A NOVEL METHOD OF RATIO CONTROL WITHOUT USING FLOWMETERS

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ABSTRACT

This paper describes the design of a ratio controller obviating the use of expensive flow meters. It uses cost effective apparatus and electronics to achieve ratio control without a sacrifice of accuracy. Here, the flow is measured in terms of the height of liquid column by relating it to the flow velocity and hence, the flow transducer is replaced with a comparatively cheaper level transducer. Using the height of the two liquid columns, the corresponding flows are calculated and in order to maintain the ratio between the flows, one of the levels of the liquid column is manipulated to achieve desired flow rate. Thus the ratio between the flow rates is maintained at the set point value without actually using flow meters.

1. INTRODUCTION

Ratio control is a technique used to control a process variable at a set point that is calculated as a proportion of an uncontrolled input. It can be the control of the ratio of the flow rates of two fluid streams[1]. Ratio control plays a predominant role in process industries. Applications of ratio control include gas-fired furnaces, gasoline blending, chemical reactors, water treatment, waste incinerators and constant reflux ratio on a distillation. The conventional method of ratio control demands the installation of two flow meters, a ratio controller that comprises of the electronic control logic components and a control valve to control the flow rate of the controlled fluid[2]. The ratio controller computes the ratio of the two flows (obtained from the flow transducers) using electronic circuits and compares the ratio of the flows with the set point given to it and computes the manipulating variable depending upon the difference between the set point and the ratio of the actual flows. The manipulated variable, which is the control valve opening in the inlet of one of the flows, is adjusted to increase or decrease the flow in such a way that the flow is manipulated to maintain the set point. The control action continues until the actual ratio is equal to the set point. The flow meters that are usually used in the ratio control, whether it is the most popularly used orifice plate with differential pressure transmitter (DPT) or an electromagnetic flow meter, are invariably expensive. As a consequence, the cost of a ratio controller increases to a great extent.

2. THEORY OF OPERATION

The main objective of this paper is to design a ratio controller precluding the use of the expensive flow meters. The flow is measured in terms of the height of liquid column and hence, the flow transducer is replaced with a comparatively cheaper level transducer. Using the height of the two liquid columns in two different tanks, the corresponding flows are calculated and in order to maintain the ratio between the flows, one of the levels of the liquid column is manipulated to achieve desired flow rate. Thus, the ratio between the flow rates is maintained at the set point value. It uses an elementary relation that exists between the height of the liquid in the tank and the velocity of the liquid from an opening at the bottom of the tank.

According to the law of conservation of energy, the pressure head due to the height of the liquid in a tank is converted to kinetic energy if the liquid is allowed to flow through a very small nozzle at the bottom of the tank. Mathematically, it can be expressed as $v = \sqrt{2gh}$ where v is the velocity of flow, h is the height of the liquid in the tank.

Liquids whose flow rates have to be controlled are allowed to flow through pipelines of same diameter from similar tanks, at the same height from the ground level. Let $v1$ and $v2$ be the velocity of the two flows respectively. The heights of the two tanks, $h1$ and $h2$ respectively are measured using a simple level transmitter like load cells. The ratio $h1/h2$ is found out using an analog divider. The cross sectional areas of the two tanks are A1 and A2 respectively. Here, the two tanks are of identical areas. Now, the flow rates q1 and q2 are given by

$q1 = v1*A1$ and $q2 = v2*A2$.

The given set point for the ratio controller is $q1/q2$. The square of the set point $(q1/q2)^2$ is found out using an analog multiplier.

Following the basic relationship between h and v, we get

$(v1/v2) \alpha \sqrt{}h1/h2$ or $(v1/v2)^2 \alpha h1/h2$ or $(q1/q2)^2 \alpha h1/h2$.

$(q1/q2)^2$ and $h1/h2$ are given as two inputs to a comparator. The output of the comparator can be used as the manipulating variable for the control valve opening to change in order to vary the flow rate of one of the two input flows. Suitable signal conditioning is required to operate the control valve opening in accordance with the manipulating variable. The control valve opens or closes in such a way that the height varies in order to make the actual ratio closer to the set point. The control action continues until the actual ratio matches with the set point. Similar to a practical industrial application, one flow is assumed to be controllable and the other wild.

