PIEZOMOTION

OPERATION OF PIEZOMOTOR IN OPEN LOOP MODE USING PWM

TECHNICAL GUIDE

Discover **affordable precision** with piezoelectric **innovation**.

PWM control of Piezo Motion piezomotors

PWM operation is enabled through the Connector J3 on the smaller +5 V powered driver board for the RAS and LAS motors and through the three-prong connector on the larger +12 V powered driver board for the RBS, LBS, and LCS. For the larger driver board Pin 1 and 2 are for control signals and Pin 3 is GND. For both boards a TTL level PWM signal is used, for the smaller board this means that 2.0 to 5.0 V is “High” and 0.0 to 0.8 V is “Low” while for the larger board 1.8 to 12.0 V is “High” and 0.0 to 0.8 is “Low”. Please note the following:

1. On the smaller board “High” level signal enables travel and “Low” level signal disable travel.
2. On the larger board “Low” level signal enables travel and “High” level signal disable travel.

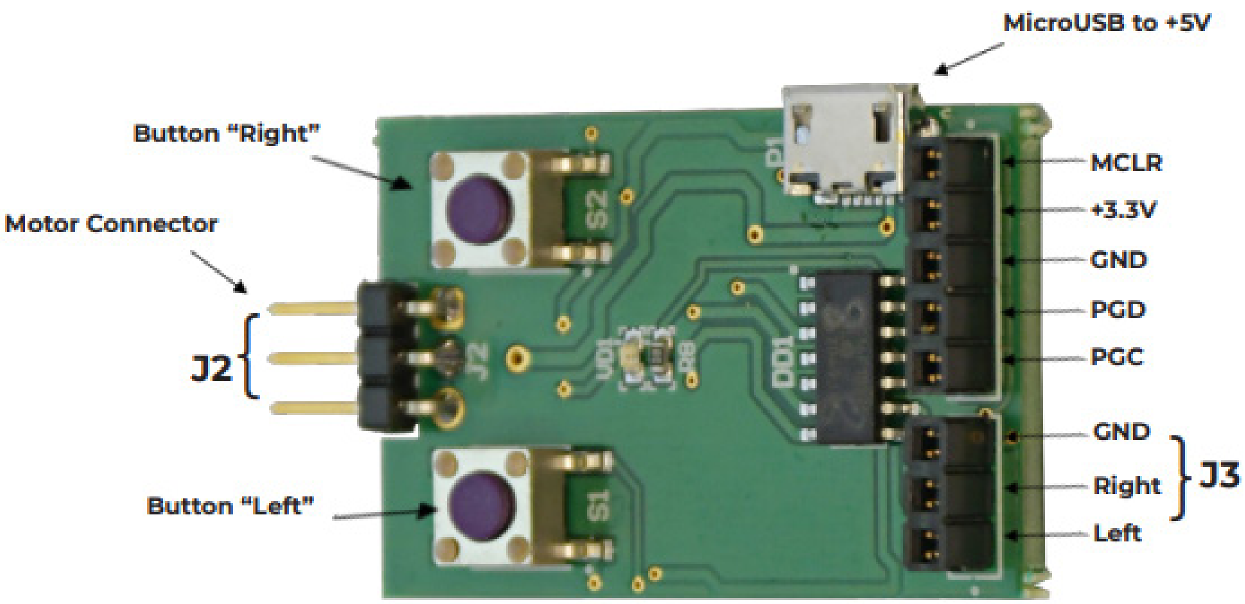

Figure 1

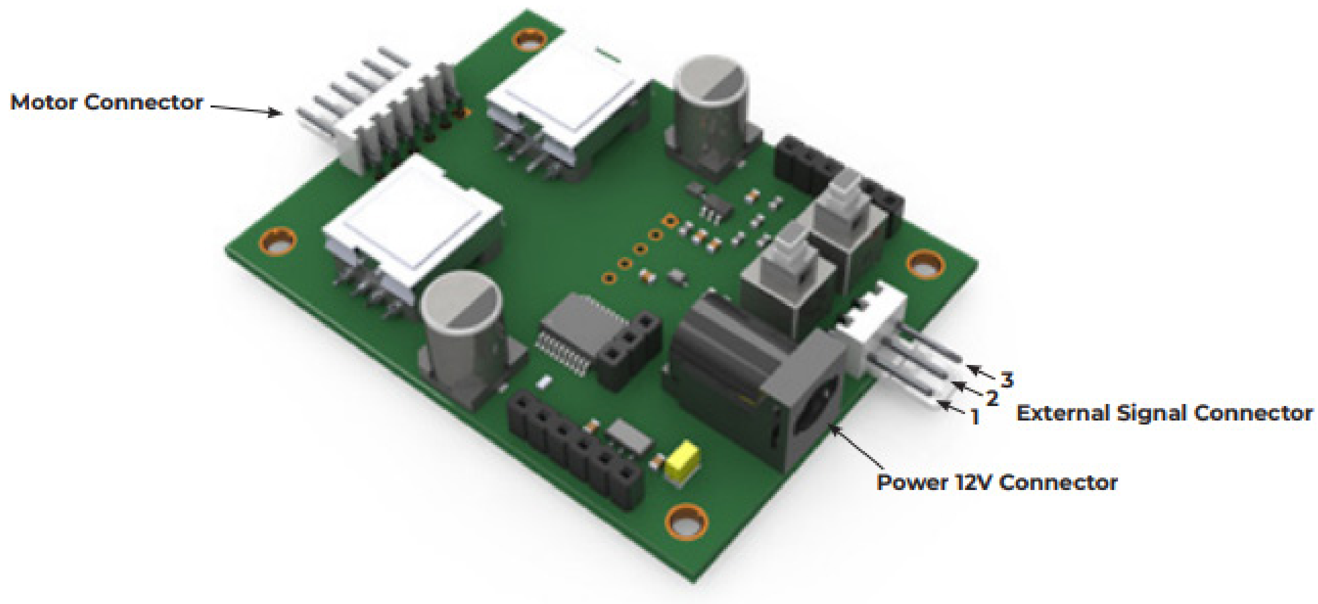

Figure 2

In PWM open loop mode the piezomotor is controlled by a train of electrical pulses supplied by a digitally controlled AC voltage source to the piezoelement. For the duration of each pulse the excitation AC voltage is applied to the piezoelement at its ultrasonic resonant frequency. The speed of the motor is altered by varying either the repetition rate of the pulses comprising the train or the duration of each individual pulse (i.e the pulses of excitation from the voltage source are modulated).

The size of each step is determined by the pulse duration, and the speed of travel is determined by the pulse repetition rate. The minimum pulse duration is approximately 25-30 μs (microseconds) for RBS, LBS and LCS motors and 10-15 us for RAS and LAS motors. The maximum repetition rate (F), measured in Hertz, for a selected pulse duration (T), measured in seconds, is determined by the formula $F = 1/T$. The range of speed variation in PWM mode can be up to 6 orders of magnitude.
This is achieved using a digital controller.

The waveform shown, Figure 3, illustrates the basic principle of control in both stepping and continuous modes of operation.

