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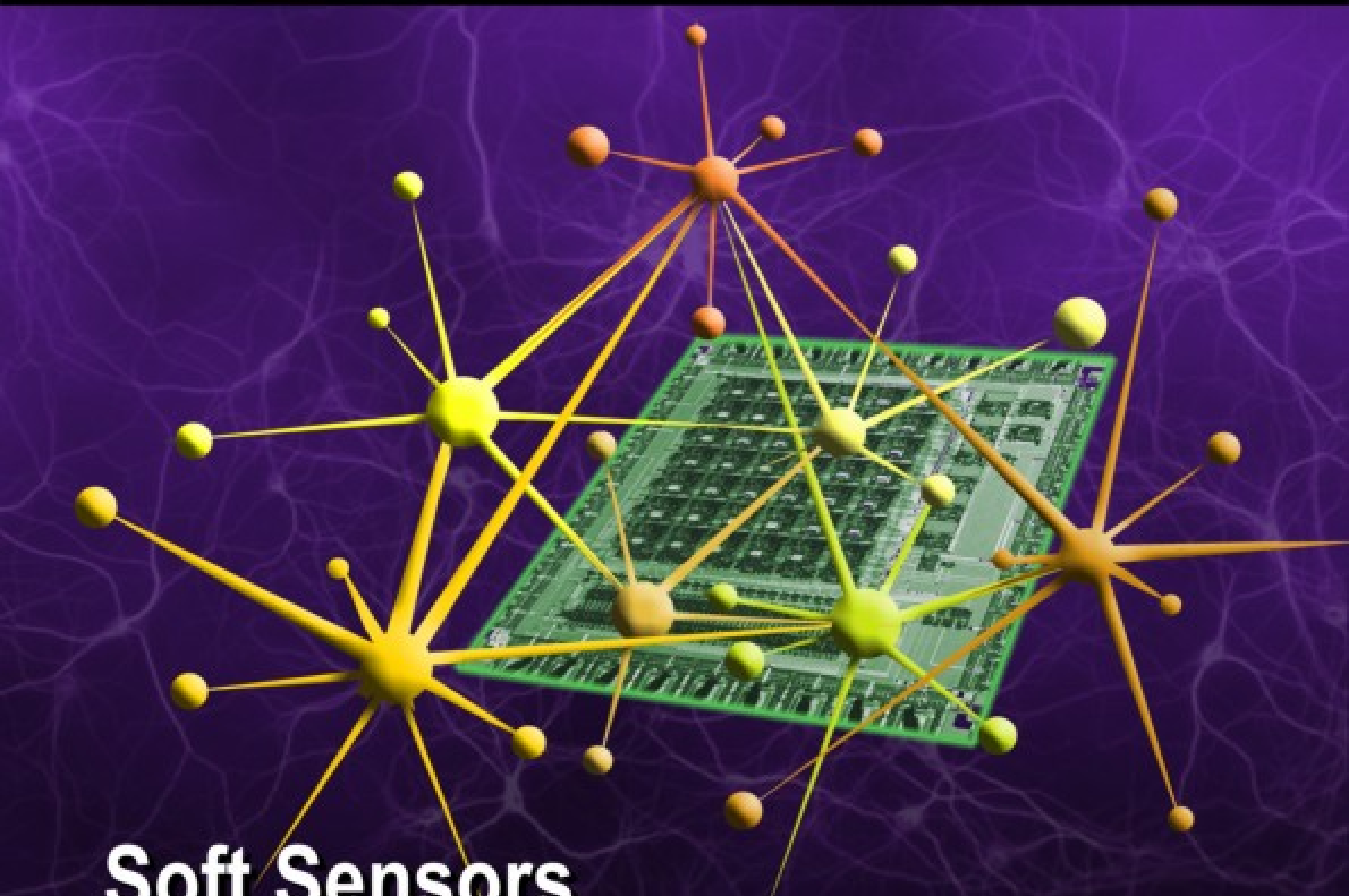

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A PC Based Level Indicating Controller Using a Hall Probe Sensor

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Abstract: A PC-based measurement and control of liquid level is a very important part of the modern instrumentation system of a process plant in any process industry. In this measurement and control system, the liquid level is measured by using a suitable level transducer. Among the different types of level transducers for measurement and control of liquid level in storage tank the cheapest one is perhaps the float type sensor and the movement of the float with level is generally converted into the movement of a pointer or that of a flapper or that of a potentiometer. In all of these system float is connected with the output device through a mechanical linkage and thus the measurement is subjected to errors due to wear and tear, friction etc. at the mechanical linkage. Here a non-contact float & magnet type level transducer using hall probe has been described in the present paper. A control system has been designed by using thyristor driven pump as the final control element, the speed of which is controlled by the computer through an opto-isolator unit. Experiments have been performed to find the operational characteristics of the transducer and the control loop. The experimental reports are presented in the paper. A very good performance characteristic has been observed. *Copyright © 2007 IFSA.*

