Design of a Motion Control System using Stepper Motors

There are four basic components of a single axis motion control system based on a stepper motor:

1. Step motor, 2. Drive, 3. DC Power Supply, 4. Controller/PLC.

A standard stepper motor does not have position feedback sensor, and hence controlled in open-loop mode (Fig. 1). However, the stepper motors with position sensors are also available and can be controlled in closed loop mode.

Controller sends the “Step” and “Direction” signals to the Driver, also called “Drive”. The “step” and “direction” command data can be carried by dedicated digital lines (one for each) or by a high speed serial communication protocol such as EtherCAT.

The Drive controls the power transistor “Switch Set”, ON/OFF/Proportional state, based on the configuration of the drive which is implemented in the “Translator”. The power transistor switch set carries the current to the stepper motor phase windings.

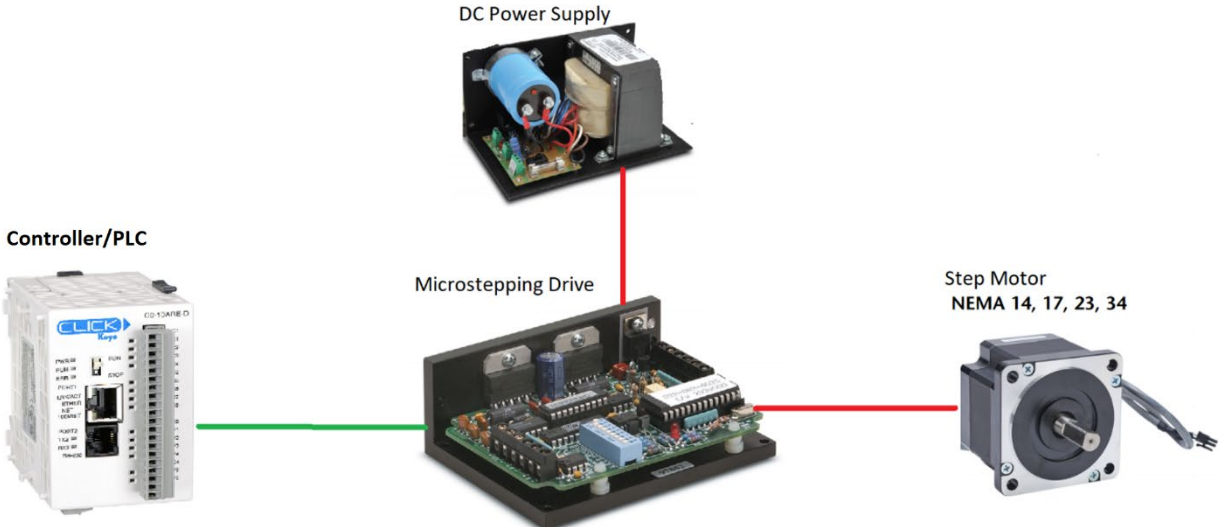


Fig. 1 – Single axis motion control system using a stepper motor (open-loop mode).

The wiring diagram between Controller, Stepper Driver and DC Power Supply is shown below (Fig. 2). The connection between the controller and driver shows the minimal requirement: STEP and DIRECTION signals. It is advisable to also connect the ENABLE (input to the drive) and FAULT (output from the drive) lines. Electrical polarity and type of wiring for digital IO can be one of three different types: Sinking, Sourcing and Differential I/O signal wiring.

