Controlling an AC Motor

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Abstract

The goal of this project was to implement a PID motor controller to control velocity in LabVIEW. The motor was a universal motor, commonly used in hand tools, controlled by phase control.

Background

Many power tools use universal motors. The universal motor is a series wound motor designed to run directly on AC power. It is called the universal motor because it will rotate the same direction with either polarity of DC current and therefore will also run on AC current. Other AC motors like synchronous or induction are limited to 3600 rpm when operated from a 60 Hz power source. The universal motor can operate at significantly higher speeds. Operating at a higher speed allows a higher power output for a given size and weight, a major benefit for handheld tools. A high speed motor with a mechanical gear reduction is almost always lighter and usually cheaper than slow speed motor.

Pulse width modulation is an efficient way to control DC motors. The motor responds to the average voltage as if it were a constant DC voltage. This is very convenient because the modulating transistors can run in saturation, reducing power losses. Because the universal motor is a type of DC motor it also responds to the average voltage. This means that pulse width modulation can be applied directly to the AC voltage and it will control the average voltage to the motor. Many semiconductors allow current flow in one direction only. A TRIAC can preform switching on AC current directly with a few conditions. One condition is that a TRIAC will remain latched on until the current falls below the threshold. Thus, the pulse width modulation must switch off as the AC line crosses zero. The switch on must occur between zero crossings. This kind of pulse width modulation is known as phase control. See Figure 1 for an illustration of phase control.
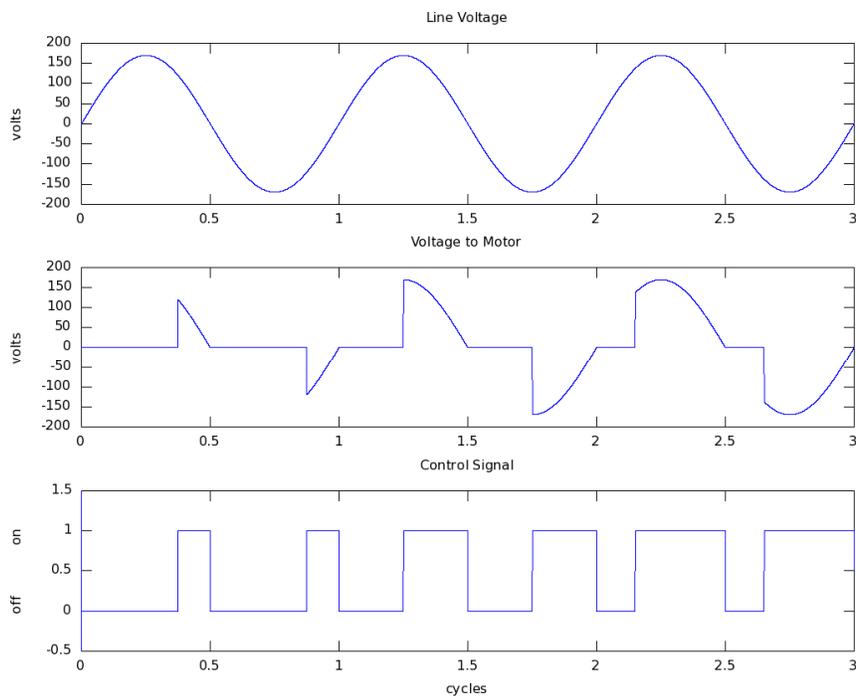

Figure 1: Phase Control

Phase control requires that the TRIAC be switched on at an exact point in the cycle. For most applications this requires the AC line voltage be monitored to detect the zero crossings. A simple dimmer switch uses an RC network to provide a phase shift to the control signal, providing a variable delay. For an digital controller, the line voltage can be sensed with an optoisolator. The optoisolator isolates the control circuits for safety as well as converting the sinusoidal wave into a square wave for easier digital processing. The output signal is also optoisolated for safety and to protect the controller from transients on the AC line, including noise generated from the phase control itself.