Keywords: Non –contact level transducer, Float, Magnet, Hall probe, Opto-isolator

1. Introduction

The PC-based level measurement and control [1-12] is a very important aspect in any process industry. Different types of well accepted techniques of level measurement where various properties of a liquid [1-12] in a storage vessel are utilized such as buoyancy, liquid pressure at a depth, absorption of radiation, reflection of light from a liquid surface, electrical conductivity and permittivity of liquid etc. The technique of utilizing the buoyancy is one popular technique, where a movement of a float or a displacer due to the change of liquid level is used to design a local or remote level indicator. This type of level measuring system may suffer from measurement errors due to the loss of motion by friction at the mechanical linkages of the pulley or lever systems.

In the present paper a Hall probe type float transducer has been designed where no such mechanical linkage exists and the measurement is free from friction effect errors. In this system a level measuring tube made of non-magnetic material is connected with storage tank and is designed such that a non-magnetic float can move freely inside the tube with the change of level. The float carries a permanent magnet on its upper surface with the Hall probe sensor on the outside top face of the level sensing tube. With the rise of level the distance between magnet and the hall sensor decreases and so the magnetic intensity at the sensor increases. The Hall sensor senses this increase of magnetic field intensity and accordingly its output voltage increases with the increase of level. But this signal is non-linearly related with level since the magnetic field at the sensor is inversely proportional to the square of the distance of the sensor from the magnet. So to linearism the signal Labtech Note Book Pro. Software is used. This level is indicated by a virtual level indicator in the PC monitor. A PID control action is produced by the PC and the control action signal is sent to the firing circuit of a thyristor operated feed pump through an opto-isolator and the level is maintained at the set point value. The control loop has been tuned by Zigler and Nichols' ultimate method and final calibration of the loop over the entire range has been tested. The experimental results are reported in the paper. The measured level versus set point characteristic curve of the controller has been found to be quit linear and stable as shown in Fig.7. The block diagram of the whole control loop is as shown in the following Fig.1.

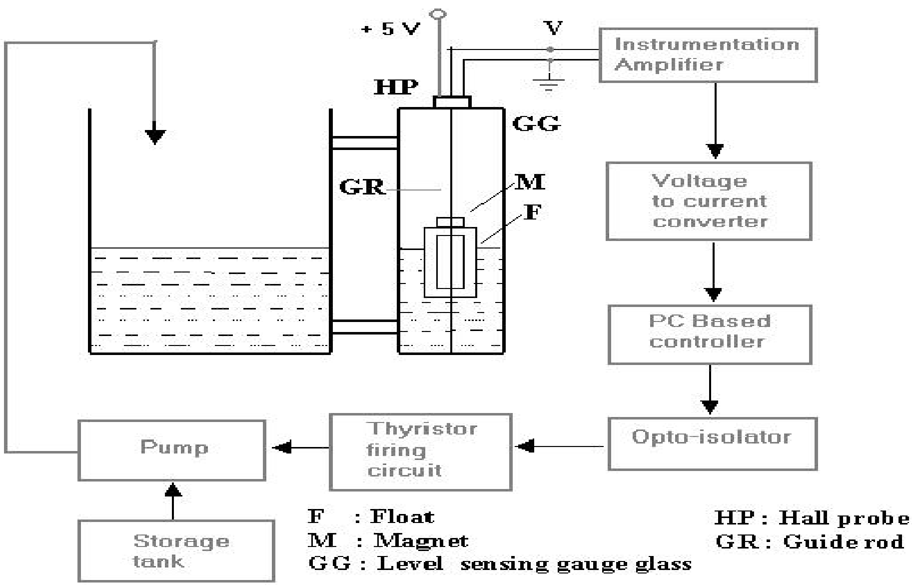

Fig.1. The block diagram of the whole control loop.

2. Method of Approach

In the present paper the level is sensed by a hall probe sensor and the hall voltage thus produced is amplified by an instrumentation amplifier INA101 and then converted into 4-20 mA current signal. The signal is transmitted to the PC based controller through DAS card.

Let the distance of the hall probe from the magnet is

$$x = H - \left(h + \frac{L}{3} + d\right), \tag{1}$$

where L is the length of float and $\frac{L}{3}$ is its selected length above the liquid level along with the magnet of depth ‘d’. In the present work the magnet is selected to be a circular permanent magnet. Let the radius and width of the magnet be ‘a’ and ‘t’ respectively. Hence magnetic field at the hall probe due to magnet is

$$B_x = \frac{K_1 x}{\left(x^2 + a^2\right)^{3/2}}, \tag{2}$$

where K_1 is the constant depending on the pole strength of the magnet, its radius and permeability of air which are all constants. If ‘H’ be so selected that at maximum level, x>> a then the above equation no. (2) is reduced to

$$B_x = \frac{K_1}{x^2} \tag{3}$$

or

$$B_x = \frac{K_1}{\left\{H - \left((h + \frac{L}{3} + d\right)\right\}^2} \tag{4}$$

The above equation is equally true for very low level also.