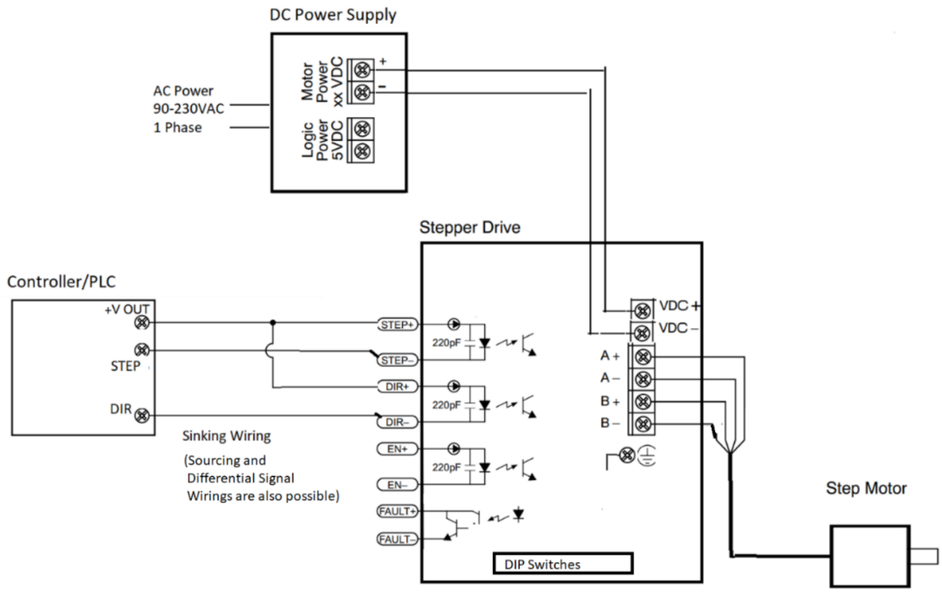


Fig. 2- Wiring diagram between components of a single axis motion control system using open-loop stepper moto (stepper motor without a sensor).

Sizing of stepper motor, drive and DC power supply must be matched. The starting point for the sizing is the application torque and speed requirements, which determines the stepper motor size, which determines the drive size, which then determines the DC power supply size. The motor-drive-DC power supply must be matched for proper power. That involves the matching of the components in terms of voltage, current and power rating.

Let us assume an application torque (rms and maximum) requirements and maximum speed requirement is given. Then, this determines the torque and speed rating of the stepper motor required.

Once a stepper motor size is picked based on that, then the motor rating for the following can be found from the specifications of the selected motor;

Motor rating: maximum winding voltage and current per phase;

$$V_{m,max}\ ; \qquad I_{m,max} = 2 * I_{phase,max}$$

Drive rating: maximum voltage drive can provide should not exceed the motor maximum voltage rating, and should have at equal or greater current capacity;

$$V_{d,max} \le V_{m,max}\ ; \quad I_{d,max} \ge I_{m,max}$$

DC power supply rating: maximum DC voltage and current it can support,

$$V_{ps,max} \le V_{d,max}\ ; \ \& \ I_{ps,max} \ge I_{d,max}$$

The Stepper Drive basically have two components: translator and switch set. Switch set has power transistors to control the current in each step motor winding. Switch set deals with controlling the flow of current at the power stage. In Uniphase type drive, the “Switch set” is four power transistors in parallel. In bipolar drive, that is two H-bridges. The “translator “stage which converts the step and direction pulses to the control signals into the power-stage “Switch set”. In Half or Full Step mode, the transistors in the switch set are simply either ON or OFF. In micro-stepping mode, they are proportionally turned ON/OFF based on the step/direction pulses (Fig. 3).

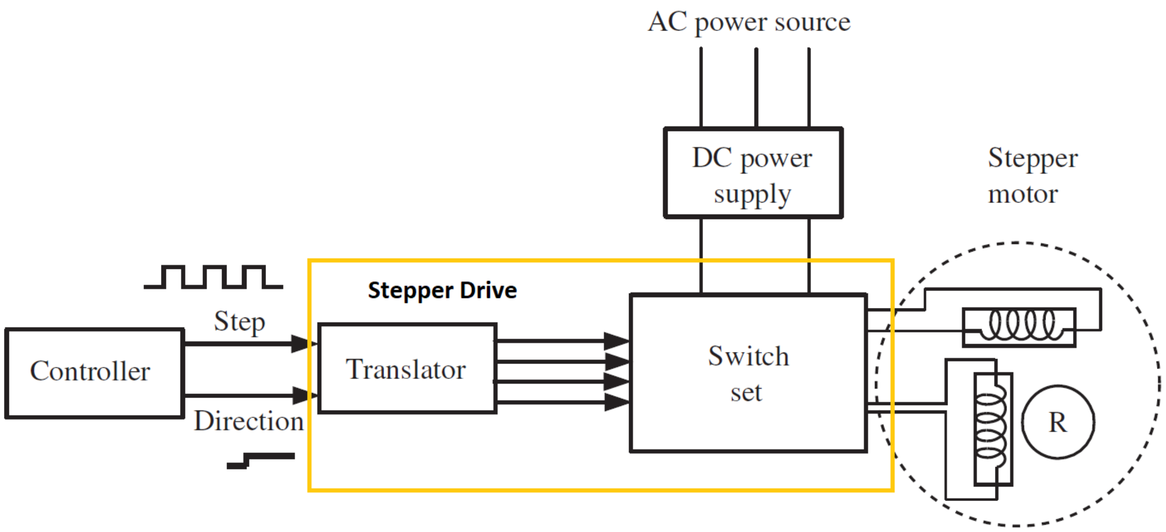


Fig. 3 – Stepper motor based single axis motion control system: two phase stepper motor and stepper drive which has "translator" module and "power electronic switch (transistor) set".