Implementation

The hardware for this project was minimal. See Figure 2 for the schematic diagram. The TRIAC used is rated for 600 volts and 10 amps, capable of handling the motor's 4.2 amp load plus a safety factor. RS and CS are intended to help filter noise generated by the phase control. Motor speed is measured with an optical encoder. The controller for this system was a personal computer equipped with a National Instruments PCI-6229 interface board and LabVIEW software.
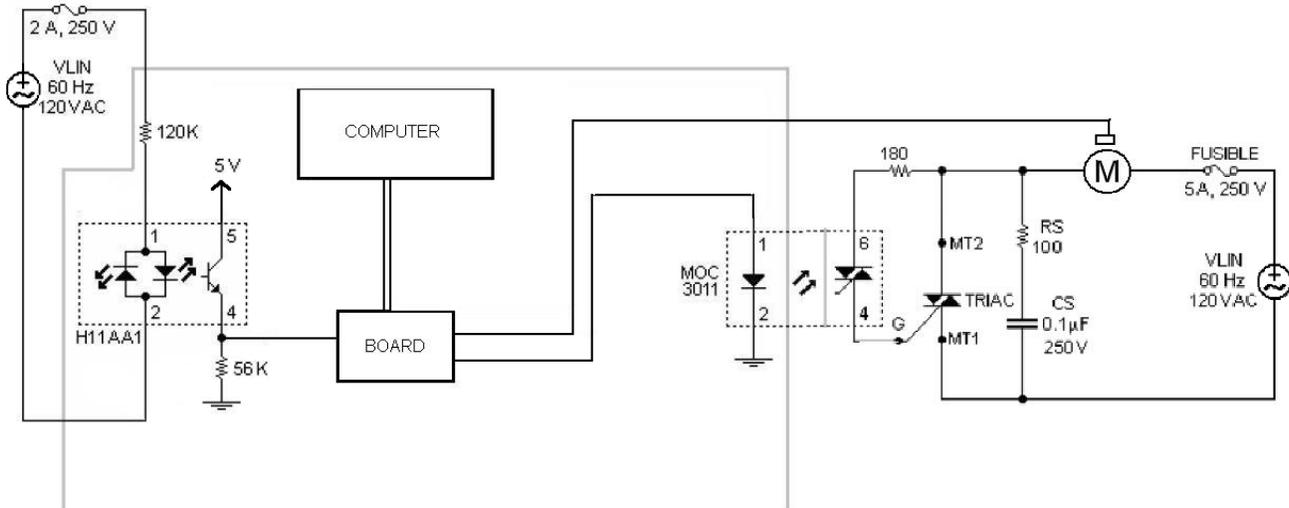

Figure 2: Schematic

The PID controller is implemented in a literal fashion by computing the integral and derivative of the error. The controller was created in modules to allow easy testing and reuse of the code. Tuning the algorithm was done by applying the tangent method to the step response and adjusting the constants according to the Ziegler-Nichols rules.
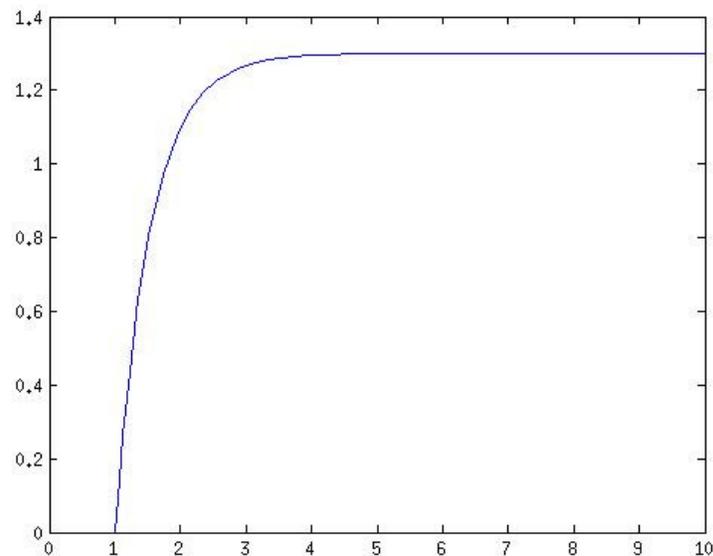

