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DISCHARGE CONTROL OF A CENTRIFUGAL PUMP BY AUTOMATION

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Abstract

Though many technologies have been used, centrifugal pumps playing a major role in fetching and transporting fluids in industries and the control valves used in centrifugal pumps are normally mechanical armatures. Instead of pneumatic or hydraulic controllers in the centrifugal pumps automated stepper motor be an efficient and accurate way in controlling the flow rate. By envisaging this concept an attempt was made on automation of control valve of centrifugal pumps using hardware kit mediated DC stepper motor, embedded system and visual basic software. While calculating the discharge variance and the time taken for the discharge at various positions of the pump such as fully opened, 30º and 60 º, automated ball valve was found superior than manually operated ball valve. Automated method was accurate but in manually operated valves the discharge variance was high.

Key words: Centrifugal pump, Stepper motor, Control valve and Embedded system.

1. Introduction

Centrifugal pumps are used in the transport of fluids by conversion of rotational kinetic energy to the hydro-dynamic energy of the fluid flow. Two third of pumps used in industry are centrifugal because of their high performance, ease in maintenance and continuous flow. The control valves used in centrifugal pumps are mechanical armatures such as ball valve, globe valve, butterfly valve, gate valve, poppet valve etc. These valves are able to regulate the flow rate and direction of fluid flow. Automation of valve control, which reduces human intervention, is a useful technology in saving energy and materials and can improve the accuracy and precision. In most of the plants pneumatic or hydraulic controllers are used in control loops (Liptak, 1970; Considine, 1974) which needs human involvement and the accuracy is questionable. In specific cases microcontrollers were also tried (Chattopadhyay *et al.*, 2009). Stepper motor also called as step motor or stepping motor is a brushless DC electric motor that divides a full rotation into a number of equal steps and stepper motor driven position control is even used in robotic applications (Sandeep Nimbalkar, 2015). The stepper motor is known by its property to convert a train of input pulses into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle. Stepper motors effectively have multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by a microcontroller. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. This means that when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to

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align with the next one and from there the process is repeated. Each of those rotations is called a "step", with an integer number of steps making a full rotation. The flow control valve manipulates a flowing fluid, such as gas, steam, water, or chemical compounds, to compensate for the load disturbance and keep the regulated process variable as close as possible to the desired set point (Andrei magyari *et al.*, 2010). Control valves normally respond to signals generated by independent devices. An embedded system is one with a dedicated function with a larger mechanical or electrical system, often with real-time computing constraints (Sagar Khole *et al.*, 2015). Microprocessors are manufactured as components of embedded systems. In this piece of research work automated stepper motor was tried in controlling valves to obtained accuracy and repeatability.

2. Materials and Methods

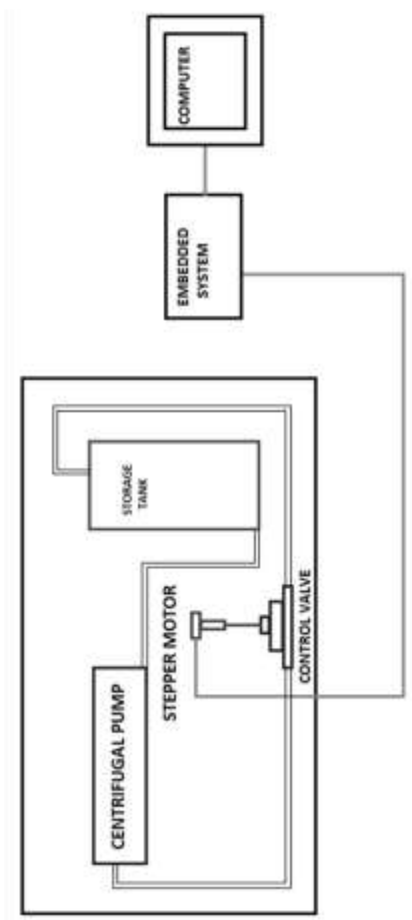

Fig – 1: Layout of the experimental setup

Centrifugal pump, Flow control valve and Stepper motor

Centrifugal pump of monoblock set, 3HP, 210 V with 80 x 65 mm was used for the transport of the fluid (Hoefer, 1944) and controlled by the shaft of the DC stepper motor (5 A ,12 V,1500rpm). The shaft was responsible for the exact positioning of the ball valve. Motor resonance frequency was calculated from the formula:

$$f = \frac{100}{2\pi}\sqrt{\frac{2p \cdot M_h}{J_r}}$$

M_h - Holding torque -cN·m
p -Number of pole pairs
J_r -Rotor inertia - kg·cm²

Embedded system

As the whole in the circuit (Fig. 2) an IC regulator (IC 7805) was used and operated on the 5V DC supply. It was a three terminal device with input, output and ground. C2 and C3 were filter capacitors while C1 and C4 were bypass capacitors. The capacitors were electrolytic polarized with 100mfd. AT89C51 an 8-bit microcontroller belongs to Atmel's 8051 family which had 4KB of flash programmable and erasable read only memory (PEROM) and 128 bytes of RAM and could be erased and program to a maximum of 1000 times. In 40 pin AT89C51, there were four ports designated as P_1, P_2, P_3 and P_0. All these ports were 8-bit bi-directional ports, *i.e.*, they could be used as both input and output ports. Except P_0 which needs external pull-ups, rest of the ports had internal pull-ups. When 1s were written to these port pins, they were pulled high by the internal pull-ups and could be used as inputs. These ports were also bit addressable and so their bits could also be accessed individually. Port P_0 and P_2 were also used to provide low byte and high byte addresses, respectively, when connected to an external memory. Port 3 had multiplexed pins for special functions like serial communication, hardware interrupts, timer inputs and read/write operation from external memory. AT89C51 had an inbuilt UART for serial communication. It could be programmed to operate at different baud rates. Including two timers& hardware interrupts, it had a total of six interrupts. Quartz crystal oscillator was connected to inputs XTALI (pin 19) and XTAL2 (pin 18) and two capacitors of 30 pF value. One side of each capacitor was connected to the ground.

Data Sheet

A 16x2 LCD display was used because of their economical and easily programmable nature. Further they have no limitation of displaying special & even custom characters (unlike in seven segments), animations. In the LCD each character was displayed in 5x7 pixel matrix and had two registers, namely, Command and Data. The MAX232 IC was used to convert the TTL logic levels to RS232 logic levels during serial communication of microcontrollers with PC.

The controller operated at TTL logic level (0-5V) whereas the serial communication in PC works on RS232 standards (-25 V to + 25V). The intermediate link was provided through MAX232. It was a dual driver/receiver that includes a capacitive voltage generator to supply RS232 voltage levels from a single 5V supply. Each receiver converted RS232 inputs to 5V TTL/CMOS levels. These receivers (R_1& R_2) could accept ±30V inputs. The drivers (T_1& T_2), converted the TTL/CMOS input level into RS232 level. The transmitters took input from controller's serial transmission pin and send the output to RS232's receiver. The receivers, on the other hand, take input from transmission pin of RS232 serial port and give serial output to microcontroller's receiver pin. MAX232 needed four external capacitors whose value ranged from 1µF to 22µF.

