Speed Control of DC Motor To Deliver Constant Throughput

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***Abstract*—The system described here automates the conveyor belt based product transportation facility prototype that is used widely in steel and cement plants in particular, and in several other industries elsewhere. It allows automatic variation in motor speed (and hence in conveyor belt speed) after sensing the load placed on the conveyor belt, using a load cell. This process ensures constant "throughput" of the material placed on the conveyor belt. It also allows for manual setting of desired "throughput".**

One of the salient features of this system is that it is designed to give constant "throughput", and hence is industry-oriented. Secondly, it is a low-cost system, with significantly reduced cost than the speed control devices available in the market.

Keywords—Speed control; constant throughput; DC motor; automation

I. INTRODUCTION

Digital electronics and microcontroller based machines have enabled large factories to adopt automation and hence save time and cost. In this paper, we have designed a low-cost system that

In industry, we have applications where you need a machine to transport a fixed weight of some product per unit time. To get a more clear idea, say want to transfer some blocks of steel from source A to destination B, using a conveyor belt. We want to transfer a total of 100kg of steel blocks from A to B per minute. That means, if 10 kg blocks are placed on the conveyor belt, it should transfer 10 such blocks from tray A to tray B (since 10 x 10 = 100). Now, if blocks of 20kg are placed on the belt, it should transport only 5 such blocks form tray A to tray B (20 x 5 = 100). For this to happen, the conveyor should reduce its speed so that it transports only 5 blocks as against 10 blocks in the previous case. This means we are achieving "constant throughput", in this illustration, it was 100kg/min. That is, when the load increases to 130% the speed proportionately reduces to 70%, to keep the throughput constant. The concept of "constant throughput" is governed by the following equation.

$$\text{Weight on motor} \times \text{Speed of motor} = \text{Throughput} \quad (1)$$

Similarly, we may set any desired throughput (say 500 kg/min) in our system and get that much amount of load transferred per unit time to destination B, that is, at the output end. So the system involves speed control of motor after sensing the load put on it, the torque remaining constant. While designing this prototype, it is assumed that the motor selected, has rated torque sufficiently greater or equal to that required torque to carry the rated load. Hence loading has no effect on motor speed if the motor were to be operated and tested individually [1].

Its simple design is the culmination of considerable research and development process into various speed control techniques used for single phase AC as well as DC motors.

II. SYSTEM

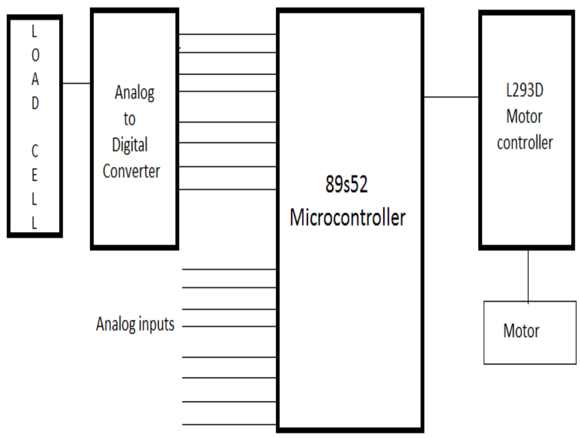

Fig. 1. Block diagram of the system.

A. *Load cell sensor*

We have used the low-capacity CZL601 load cell for demonstration purpose. It can handle a maximum load of 6 kg. It gives a proportional voltage according to the weight placed on it. This output analog voltage is usually of low magnitude, in this case 0-2V. Now, the most commonly used practice is to amplify this voltage using instrumentation amplifier, and then use for further processes. But, our goal here is to get a digital output for the load cell, and hence we found an easier and cleaner way to get around this problem. We simply connected a DC voltage of 3Vin series with the load cell output analog voltage. Now the range of the load cell output voltage has been shifted to 3V to 5V varying from no load to full load correspondingly. This is nothing but a level shifter arrangement to avoid amplifier in the circuit.