3. OVERALL SCHEMATIC DIAGRAM

The overall schematic diagram of the ratio controller is shown in Figure 1. The voltages from the two load cells and the set point are fed to the signal conditioning circuit. The comparator output, which is the output from the signal conditioning circuit, is fed to the control logic along with the generated sequence for the stepper motor. The control logic decides upon the direction of rotation of the stepper motor in order to open / close the needle valve. A needle valve fitted with stepper motor acts as a control valve. The output from the control logic is fed to the drive circuitry to drive the stepper motor in the desired direction. This contributes to the controlled flow from tank 1 whereas the flow from tank 2 is wild. The two flows are fed to the reaction tank.

4. SIGNAL CONDITIONING BLOCK

The signal conditioning schematic diagram is shown in Figure 2. The load cell voltages are given to the divider after proper amplifications. The set point of the prescribed range is fed to the multiplier as voltage. AD633 is the analog multiplier used here. AD711 along with AD633 in the feedback path acts as an analog divider. The output of the multiplier and divider are suitably conditioned so that they are proportional to $(q1/q2)^2$ and h1/h2 respectively. These two are then fed to the comparator LM324, the output of which will be +5V or 0V depending on whether $(q1/q2)^2$ is greater than h1/h2 or lesser than h1/h2 respectively. The controller used here is an on/off controller as the output from the electronic controller is either 0 or +5 V. This comparator output is then fed to the control logic circuitry.

5. SEQUENCE GENERATOR

The required sequence for the stepper motor is generated using 7474 (4 D flip-flops). The circuit diagram for the sequence generator is shown in Figure 3. along with the generated sequence. The sequence when fed to the control logic is used for both clockwise and anti-clockwise motion of the stepper motor. The speed of rotation can be controlled using the clock frequency. If a higher speed of response is required, then the clock frequency is tuned to a higher value. The clock has to be inverted and given to the flip-flops as the values get shifted at the transition of the negative going edges. The sequence generated is given to the control logic circuitry. Here the stepper motor is operated in the unipolar mode i.e., each of the 4 coils (red, green, orange, blue) is activated one at a time and black and white coils are grounded.

6. CONTROL LOGIC BLOCK

The block diagram of the control logic is shown in Figure 4. The sequence from the sequence generator is fed to a shift register in parallel load mode, which acts as a buffer. The sequence along with the comparator output (0 or +5 V) is fed to the AND-OR logic as shown in the Figure 4. When the comparator output is 5 V i.e., $(q1/q2)^2$ is greater than h_1/h_2; the sequence is applied as such to the stepper motor, which results in a clockwise rotation of the stepper motor causing the needle valve to open. When the comparator output is 0 V i.e., $(q1/q2)^2$ is lesser than h_1/h_2, then the sequence will be applied in reverse order, which results in an anticlockwise rotation of the stepper motor causing the needle valve to close. Thus the direction of rotation of the stepper motor reverses with the comparator output. The stepper motor will continue to close or continue to open, as the situation demands, till the comparator changes it's output from 0 to 5 V or vice versa. This method of controlling comes under the category of single point floating control where the opening or closing of the control valve continues in an uniform pace until the error changes it's sign. The output of the control logic is fed to the drive circuitry.

7. DRIVE CIRCUITRY BLOCK

The block diagram of the drive circuitry is shown in Figure 5. The output from the control logic is fed to a Darlington transistor array. This acts as a buffer. The output is fed to the base of the power transistor TIP42C through a resistor. The excitation voltage for the stepper motor is applied to the emitter of the power transistors. The power supply that is required to excite the stepper coils should have a sufficient current rating as indicated in the stepper motor specifications. A lesser current rated power source will lead to loading which will further lead to a resulting drop in the voltage applied across the motor. The stepper motor coils are connected to the collectors. Whenever a pulse appears at the base of the transistor, that particular transistor will conduct causing the excitation voltage to be applied to the stepper motor coil. Depending upon the order in which the various coils of the stepper motor (given by colors Red, Blue, Orange, Green) are excited, the stepper motor moves either in the clockwise or anticlockwise direction and thereby making the needle valve coupled with it to either open or close.