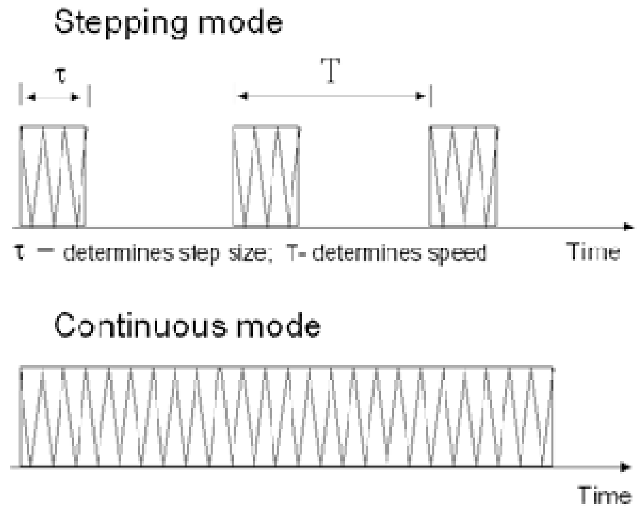

Figure 3

The PWM control will be a proportion of the maximum speed of the motor.
For example:
A linear motor has a maximum speed of >200 mm/s
To achieve approximately 20 mm/s speed requires a 10 times reduction. Please note: For precise speed adjustment, an encoder fitted motor would need to be used and closed loop control needs to be implemented.
If a PWM frequency of 100 Hz is utilized the period will be 10 ms and the pulse (TTL Low) should be at 1 ms

Making small steps consistently

The reproducibility of small steps produced by piezoelectric actuators depend on several factors.

1. **Variability in the manufacturing process of the Piezo Ceramic resonator**
   The Piezoceramic resonator is sintered from a powder mix. It is then polarized to achieve the required properties, the surfaces are plated with the electrode layers and finally the resonator is finish machined to final size. Process variation leads to small differences in the characteristics of the final resonator and its response to applied electrical signals.

2. **Tolerances in machining of the rotor/slider surface**
   The tolerances in machining of the rotor/slider surface is a major factor in determining the intimate contact between the piezoelectric resonator and the rotor/slider surface. The tolerance requirements are determined by the specificity of the mating piezo resonator and rotor/slider couple.

3. **Consistency in the friction force along the rotor/slider surface**
   The first factor, which determines the consistency on the friction force is the cleanliness of the surface. Localized deposit of impurities on the surface of the rotor can decrease or increase the friction force, leading to variation in the commanded micro-step. Most of the time, the vibrating nature of the piezo resonator leads to self-cleaning of the rotor/slider surface. In extreme cases, oil or other slippery deposits can compromise the work of the piezo motor.

A second factor, which determines the consistency on the friction force is the consistent spring load along the movement range of the actuator. This factor is mainly determined by the mechanical design of the actuator.

4. **Variations in resistive load of the motor**
   Variations in resistive load of the motor during movement can lead to change in step size and speed of movement due to the dependence of speed from load (see Load Curve).

5. **Tolerances in the duration and amplitude of the applied pulses to the piezo resonator**
   These tolerances directly affect the time the piezo resonator is excited during each pulse and the amplitude at which it vibrates. Increase in pulse time and bigger amplitude lead to bigger steps.

6. **Environmental conditions, specifically temperature**
   Temperature variations due to variations in the environmental temperature or due to heating of the piezomotor during work may affect the physical dimensions of the rotor/slider tens of micrometers, which may affect the length of the micro-step.

Experimental data

Movement at small distances

Some examples of operation in open loop mode are given below. Figure 2-4 show proportional control with Piezo Motion linear motor with single steps, sequence of 10 steps or sequence of 100 steps in open loop mode and PWM control.