The output voltage of the load cell serves as the input voltage for the A to D converter (Analog to Digital converter). It should be noted here that the A to D converter chip ADC0804 that we have used, has an option to decrease the input voltage range from the conventional 0-5V range to 0-2V range. This is done to make it convenient to interface low range voltages to the A to D converter. Hence if we choose to use ADC0804 in the 0-2V input voltage range, we will not even require the level shifter arrangement.

B. Analog to Digital converter

We used a standard ADC0804 chip to convert load cell output analog voltage into digital form. It is a single channel 8-bit A to D converter. To give a continuous digital output of the load cell weight, the chip has to receive control signals such as Read and Write continuously. This is handled by interfacing the chip control signals to the microcontroller and programming the controller to provide the control signals continuously by running them in a software loop.

As cited above, this chip provides the option of 0-5V input as well as 0-2V input. Having the option of 0-2V input makes it very convenient to interface low output voltage devices such as load cells to the A to D converter chip. This option is exercised by supplying 1V to pin 9 ($V_{ref}/2$ pin) of ADC0804 chip. A total of 6 input voltage ranges are available and one can refer additional literature on this chip for details of the same.

C. Motor controller L293D chip

L293D is a chip that makes it easier to implement PWM (Pulse Width Modulation) control. It is essentially an H-bridge that makes it possible for DC motor to rotate clockwise and anti-clockwise. However, in our application, we need the motor to rotate in any one direction only. When we give a PWM pulse at input pin of the chip, the motor connected at the output pin will rotate at the speed proportional to its PWM input pulses. One can connect motors up to a maximum of 36V supply to this chip. We are using a DC motor at a supply voltage of 12V for our application.

D. Microcontroller and Analog inputs

We have selected the widely used 89S52 microcontroller, from the 8051 family. The choice of this controller was made considering the fact that this controller has sufficient capabilities to address all the requirements of this project, simultaneously also keeping up with the promise of a low-cost solution. Fairly advanced controllers (such as ARM) are available in the market. However it is worth noting, that selecting a controller with capabilities in excess of the requirement of the system, is firstly, a waste of its unused capabilities and secondly, is economically imprudent (especially in low-cost system design).

The controller performs two main tasks. First, it provides continuous control signals to ensure smooth working of the A to D chip. Secondly, it provides the PWM pulse to the input of L293D chip.

The PWM pulse should vary depending on the load placed on the load cell. This means, it should vary in accordance with the digital output of the A to D converter. We used Timer function in the controller to do this. The Timer takes the digital value fed by the A to D converter as an input. We used a conversion factor to convert the digital value into appropriate Timer count. This Timer count decides the time delay used to create the PWM pulse [2]. Hence load placed on the load cell controls the PWM pulse, ultimately resulting in load based speed control of motor. The speed is adjusted in such a way by the algorithm in the controller, that the throughput remains constant [3]. That is, the algorithm adjusts the speed to such an appropriate value, that the load transported to the destination per unit time, remains constant.

Running the system using the A to D converter operates the system is automatic mode, where the speed is set automatically depending upon the A to D output. However, the system can also be run in manual mode, where the user can input any arbitrary speed to operate the motor. This speed is independent of the “constant throughput” calculations fed into the microcontroller. Such manual control becomes necessary in certain cases. For example, a constant amount of coal is being fed into the boiler at a power plant per unit time. The “throughput” calculations will be made assuming calorific value of a certain standard-grade coal. Suppose standard-grade coal is out of supply and low-grade coal has to be fed as a temporary arrangement. Now, an increased amount of coal is now required to be fed to compensate for its low calorific value. The calculations for automatic control will not hold true now, and the system needs to be operated under manual control to account for this increased amount of coal required to be fed. The speed of the motor will depend on the input digital value fed to the 8 data lines shown in Fig. 1. This input data word will ultimately deciding the duty cycle of the PWM pulse through the timer load value.