Figure 3: Open Loop response

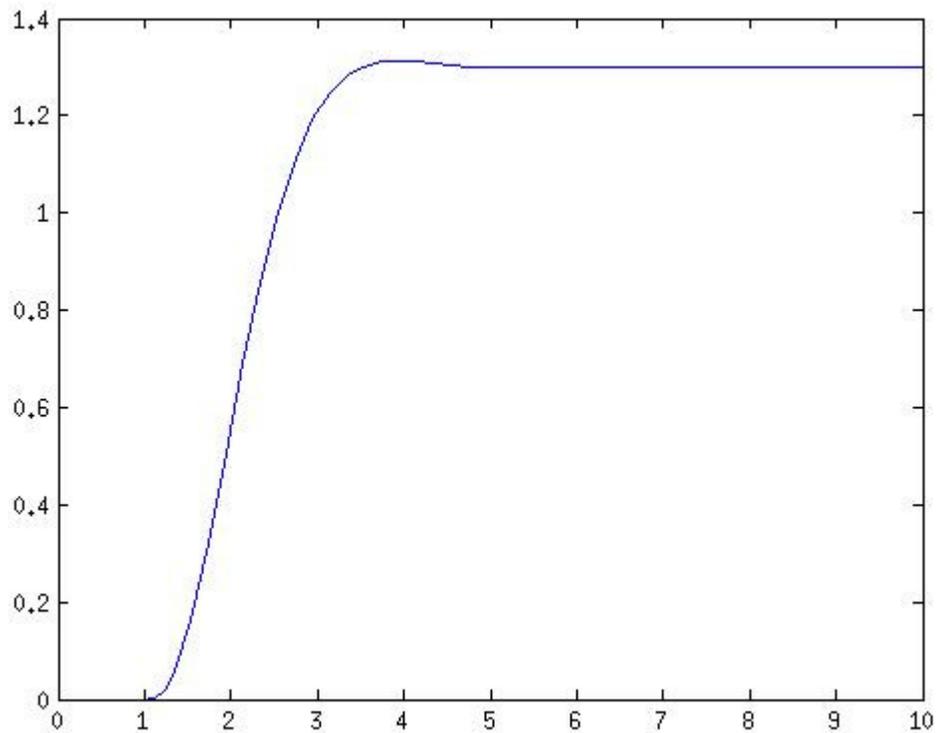These rules suggested Kp=4.334, Kd=2.167, and Ki=18.84.