8. EXPERIMENTAL SETUP

The experimental set up of the ratio controller is shown in Figure 6. The liquids whose flow rates have to be controlled are allowed to flow through two tanks. The outlet from the tanks is through taps fitted at the bottom of the tanks. The outflow will be proportional to the height of the tank. The two flows are let into the reaction tank. The height of the liquid in the two tanks is measured using load cells. Depending upon the height of the liquid in the tank, the weight of the tank varies proportional to the height. The load cell is a load-measuring sensor whose output is proportional to the weight. Based on this principle, load cell is used here for height measurement. The heights h1 and h2 as measured by the two load cells are given to an analog divider after proper amplification. The output of the divider will be h1/h2. The set point q1/q2 is given to an analog multiplier, which acts as an squarer. The output will be $(q1/q2)^2$. These two outputs are fed to a comparator. The output of the comparator is fed to a control logic which is used to control the inlet valve opening for the 1st tank which in turn controls the height and hence the flow rate from tank 1. A needle valve fitted with stepper motor acts as a control valve. A drive circuitry is included to drive the stepper motor depending upon the control logic output.

9. EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental tests were carried out in three different sections to assess the performance of this ratio controller. The first set of readings were taken to verify that the outflow of the liquid filled tanks actually follow a square root relationship with height of the liquid in the tank i.e., $v = \sqrt{2gh}$ is experimentally verified. The results obtained are as shown in Table 1 and 2. Initially the controller was given a set point of 0.5 and allowed to reach a steady state. Then the set point ratio was changed and readings were taken after allowing the process to reach the steady state. As seen in Table 1 and 2, the controller's performance was good with a credible accuracy and the actual ratio was found out to be in good concordance with the theoretical claim.

The controller was also subjected to load disturbance by both increasing and decreasing the inflow rate to the wild flow tank, which resulted in the liquid level of the tank reaching a different steady state height. The controller reacted properly by increasing or decreasing the inflow to the controlled tank to maintain the ratio at the initial set point. The readings in Table 3 and 4 manifest the above facts. Table 3 shows the readings taken at steady state after effecting a slight increase in the inflow rate. Table 4 indicates the readings taken after inflicting a load disturbance by reducing the wild inflow rate.

The advantages of our ratio controller over the conventional ratio controllers are as follows:

i) Accuracy is comparable with the ratio controllers available in the market.

ii) It obviates the use of expensive conventional flow meters.

iii) It gives fast response for changes in set point / wild flow and control action is taken continuously and instantaneously.

iv)Signal conditioning is very simple and inexpensive and involves simple analog devices like dividers, multipliers and comparators.

v) Costly control valve is replaced with a cheaper needle valve fitted with stepper motor. Stepper motor is controlled without using a microprocessor or a personal computer or using costly drive circuits available in the market, hence the control valves are replaced by a cheaper alternative.

vi) Merely tuning the clock frequency of the sequence generator can change the speed of control.

vii) The experimental set up is simple and can be installed any where in a plant.

viii) The load cell is a cheap non-contact level transmitter when compared to DPT or other linear level transmitters and is not affected by corrosive liquids.

ix) It can be used for both flows from pipes / tanks. If the flow is through pipeline, then the fluid can be made to flow through a tank on its path for the sake of measurement.

x) The principle used here may be extended to the measurement of flow. However the flow measurement is applicable only for fairly constant flows and where the total span of flow variation is very small as it has a relatively longer response time. The range of flow that can be measured will be limited by the height of the tank.

10. CONCLUSION

This design had the main objective of obviating the necessity of flow meters when it comes to ratio control and hence to reduce the cost involved for the ratio controller without a sacrifice of accuracy. Further improvements can be employed in the following areas:

i) The effect of viscosity of liquids on the flow rate from the tank has not been studied. The ratio controller can be applied to a wide range of liquids only if the effect of viscosity for sluggish liquids is analyzed and necessary corrections included.

ii) Calibrated flow meters should be used to measure the instantaneous flow rates in order to check the dynamic response of the controller before the steady state is reached. The speed of response for changes in set point and load disturbances should be analyzed before making further improvements on the design.

iii) The relation with that exists with respect to pressure and flow rate of gases can be studied to implement this principle to the air-fuel ratio controllers in which pressure transmitters can replace the flow transmitters.

iv) If the density is varying, then necessary compensations have to be made in the signal conditioning so as to compensate for the density variations.