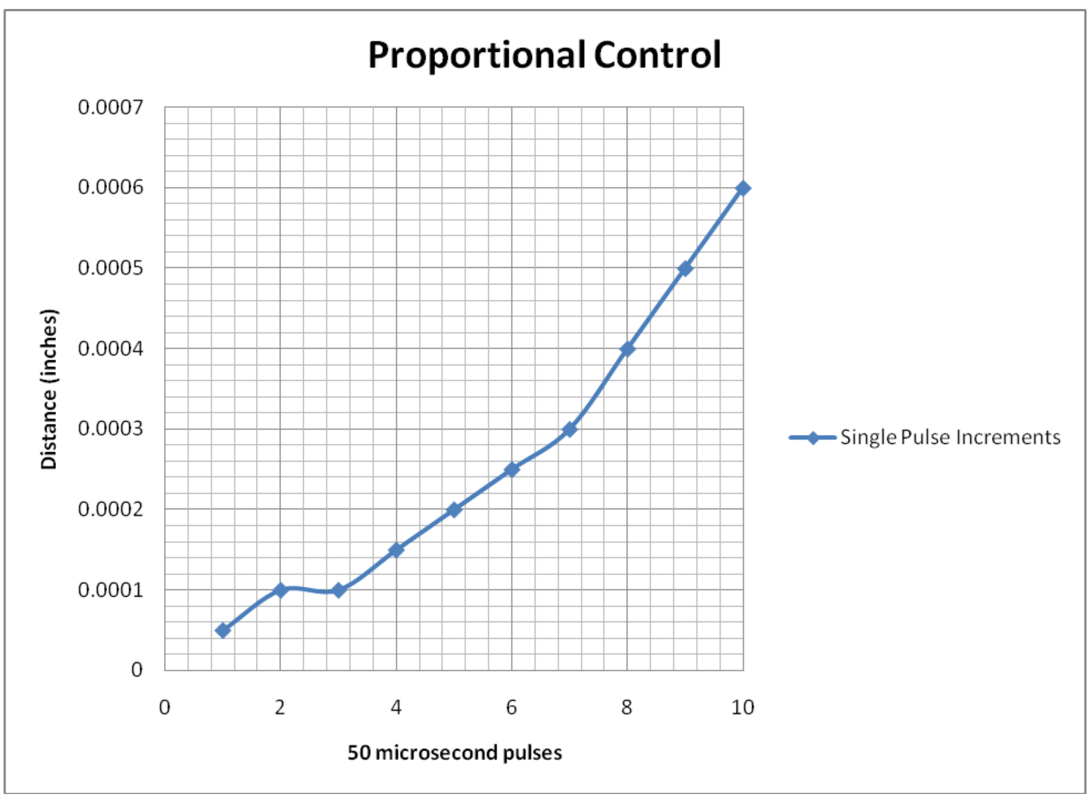

Figure 4. Proportional control single pulse increments

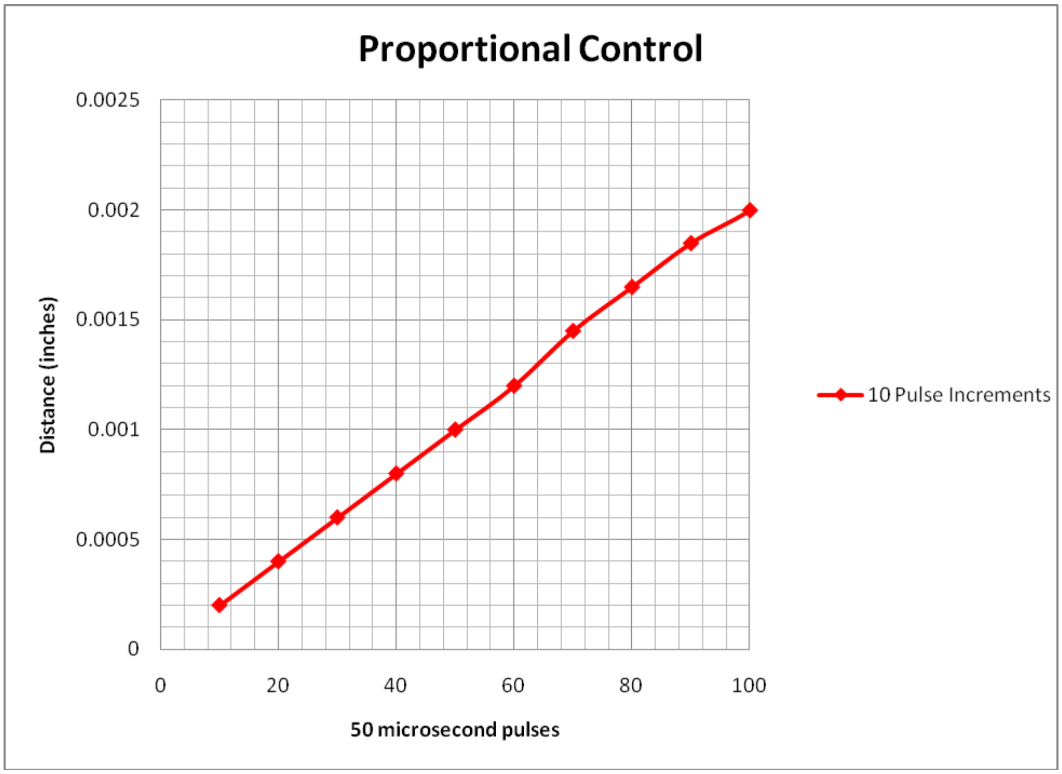

Figure 5. Proportional control 10-pulse increments

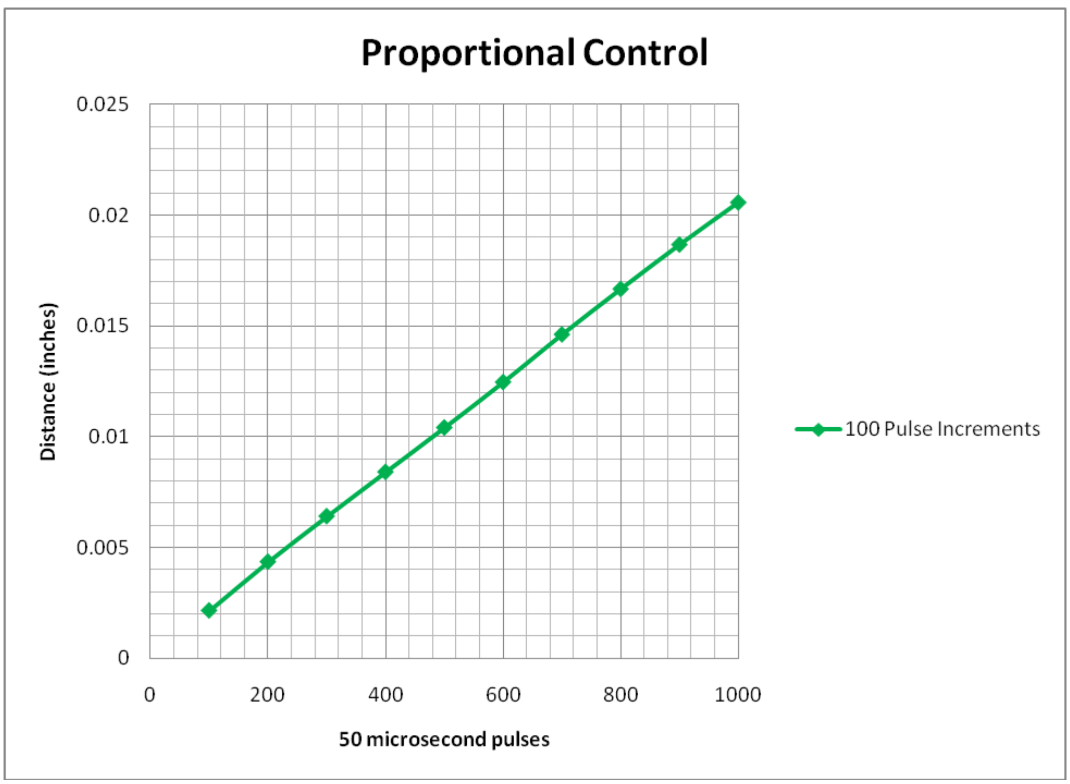

Figure 6. Proportional control 100-pulse increments

It is seen that the biggest deviation is with singles steps, which can differ with as much as 50%, Figure 2. When the movement is implemented with a series of 10 steps the deviation falls to 14%, Figure 3. When the movement is implemented with a series of 100 steps the deviation in each consecutive series is insignificant, Figure 4.

There is a nonlinear relationship between pulse duration and step distance from the minimum duration up to around 100 us. After this the step size is relatively proportional to the pulse duration. Figure 5 shows the results for an LCS motor as an example.

