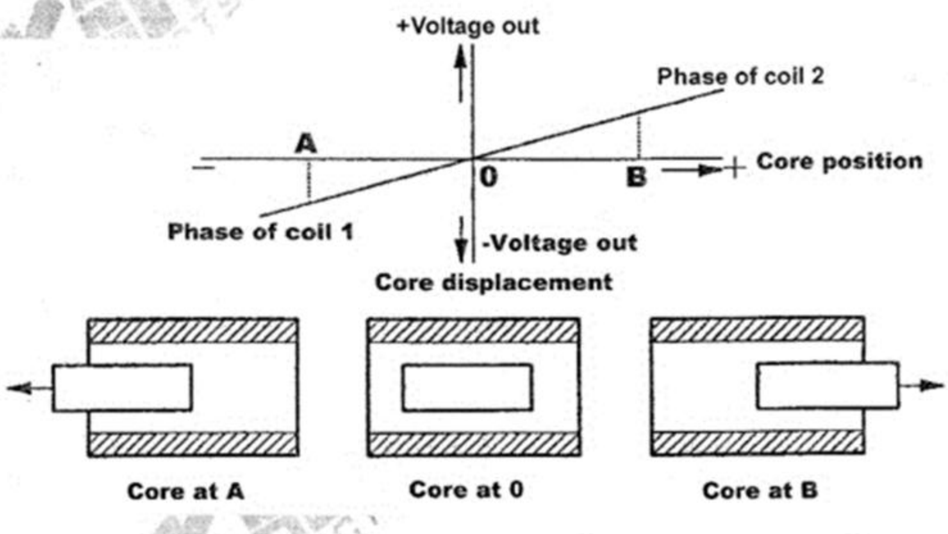


Figure 9-4. Output voltage and phase as a function of LVDT core position

LVDT are widely available in position sensing due to the following features:

1. High linear accuracy: from ±0.1% to ±1%.
2. High sensitivity: 1 mil (1/1000 In) of core displacement can result in voltage variations of anywhere from 10 up to 45mV.
3. Wide load impedance range.
4. High stability at null (center): approximately 1 μm.
5. Wide excitation frequency range: from 50 Hz to 10 KHz.
6. Long operating life: no mechanical contact, no frictional wear.
7. Vibration proof.

The sensitivity of an LVDT is defined as the magnitude of the output voltage when the core displacement is 0.001" for each volt of input voltage (mVout / 0.001" / Vin). Since the sensitivity depends on the operating frequency variation, a nominal frequency is usually marked. The practical output voltage at an LVDT is the product of the sensitivity multiplied by 0.001" and input voltage Vin.

In general, the rating displacement of an LVDT is within ±1". In other words, the core does not move more that 1" away from the center in either directions. In applications where displacement of more than 1" are necessary, mechanical devices such as gears should be added to increase the displacement.

9.3 DESCRIPTION OF EXPERIMENTAL CIRCUITS

The circuit of Figure 9-5 is capable of converting the LVDT displacement into DC output voltages with a transduction ratio of ±1V/mm. The KL-68004 LVDT uses model 225b-125 LVDT, which has a maximum displacement of ±0.125 in (±3mm), AC excitation of 5 Vrms (or 14.14 Vp-p) and the optimum operating frequency of 350 Hz.

OPA U1 and its surrounding elements forms a Wien bridge oscillator circuit to supply a 5 Vrms AC excitation voltage at 350Hz. The oscillating frequency f_O is determined by resistors R1(10KΩ), R2(10KΩ) and capacitors C1(0.047μf), C2(0.047μΩ) using this equation:

$$f_O = 1/2\pi(R1R2C1C2)^{1/2} \equiv 338.6\text{Hz}$$

Resistors R3, R4, R5 and VR1 constitute a negative feedback network which determine conditions for oscillation and the output amplitude. Adjusting the VR1 may change the magnitude of negative feedback, and then change the output amplitude. In Figure 9-5, diodes CR1 and CR2 paralleled with resistor R3 to improve the stability of the output amplitude. Transistors Q1 and Q2 constitute an amplifier for promoting the driver ability.