REFERENCES

1) Robert A. Mollenkamp, “Introduction to Automatic Process Control”, Instrument Society Of America. (1984)
2) William L. Luyben, “Essentials of Process Control”, McGraw-Hill International Editions. (1997)

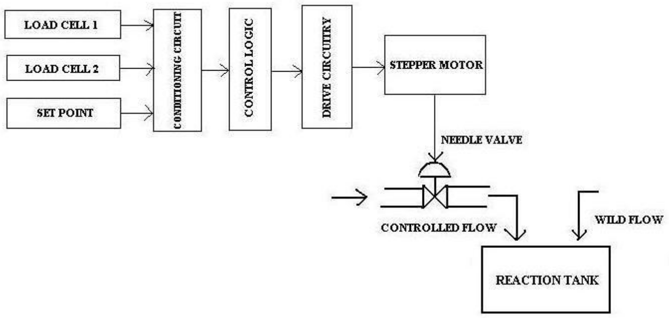


Fig. 1: Overall schematic diagram

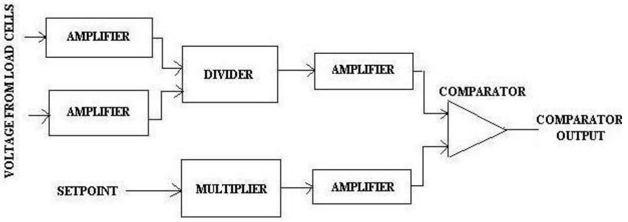
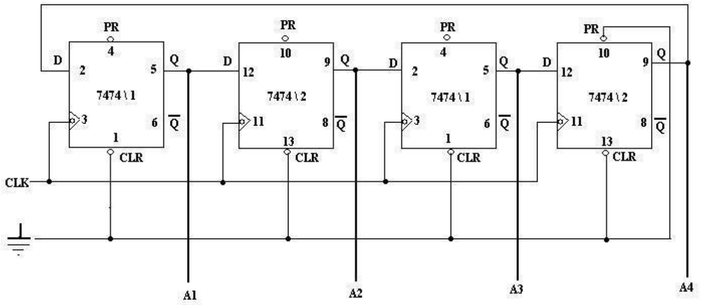


Fig. 2: Signal conditioning block



A1	A2	A3	A4
1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Fig. 3: Sequence generator