Since at low level $H > \left(h + \frac{L}{3} + d\right)$, so the above equation no. (4) is reduced to

$$B_x = \left(\frac{K_1}{H}\right)\left[1 + \frac{2\left(h + \frac{L}{3} + d\right)}{H}\right] \tag{5}$$

Now the output hall voltage V_h of the hall sensor is proportional to B_x if the current passing through the sensor be kept constant and hence it is given by

$$V_h = K_2 \times B_x, \tag{6}$$

where K_2 is the constant of proportionality.

Hence from Equation no. (4) & (6)

$$V_h = \frac{K_1 K_2}{\left\{H - \left(h + \frac{L}{3} + d\right)\right\}^2}$$

or

$$V_h = \frac{K}{\left(H^{/} - h\right)^2}, \tag{7}$$

where K = K_1K_2 and

$$H^{/} = \left(H - \frac{L}{3} - d\right) \tag{8}$$

3. Design

In the present design a cylindrical permanent magnet is selected of inner radius 0.011m, depth 0.008m, width 0.011m. The float is selected to be a hollow cylinder made of stainless steel of length 0.1181m. The thickness of the cylinder is calculated so that it floats with the magnet with (1/3) of the total length is above the liquid. In our present design, H= 0.45 m, L=0.1181 m, d=0.008 m, a=0.015 m. Hence assuming value of K_1K_2 to be 1 the above Equation no. (7) is reduced to

$$H^{/} = \left(H - \frac{L}{3} - d\right) = 0.45 - 0.1181/3 - 0.008 = 0.4026$$

$$V_h = \frac{K^{/}}{\left(H^{/} - h\right)^2} = \frac{K^{/}}{\left(0.4026 - h\right)^2} \tag{9}$$

Assuming K' to be unity the above Equation no. (9) is reduced to a normalized equation given by

$$V_h = \frac{1}{\left(0.4026 - h\right)^2} \tag{10}$$

From Equation. no. (9) the value of level from the measurement of the change in output voltage (V_h) is given by

$$h = 0.4026 - \frac{K}{V_h^{\frac{1}{2}}}, \tag{11}$$

where K= (K ')$^{1/2}$ and V_h denotes the change in output hall voltage from its value at datum level. Assuming, $y = \frac{1}{V_h^{\frac{1}{2}}}$ the above Equation no. (11) is reduced to-

h=0.4026 - Ky

or

$$y = \frac{(0.4026 - h)}{K}$$

or

$$y = -ah + b, \quad (12)$$

where

$$a = \frac{1}{K} \text{ and } b = \frac{0.4026}{K} \quad (13)$$

From experimental graph as shown in Fig.4 this equation is found to be given by

$$y = -0.1276 h + 28.147$$

Hence

$$h = \frac{(28.147 - y)}{0.1276} \quad (14)$$

This equation no.(14) is utilized to calculate the level in the PC based monitor by using mathematical icon blocks in the LabTech note book pro software. Hence the Hall voltage is nonlinearly related with level. By using linearization technique the equation may be linearized. Now the control action signal produced by the computer is the analog voltage signal in the range 0-5 volts. This 0-5 volts analog signal is utilized in driving the liquid lifting pump to the storage tank. The proposed low cost opto-isolator circuit used to protect the measuring or control system at the input from the effect of the high voltage surge of the final control element at the output as shown in Fig.2.

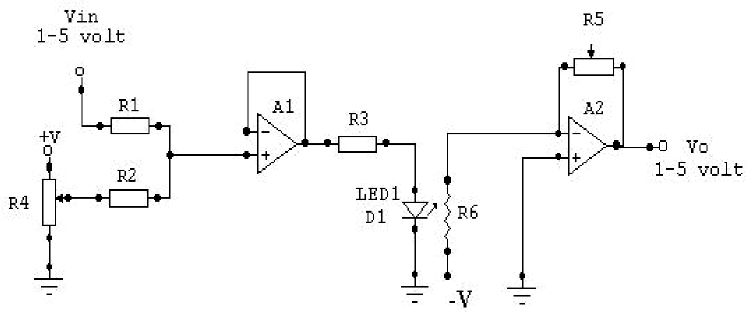

Fig.2. Low cost opto-isolator circuit.