Figure 4: Closed Loop Response

Buffers in the board and in LabVIEW's processing added delays to the output signal in relation to the AC line reference. To compensate for this we added a phase offset to the output. The delay was consistent so the offset was adjusted manually, using an oscilloscope to monitor the output. This offset is the calibration input in the program.
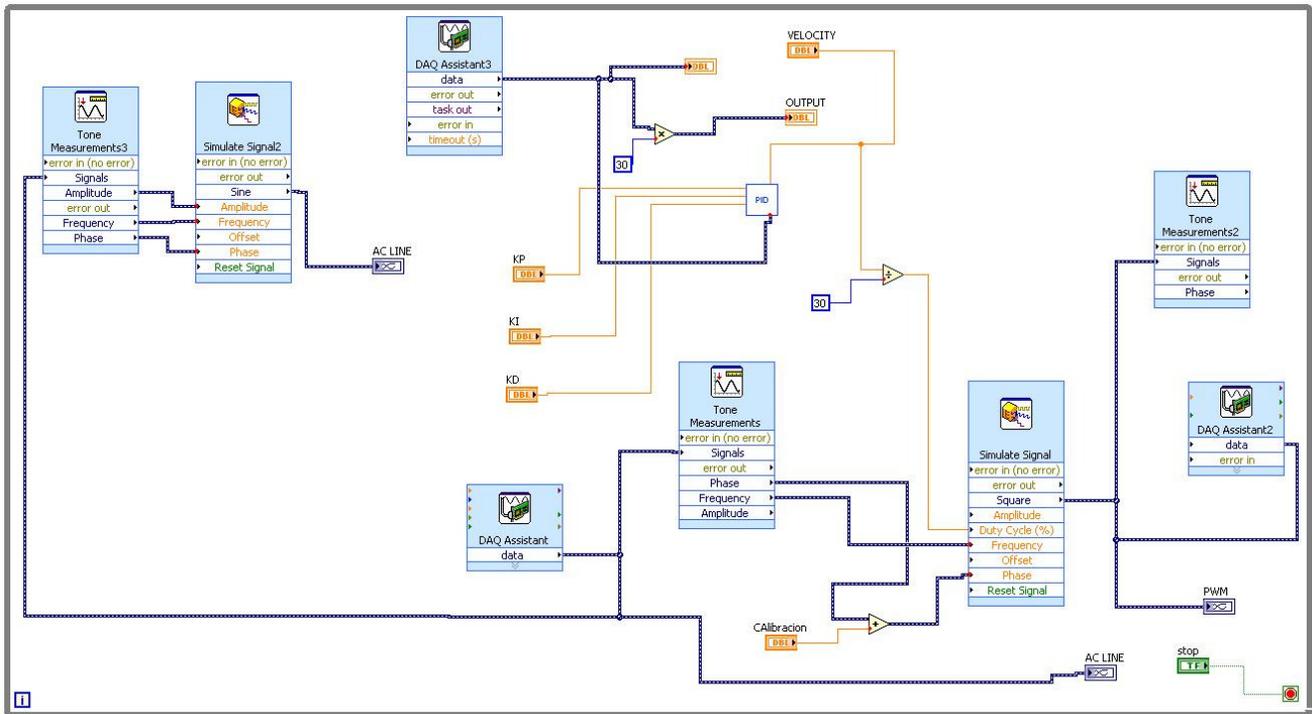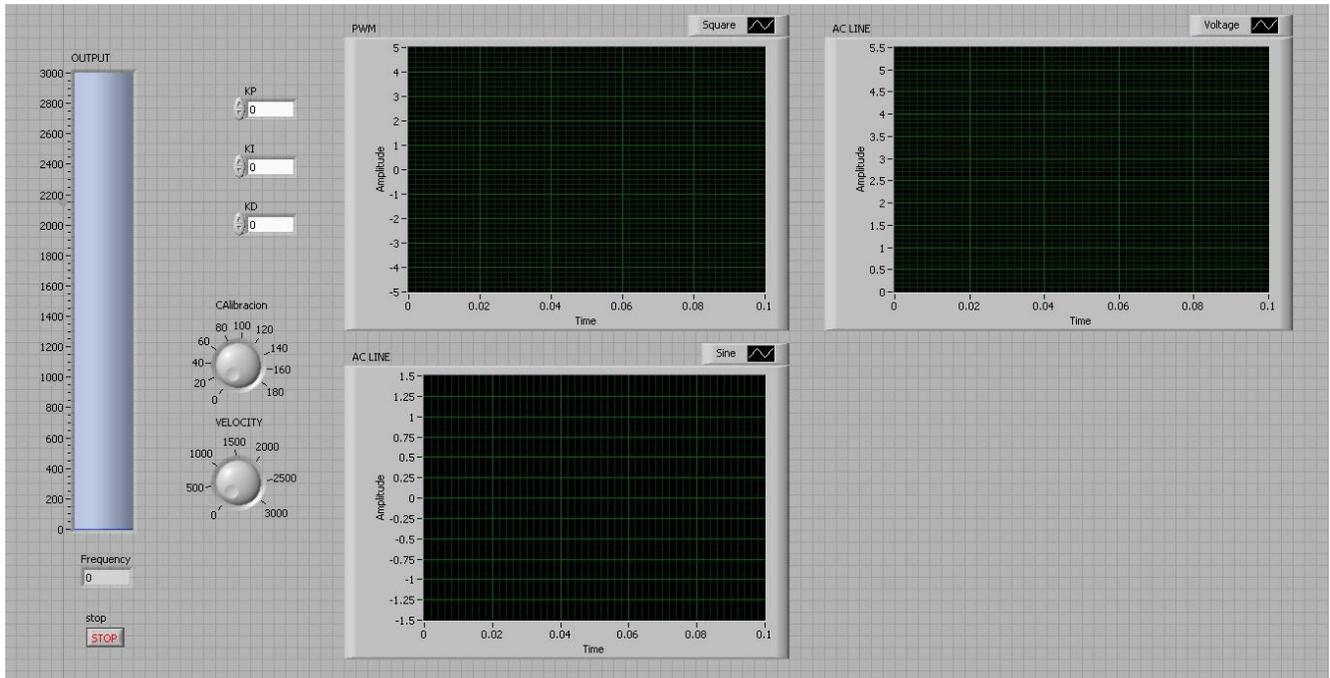
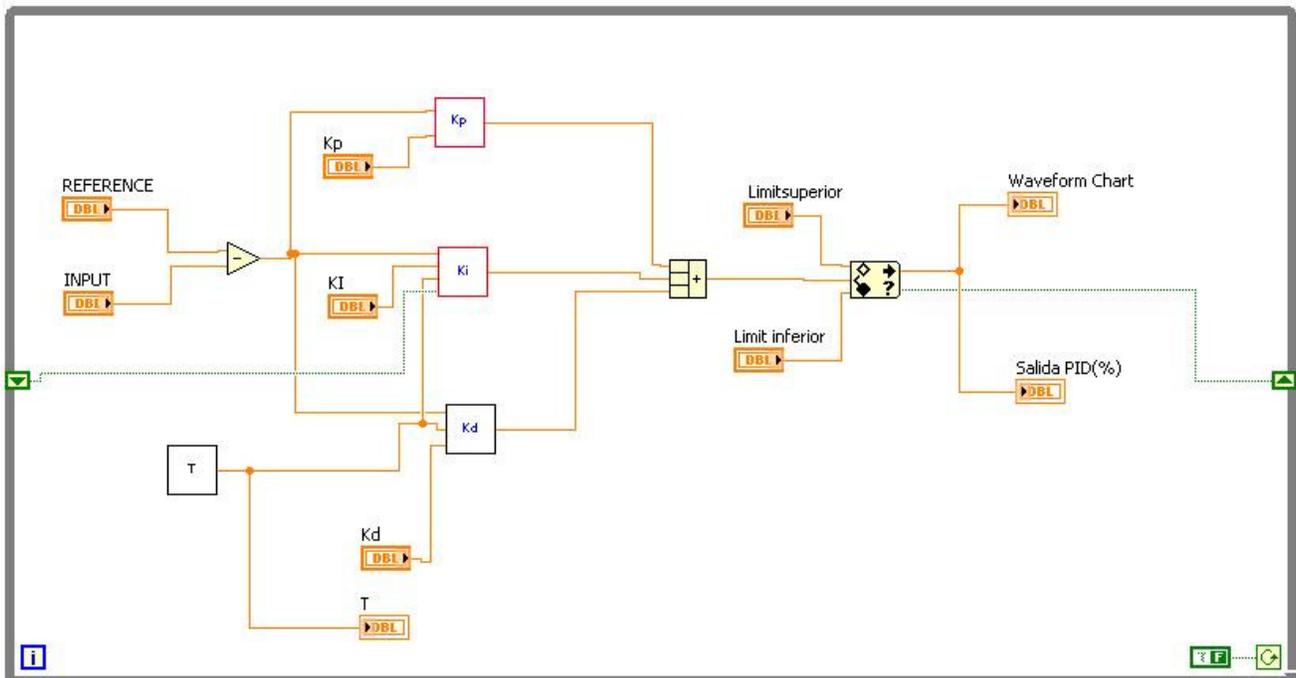Figure 5: Main Program Source