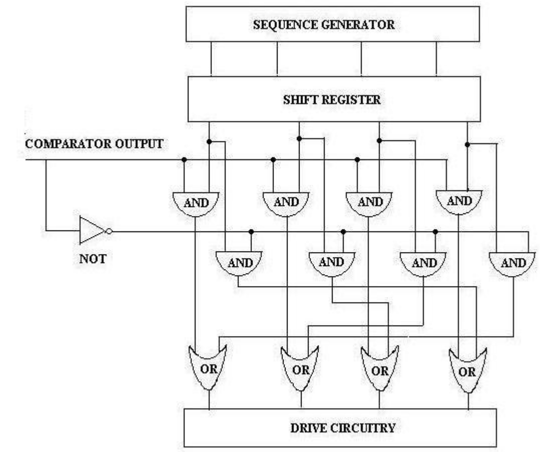


Fig. 4: Control logic block

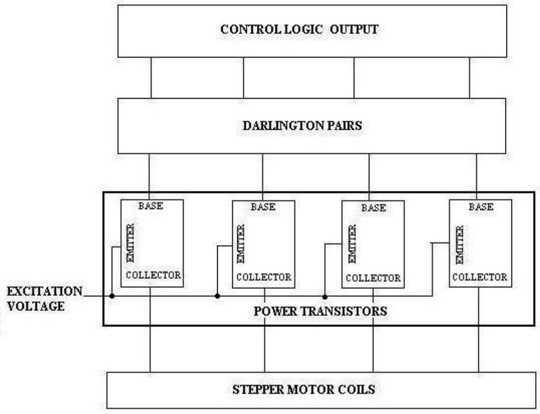


Fig. 5: Drive circuitry block

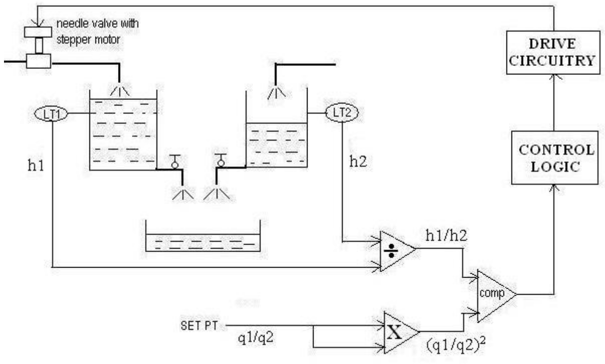
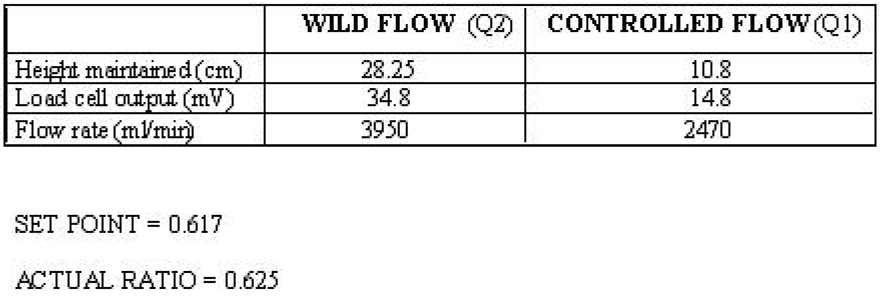


Fig. 6: Schematic Representation of the Experimental setup

Table 1: Calibration Table for Set Point Change I

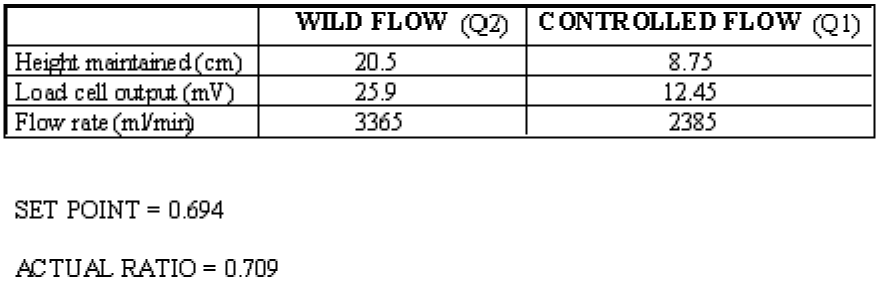


	WILD FLOW (Q2)	**CONTROLLED FLOW**(Q1)
Height maintained (cm)	28.25	10.8
Load cell output (mV)	34.8	14.8
Flow rate (ml/min)	3950	2470

SET POINT = 0.617

ACTUAL RATIO = 0.625

Table 2: Calibration Table for Set Point Change II

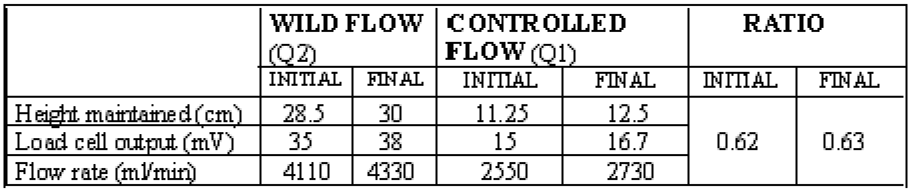


	WILD FLOW (Q2)	**CONTROLLED FLOW** (Q1)
Height maintained (cm)	20.5	8.75
Load cell output (mV)	25.9	12.45
Flow rate (ml/min)	3365	2385

SET POINT = 0.694

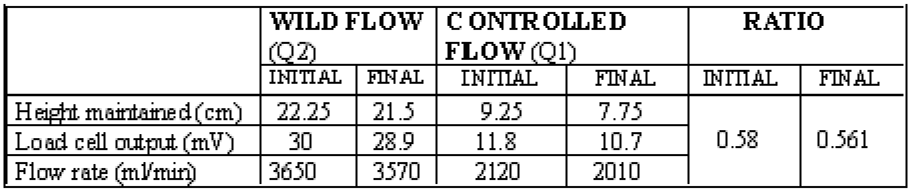
ACTUAL RATIO = 0.709

Table 3: Calibration Table for Wild Flow Disturbance I



	WILD FLOW (Q2)		**CONTROLLED FLOW** (Q1)		**RATIO**	
	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
Height maintained (cm)	28.5	30	11.25	12.5	0.62	0.63
Load cell output (mV)	35	38	15	16.7		
Flow rate (ml/min)	4110	4330	2550	2730		

Table 4: Calibration Table for Wild Flow Disturbance II



	WILD FLOW (Q2)		**CONTROLLED FLOW** (Q1)		**RATIO**	
	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
Height maintained (cm)	22.25	21.5	9.25	7.75	0.58	0.561
Load cell output (mV)	30	28.9	11.8	10.7		
Flow rate (ml/min)	3650	3570	2120	2010		