In Fig.2 R_6 denotes the light dependent resistor (LDR), D_1 denotes light emitting diode (LED), V_i denotes the input analog signal, V_z denotes a zero adjustment signal, A_1 denotes a summing operational amplifier and the input and A_2 denotes a gain adjustment operational amplifier at the output. The basic principle in this technique lies in the fact that when an analog DC current is passed through a light emitting diode in the forward biased condition, the intensity or power of light emitted from the LED is linearly related with the DC current passing through it and when this light is incident on a light dependent resistor the resistance of LDR decreases with the increase of intensity or power of the incident light. Hence the resistance of LDR unit will decrease with increase of the DC current passing through LED. Thus the output-isolated voltage following the input voltage can be produced.

4. Experiment

Experiment is performed with the experimental set up as shown in Fig.1. To determine the characteristic of the level transducer the water in the storage tank is increased in steps and at each step the Hall voltage output of the Hall sensor is measured. The characteristic graph obtained by plotting Hall voltage against water level is as shown in Fig. 3. The linearization characteristic obtained by plotting reciprocal of square root of output voltage against level is shown in Fig.4. The theoretical characteristic graph by assuming unity sensitivity constant as shown in Equation no. (10) is also drawn by plotting the output voltage against level and is shown in Fig.5, which shows a close similarity between the experimental and theoretical graphs. From the experimental graph the characteristic equation is determined and in the PC based linearization program the level signal from these characteristic equation is calculated by the computer and the level is displayed in the monitor. The characteristic graph obtained by plotting the observed level in PC monitor against the true level is as shown in Fig.6.

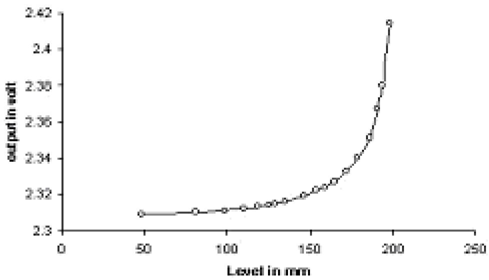

Fig. 3. Characteristic graph obtained by plotting Hall voltage against water level.

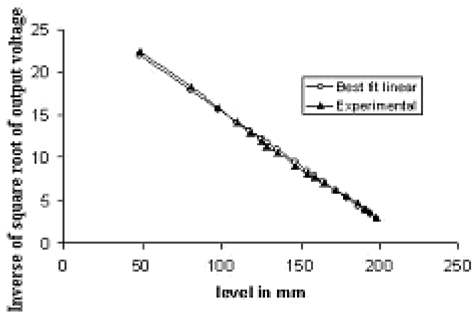

Fig.4. Linearization characteristic obtained by plotting reciprocal of square root of output voltage against level.

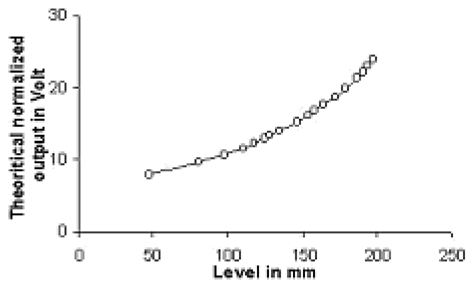

Fig.5. Output voltage against level.

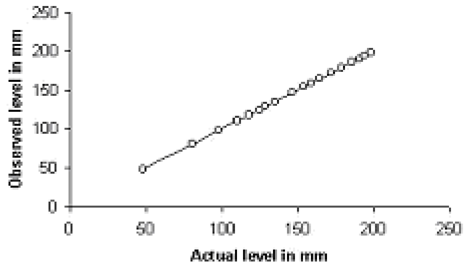

Fig.6.Characteristic graph obtained by plotting the observed level in PC monitor against the true level.

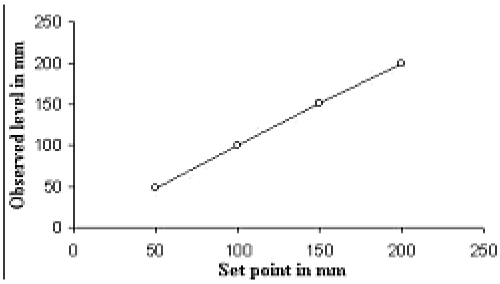

Fig.7. Observed level against Set point.

5. Discussions

From the characteristic graph of the level transducer as shown in Fig.3 and theoretical normalized graph as shown in Fig.5 it is found that both the graphs are of similar nature. The linearization graph obtained by plotting $\frac{1}{\sqrt{V_h}}$ against level (h) where V_h is transducer output has a good linearity within tolerable limit. The final static calibration graph of the PC based level indicating controller as shown in Fig.6 has a very good linearity.

The design of the system is very simple and the hall probe & the permanent magnet are now -available at a very low cost. Hence the cost of the level transducer will be low. Moreover the lifetime of the transducer will be high since the hall probe is not in contact with the liquid. The only difficulty is due to the float, which may be designed with synthetic or stainless steel material depending on the type of the liquid.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
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