Two rectifier/filters consist of CR3, C4, R9, CR4, C5 and R10 to convert the secondary AC output voltages V_R and V_F to DC voltages. Voltage followers U2, U3 and U5 are used as buffers. Output voltage of differential amplifier U4 is $V_{K3} = (R13/R11)(V_{K2}-V_{K1})$. The output voltage of this transduction circuit can be set to ±1V/mm by adjusting the potentiometer VR2.

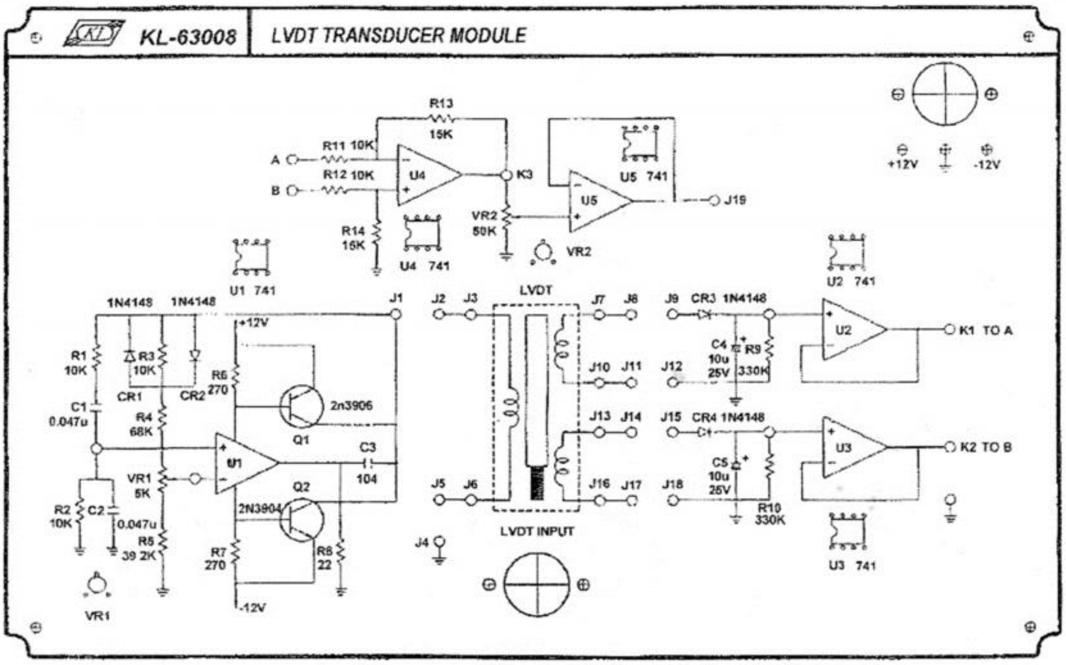


Figure 9-5. LVDT transducer circuit

Figure 9-6 shows a LVDT core direction indicator circuit. LEDs 1 and 2 on the KL-61001 indicates the core position to the right and left of the center, respectively. When the core is to the left of center, potential of V+ will be larger than the V- set by the potentiometer VR, so the comparator output voltage is +Vsat, and LED1 is turned on. Inversely, LED2 is turned on when the core is on the right side of center.

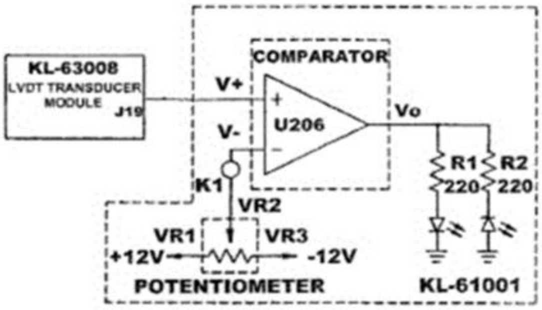


Figure 9-6. Position detector

By connecting modules KL-63008 to the KL-61001 as shown in Figure 9-7, a digital position indicator can be formed. The readout on the digital display indicates core distance away from the center. Since the transduction ratio is $\pm$1V/mm, the A/D converter should be set to its full-scale voltage of 20V, and the RANGE should be set to AUX position, in unit of mm.