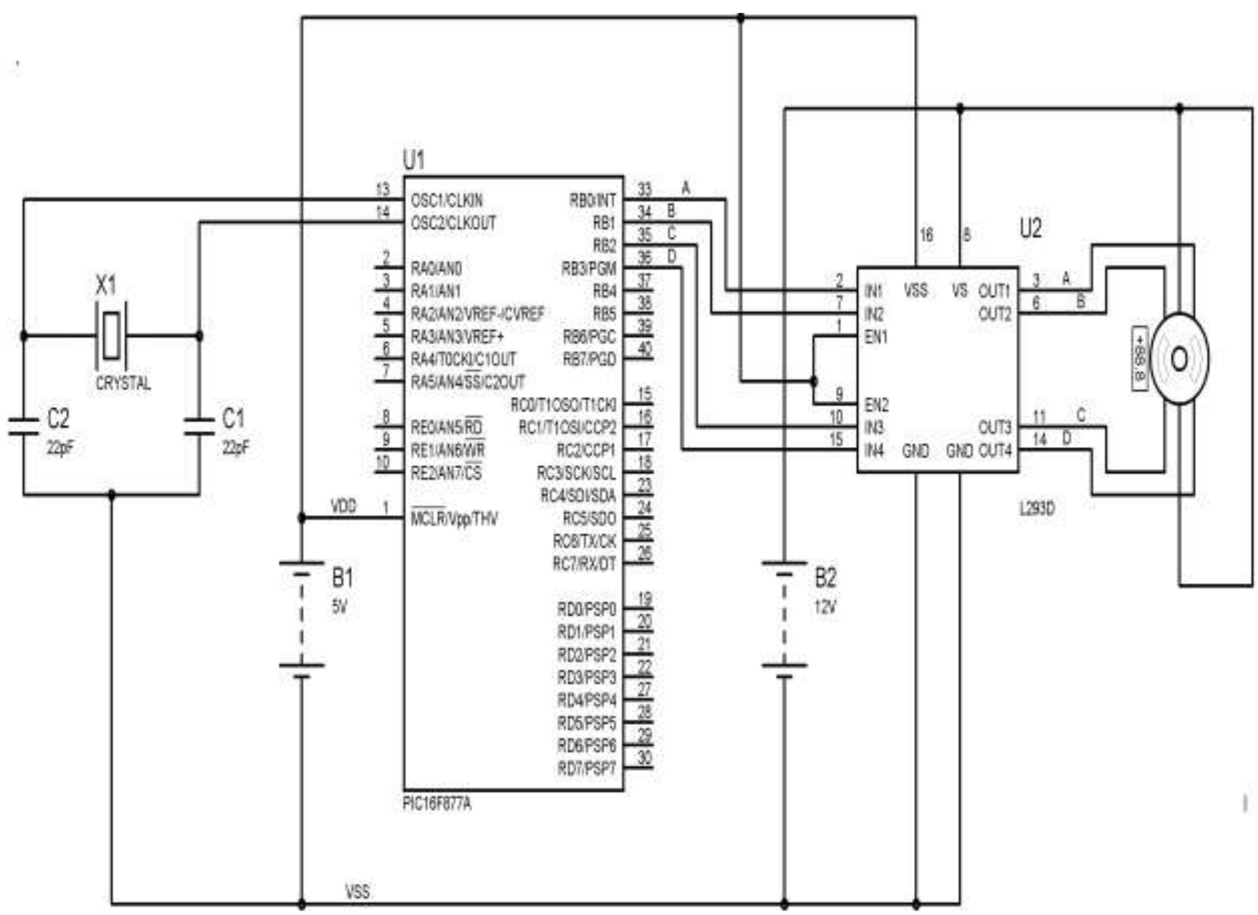

Fig - 2: Embedded circuit diagram

Controlling software

Visual Basic a third-generation event-driven programming language and was derived from BASIC and enables the rapid application development (RAD) of graphical user interface (GUI) applications. After, all the connections were made with the help of visual basic software to screen displays both the directions and by clicking the desired direction either clockwise or anticlockwise and the valve position could be altered.

Experiment

DC stepper motor (5 A, 12 V, 1500 rpm) mounted on the valve and inputs were given to the stepper motor as an embedded program to actuate the valve. Visual Basic software was used to govern the direction of rotation of valves and their position. There were five replications in the experiment. The valve was adjusted to 30 º, 60 º from the fully opened position. By following the formula "Discharge Q = Volume/time taken" the amount of discharge was calculated. Manual method was also followed and was considered as a control. Three litres of water was used uniformly in this experiment.