E. Motor controller chip L293D

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F. DC Motor

DC motors are available in two varieties- geared and gearless. Gearless DC motor is the motor in its original form without any gears added to it. In this form, DC motor provides rotates with a greater speed, at very high RPM (Revolution per Minute). However, the torque produced by this gearless motor is very small. Hence this motor cannot support much load on its shaft.

When we want to use a DC motor in applications requiring more torque, we need a geared DC motor. Here, the torque will be more, but the speed of rotation will decrease a little. There is always a trade-off between the torque and speed in a DC motor, provided the supply voltage remains constant.

In our application, we require greater torque generating motor to power a load carrying conveyor belt system. Hence we have opted for a geared DC motor, rated to operate at 12V, providing enough torque to carry a load of 1kg on it shaft, at 1200 RPM. It may also be noted that this same motor is rated to operate at 24V, with slightly lesser torque output, at 2400 RPM. We may use two such motors at 12V to produce enough torque to support loads a little in excess of 1kg, for the purpose of reasonable demonstration of our model project.

G. *Circuit Assembly*

The entire circuit was assembled together on a PCB. Input and output terminals were provided on the PCB. The load cell was connected the input, while motor was connected to the output. The load cell and the motor were placed outside the PCB. The conveyor belt arrangement was put in place. Here, pulley connected to motor shaft formed one end while a lone free-wheeling pulley was placed at the other end. A conveyor belt was placed between the two ends.

III. TESTING AND SIMILATION

All individual components of the system, namely- A to D converter (ADC 0804), microcontroller interface, motor controller chip (L293D), and the DC motor were tested individually. After satisfactory results of individual testing, the microcontroller interface with each of the chips, that is, ADC0804 and L293D was tested separately. Final testing involved monitoring the performance of the entire circuit fabricated on PCB.

IV. RESULTS

The speed variation at no load condition, in response to PWM signal was observed as follows. However, the conveyor belt and pulley assembly was attached while recording the measurement. RPM was measured using a digital tachometer.

TABLE I. SPEED AS A FUNCTION OF DUTY CYCLETABLE STYLES

On time Duty cycle as percentage	Speed of motor in RPM
100	1176
70	827
50	583
30	348
10	102

It should be noted that the frequency of all PWM pulses was maintained constant while varying the duty cycle of the pulses to effect PWM scheme. This means that the duration of each square wave was maintained constant, and only its ON/OFF time was varied to vary the power supplied to the motor.

V. APPLICATIONS

It should be noted that is "constant throughput" system described here is a prototype for applications in other larger systems. For example, this system is used in "Weighfeeder" machines used in the Steel and Cement industries.

Further, this prototype finds an interesting application in the elevator system. Here, the maximum power supplied to the motor running the elevator is constant. Hence the maximum current that the motor can draw is also constant, which defines the maximum number of people (load) that the elevator can carry (for a fixed RPM of motor). When this maximum load is exceeded, more than maximum permissible current needs to be drawn by the motor (causing damage to the motor), and we call this situation as overloading. Hence, the elevator gives an alarm to reduce the load. However, there is an alternate solution to the problem. We can maintain the current constant even when the load on the motor is increased [4]. This can be achieved by decreasing the RPM, and therby increasing the torque produced by the motor, at the same power and current. Hence the prototype designed here, can be used to control the elevator speed depending on its load. Hence the elevator can now carry 150% of its maximum rated load, by decreasing its speed to 50% of the original. This can be mighty useful to meet passenger traffic requirements during peak hours of elevator use, especially in large commercial properties. Our prototype applied to the elevator system, can also work as an overload protection system, preventing the motor from drawing excess current, hence preventing burnout [5].

VI. CONCLUSION

The above system serves as a model of the automated machine systems required at the assembly line level. Our model demonstrates the use of electronics to control heavy electrical systems, making them sophisticated tools of automation. Similar automation can be implemented involving AC operated electrical machines used in conjunction with thyristors. This will help supply the industry with energy saving technology, helping generate the same production with lesser resources. Consistent focus on creating automated machine systems as a product of research and development process produces truly sophisticated tools to create state-of-the-art industries.

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