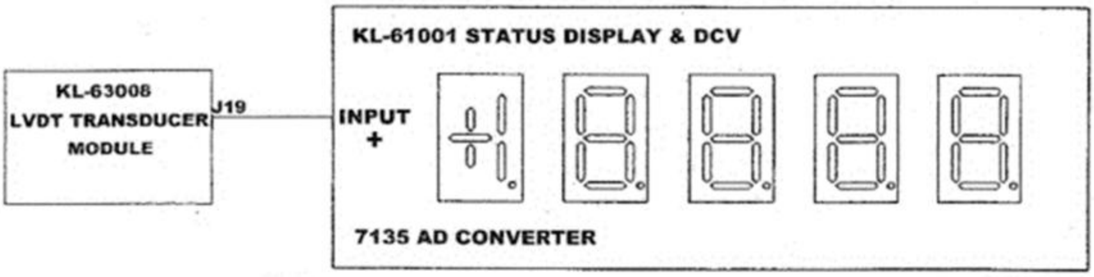


Figure 9-7. Digital position indicator

9.4 EQUIPMENT REQUIRED

1 - KL-61001 Trainer
2 - KL-63008 LVDT Transducer Module
3 - KL-68004 LVDT Load
4 - DMM
5 - Oscilloscope
6 - Resistor, 220 ohms
7 - LED, 3 mm

9.5 EXPERIMENTS AND RECORDS

9.5.1 Characteristic of LVDT

1. Place module KL-63008 on the KL-61001.
2. Connect the LVDT to the input.
3. Connect J1 to J2; J4 to J5; J11 to J12; and J17 to J18. Turn the power.
4. Adjust potentiometer VR1 to set V_{J1} to 5Vrms (or 14.14Vp-p) AC.
5. Connect oscilloscope probe to J8 and J14, adjust the displacement for a minimum available waveform on the scope. Record the position and use it as the LVDT center position.
6. Measure and record voltages V_{J8}, V_{J14}, and $V_{J8\text{-}J14}$ at each displacement on Table 9-1.

Table 9-1

Displacement (mm) / Test points	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5
J_8 (V_{P-P})											
J_{14} (V_{P-P})											
J_8-J_{14} (V_{P-P})											

Notes: + upward
- downward

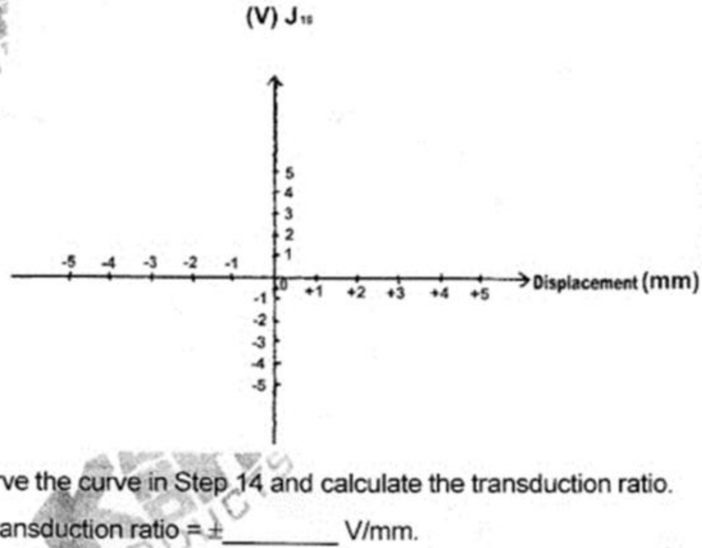
7. The phase difference between VJ8, and the input voltage at J1 is ________.
8. The phase difference between J14 and the input voltage at J1 is ________.
9. Describe the relationship between displacement and the phase difference between VJ8 and VJ14. In other words, how does the phase difference between J8 and J14 change when the displacement is varied?
10. Connect J8 to J9, and J14 to J15,and K1 to A, and K2 to B.
11. Adjust the displacement so that the voltage at J19 is at its minimum(or zero). Record the position indicated and compare it with the center position in Step 5.
12. Adjust the displacement of the platform apart 3mm from the center, and adjust the potentiometer VR2 for the voltage at J19 being 3V.
13. Complete Table 9-2.

Table 9-2

Displacement (mm) / Test points	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5
K_1 (V)											
K_2 (V)											
J_{19} (V)											

Notes: + upward
- downward

14. Plot the displacement vs. voltage curve using datum on Table 9-2.



15. Observe the curve in Step 14 and calculate the transduction ratio.

The transduction ratio = ± ________ V/mm.