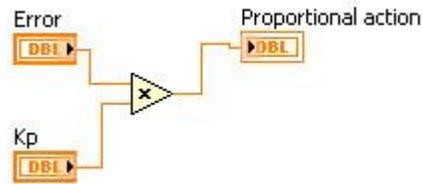Figure 6: Control Panel

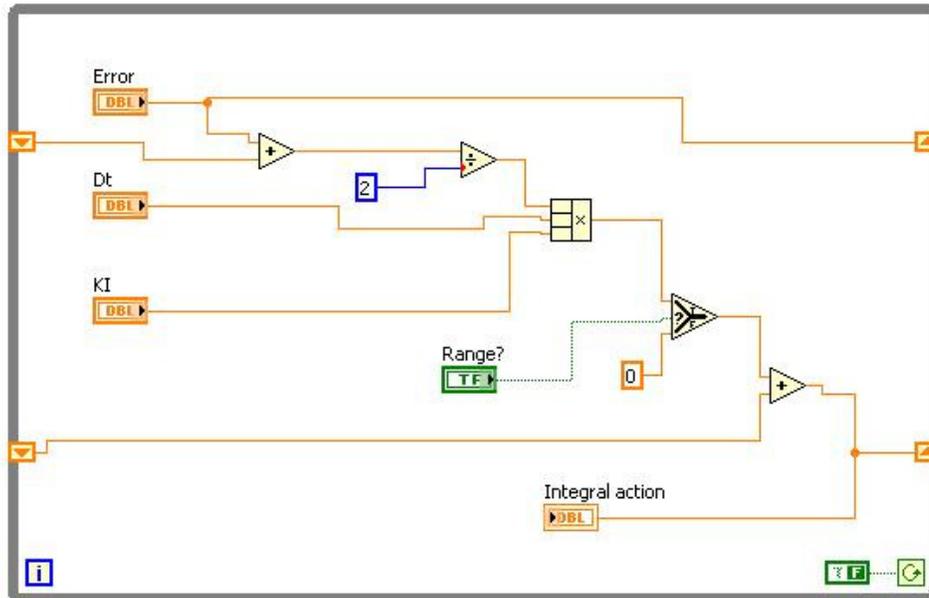Figure 7: PID Controller Block

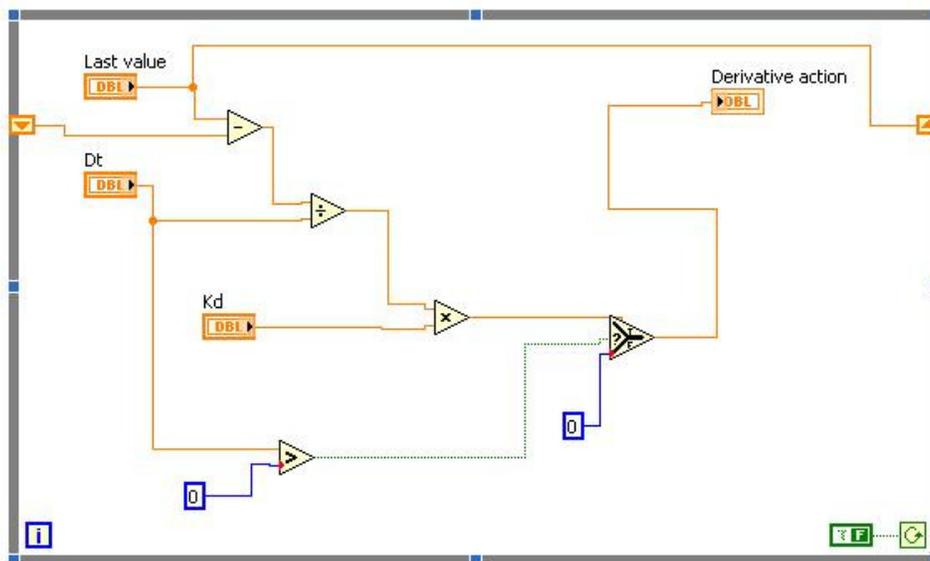Figure 8: Proportional Section

Figure 9: Integral Section

Figure 10: Derivative Section

Conclusion

The combination of a universal motor and phase control is a simple and elegant means of providing controlled motion from AC line power. This combination provides good control, light weight, and low cost. Phase control create large amounts of electrical noise that may be a problem in some applications.

LabVIEW is well suited for controls applications. Using a LabVIEW program for the controller allowed quick and easy changes, as well as easy monitoring of inputs and outputs. One does need to remember and compensate for additional delays caused by processing as most operating systems are not designed for realtime operation. A logical design path would be to replace the interface board with a microcontroller after the control system design is finished. This design process could be faster and easier than trying to tune the control system on a microcontroller.

References

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