NEW CONCEPT FOR ANGULAR POSITION MEASUREMENTS

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INTRODUCTION

Angular position sensing is an essential measurement in control system applications, various industrial applications and physical measurements. The three type of angular sensors available are capacitive, inductive and resistive. Due to non-contact moving behavior of rotary capacitors, capacitive sensors are more popular in position sensing.

Existing measuring methods in both capacitive and inductive sensors use alternating currents to obtain measurements. It requires oscillators to generate AC waves. As a result, measuring methods get complex, are high in cost and more difficult to use.

The purpose of this paper is to introduce a new concept for angular position measurements. This concept focuses on an innovative approach to capacitance measurements, where it can be used in position sensing.

As a replacement for AC currents in conventional systems, charging time of a capacitor under DC current is used as the key variable. This research is carried out to derive a direct proportionality between charging time and the capacitance.

METHODOLOGY

Moving parallel plate type rotary variable capacitor is used as the sensing element. For a variable capacitor, the area of coincided plates is proportional to angle.

$$\text{Capacitance} \propto angle.$$

Charge of a capacitor is given by $Q = CV$. Where Q is charge, C is capacitance and V is voltage. Differentiating both sides with respect to ‘t’ gives equation (1)

$$\frac{dQ}{dt} = C\frac{dV}{dt} \Rightarrow i = C\frac{dV}{dt} \ldots\ldots\ldots\ldots (1)$$

Where ‘i’ is the current through the circuit. Integrating both sides with respect to *t* and making ‘*i*’ constant gives the equation (2)

$$it = VC \ldots\ldots\ldots\ldots (2)$$

If variable taken as capacitance, time taken to charge the capacitor to a fixed voltage is proportional to capacitance. This yields to:

$$t \propto C$$

The capacitor charging circuit can be implemented as shown in Figure 1. The constant current supply is achieved by maintaining the voltage at node A constant.

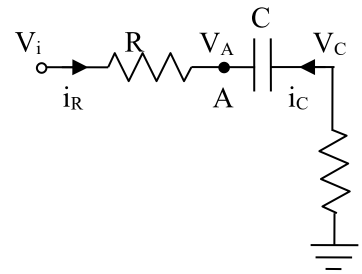

Figure 1: Constant current charging

Applying Kirchhoff's current law to node A gives equation (3)

$$i_R + i_C = 0 \Longrightarrow \frac{(V_{in} - V_A)}{R} + C\frac{d(V_C - V_A)}{dt} = 0 \ldots\ldots\ldots\ldots (3)$$

Integrating both sides with respect to 't' gives equation (4)

$$\frac{(V_{in} - V_A)}{R}t + C(V_C - V_A) = constant \ldots\ldots\ldots\ldots (4)$$

The capacitor is the independent variable and the voltage ($V_C - V_A$) is predefined. Constant is due to the initial charge of the capacitor. This can be ignored if the initial charge is set to zero. Expected relationship can be achieved as given in equation (5).

$$t = \frac{-(V_C - V_A)R}{(V_{in} - V_A)}C \ldots\ldots\ldots\ldots (5)$$

To maintain V_A at a constant value, an operational amplifier configured as an integrator. Figure 2 shows the circuit arrangement. The output voltage is equal to the integration of the input voltage. Considering the op-amp has zero offset at differential inputs and applying Kirchhoff's current law to node A gives,

$$\frac{V_{in}}{R} + C\frac{d(V_{out})}{dt} = 0 \ldots\ldots\ldots\ldots (6)$$

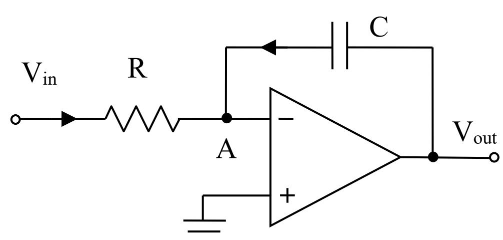

Figure 2: Op-Amp Integrator

Integrating both sides with respect to 't' gives,

$$V_{out} = \frac{-1}{RC}\int V_{in}dt \ldots\ldots\ldots\ldots (7)$$

Since V_i is constant the relationship is achieved as,

$$C = \frac{-V_{in}}{V_{out}}\frac{1}{R}t \ldots\ldots\ldots\ldots (8)$$

The equation (8) verifies conversion of angular position into a time equivalent, prior to start integration.

Prior to starting integration, initial charge of capacitor should be set to zero. Time counter must be started (T_1) to measure the time by applying a fixed known voltage to the input (V_{in}) of the integrator. Time counter value obtained after the output voltage is increased to the predefined voltage (V_R) . Final timer value is proportional to the capacitance. This process is illustrated in figure 3.