Time,us	Distance,um
20	0,05
28	0,1
50	0,7
80	4
100	10
200	30
300	50
400	72
500	100

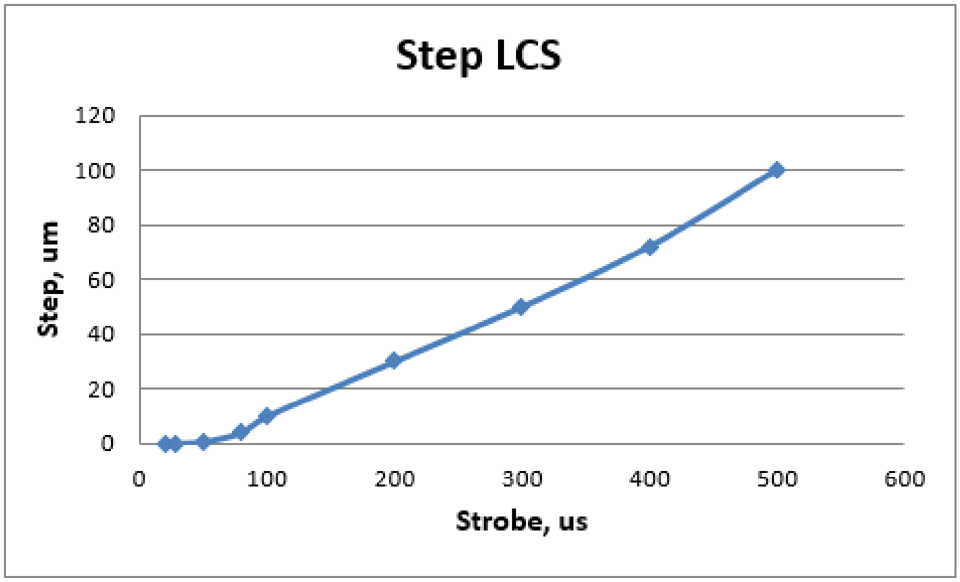

Figure 7. Input pulse duration vs step size for Linear LCS motor

Movement at larger distances

The examples above account only for relatively small amplitude of movement, about 1 mm movement for each point on Figure 4. On larger distances, the tolerances in the preparation of the rotor/slider and the spring loading system can lead to fluctuations in the step size/speed in the order of 5-10 % along the movement of the surface of the rotor/slider.

Movement in opposite directions

The same considerations apply to movement in opposite directions. Asymmetry due to tolerances in the spring loading system, piezoresonator and other mechanical components of the motor can lead to differences in step size/speed in the order of 5-10%.

Practical recommendations for using Piezo Motion piezo motors in open and close loop with PWM control

The results above indicate that the user must choose wisely the mode of operation (open loop mode without encoder feedback) or closed loop mode (with encoder feedback) depending on their application.

Open loop Control setup will need to be determined by experimentation for a specific motor.

Due to variables discussed there may be different performance between motors. For a specific motor with documented control structure and constant conditions the open loop control may be acceptable.

If the application requires reproducible and repeatable movement between two positions, better than the described above errors, a piezo motor with an encoder and feedback-based, close loop control is recommended.

An example for this mode of operation applies to situations where repeatable scanning in both directions is required. If open loop mode is selected for this application the end stop points will drift gradually, because of the small differences in open loop step size/speed for the two opposite directions of movement.

Open loop mode can be selected in applications where mechanical stoppers can be installed to limit the movement of the motor within a certain range or if the tolerances and repeatability are found to be within the range of accuracy for the application. Additionally, open loop control is most likely possible when always returning to a home position after the motion path. Potentially the open loop response could be mapped and control signal adjusted according to a look up table in response to a known variable such as temperature.

Please note, that Piezo Motion piezo motors are constant current motors and if the motors are stopped by opposing force or mechanical restriction, the current of the motor is not increased. In contrast, any electromagnetic motor, which is forcefully stopped, increases its current significantly, which may lead to its overheating and damage.

Please contact Piezo Motion Support team if you have questions about your specific application.