Embedded Coding

```
Void main ()
{
 CMCON = 0x07; // To turn off comparators
 ADCON1 = 0x06; // To turn off analog to digital converters
 TRISB = 0; // PORT B as output port
 PORTB = 0x0F;
do
 {
  PORTB = 0b00000001;
Delay_ms(500);
  PORTB = 0b00000011;
Delay_ms(500);
  PORTB = 0b00000010;
Delay_ms(500);
  PORTB = 0b00000110;
Delay_ms(500);
  PORTB = 0b00000100;
Delay_ms(500);
  PORTB = 0b00001100;
Delay_ms(500);
  PORTB = 0b00001000;
Delay_ms(500);
  PORTB = 0b00001001;
Delay_ms(500);
}while(1);
}
```

3. Results and Discussion

While calculating the discharge variance and the time taken for the discharge at various positions of the pump such as fully opened, 30º and 60 º, automated ball valve was found superior than manually operated ball valve. Automated method was accurate but in manually operated valves the discharge variance was high (Table - 1). The time variation in manually operated valve at fully opened condition was 19± 1.5 seconds and in automated valve it was recorded 19±0.02. The same trend was noted at various positions of opening. The readings plotted in the graph showed clear picture related to the deviation. In the graph blue dots indicates the values of automated experimental setup and the black dots notes the values of manual method. Hence by this, we can eliminate the need for man power to operate it and it also proves a time saving process and accurate method of controlling the flow.

4. Conclusion

Thus this way of discharge control will increase consistency of output and its accuracy. It replaces hard physical or monotonous work. The process can be made quite simple and it proves to be time saving and no skilled labour is necessary in controlling the discharge. We can make few simple changes in the embedded program a change the valve position thus we can vary the discharge effectively. The main aim of this paper is to achieve accuracy and it could be achieved easily by this simple design and by fabricating it.

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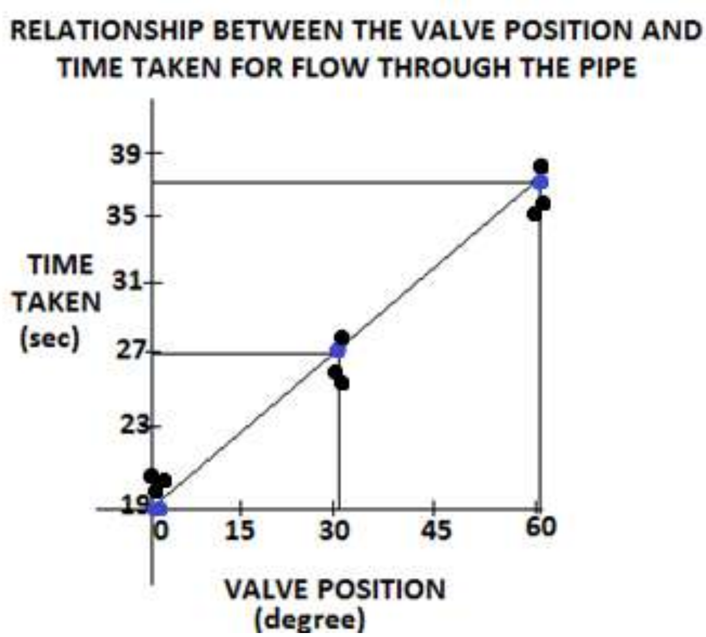
Table – 1: Comparison of manually and automated valves in terms of time and discharge variance

Position of Valve	Manually operated		Automated valve	
	Time taken (S)	Discharge variance m^3/s	Time taken (S)	Discharge variance m^3/s
Fully opened	19± 1.5	0.171 – 0.146 × 10^ $^{-3}$	19±0.02	0.157 – 0.154 × 10^ $^{-3}$
Open at an angle of 30º	27± 2.7	0.123 – 0.101 × 10^ $^{-3}$	27±0.05	0.112 – 0.111 × 10^ $^{-3}$
Open at an angle of 60º	35± 2.9	0.093 – 0.0789 × 10^ $^{-3}$	37±0.06	0.083 – 0.081× 10^ $^{-3}$



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