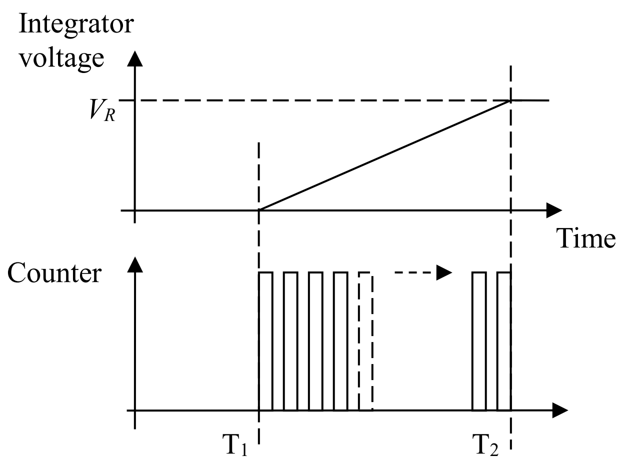

Figure 3: Timing diagram

V_R = Predefined voltage

T_1 = Instance of start of integration

T_2 = Instance of integration stops

$T_2 - T_1$ = Time taken to reach predefined voltage

RESULTS AND DISCUSSION

Practical aspects in capacitance measurements

To set the resolution of the measurement, the maximum measuring time and counter step duration have to be considered.

Maximum measuring time is the time taken to charge the capacitor at which the capacitance is maximum. The equation (9) used to compute the number of counter steps within the maximum measuring time.

$$number\ of\ steps = \frac{maximum\ time\ (s)}{duration\ of\ step\ (s)} \dots\dots\dots\dots (9)$$

The ratio of full angular span divided by the number of steps, gives the resolution of the measurement.

$$resolution^\circ = \frac{full\ span^\circ}{number\ of\ steps} \dots\dots\dots\dots (10)$$

It is clear that duration of counter step limits the number of steps per full span. According to equation (10) the resolution is inversely proportional to the number of steps.

Even though, time measurement is discrete, it is possible to get a voltage equivalent at a predefined time interval. For a short time period, the integrator can get a proportional voltage to the capacitance. This voltage can be used to integrate a 2nd integrator which has a fixed precision resistor and capacitor. A proper combination of capacitor and resistor will produce an acceptable time span for the full resolution needed. In [1] a similar method is shown with only one integrator. Therefore the resistor of integrator affects the integration time and hence the resolution. Another method shown in [2] uses a capacitive controlled oscillator which is also affects the resistor value. Double integrator method used in this research eliminates this resistor issue.

1st Integrator equation $V_1 = \frac{-V_{in}T}{R_1 C_V} \dots\dots\dots\dots (11)$; 'T' is fixed time period

2nd Integrator equation by substituting V_1 as input $V_{out} \frac{=-(-V_{in})T}{R_1 R_2 C_V C_2} t \dots\dots\dots\dots (12)$

Rearranging the equation with $V_{in} = V_{out}$ $t = \frac{R`_1 R_2 C_2}{T} C_V \dots\dots\dots\dots (13)$

'C'$_V$ is the independent variable and '*t* ' is the dependent variable. Hence, the concept is proved theoretically.

According to equation (13) if the sensor is having small capacitance values, the time range will also have smaller quantities. If a fixed capacitor is added in parallel to the variable capacitor the variable range will be shifted up without changing the span of capacitance. Total integration time now has an additional time quantity added by the fixed capacitor. The new configuration is given by equation (14). This is derived from equation (13).

$$\mathbf{C_V + C = \frac{T}{R_i R_I C_I} t \dots\dots\dots\dots (14)}$$

Writing equations for the minimum and maximum capacitances and subtracting 1st equation from 2nd one gives,

$$\mathbf{(C_{Vmax} + C) - (C_{Vmin} + C) = \frac{T}{R_i R_I C_I} t_{max} - \frac{T}{R_i R_I C_I} t_{min}}$$
$$\mathbf{C_{Vmax} - C_{Vmin} = \frac{T}{R_i R_I C_I} (t_{max} - t_{min}) \dots\dots\dots\dots (15)}$$

Referring to equation (15), it can be stated that only the difference of two time limits is required for the measurement. Therefore, minimum time is the starting time of actual time count. As a result, final output can be calculated by subtracting minimum time from counted value.

CONCLUSIONS/RECOMMENDATIONS

Mathematical model of capacitance and time relationship is proved theoretically. It can be used to measure capacitance. It is applicable for capacitive angular position transducers.

The concept is recommended for electronic angle meters.

The variable capacitor must be made application specific. Maximum span and capacitance range are the parameters to be considered. Linearity of capacitance variation over rotation is essential.

As a second phase of this research the proposed concept will be implemented. Electronic circuits with test results will be included in the next phase.

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