The application power requirements determine the step motor size requirement; torque rating and maximum speed required. In addition, positioning resolution (accuracy) requirement of the application determines the required step resolution of the step motor-drive combination. The positioning resolution capability is determined not by stepper motor alone, but by the type of stepper drive (i.e. capable of full, half, microstepping modes) and the stepper motor combination.

Once the step motor size is selected the Stepper Drive can be sized to support the Step Motor. Quite often, one Stepper Drive is sized to be configurable to multiple sizes of motors. The drive current output limit is configured (either via software setup or DIP switch settings) to customize and match it to the step motor size; that is the current capacity of the step motor. For example, a stepper drive is capable of carrying current magnitude from 0.4 $A/phase$ to 3.5A/phase, and it can be configured to any value between these limits in increments of 0.1 A/phase. Drive can be further configured either using a setup software or DIP switches for

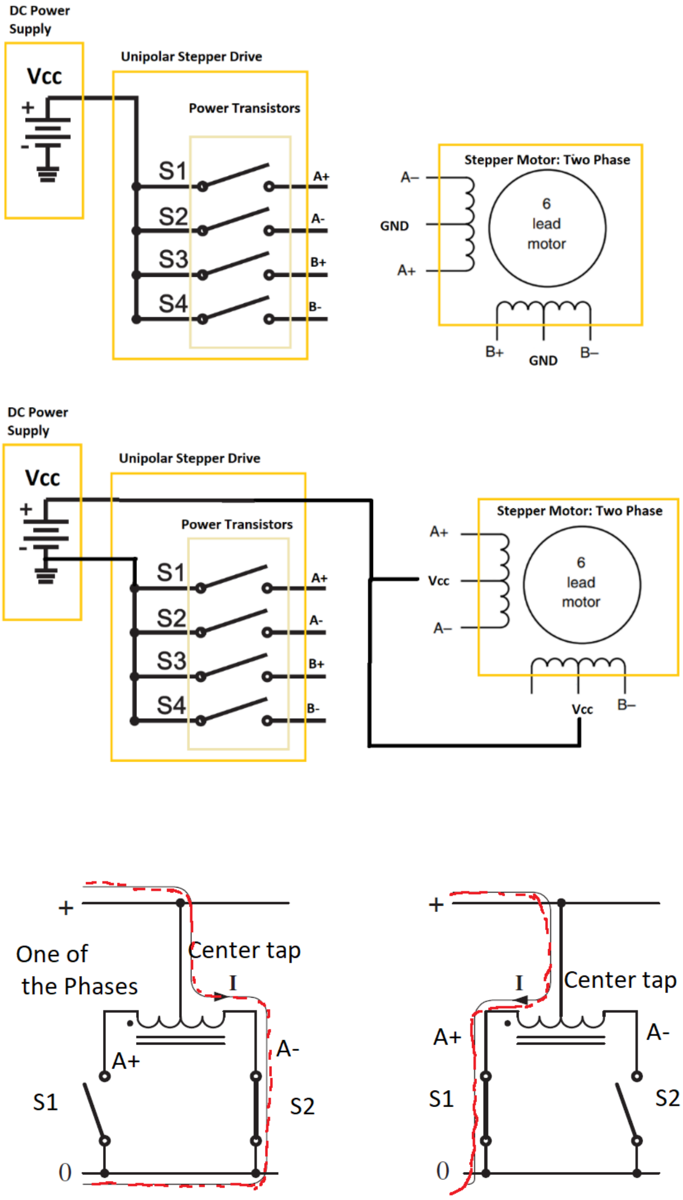
- Output current limit to match to the motor
- Step resolution: micro-stepping (number of steps/rev), half-step, full step modes chosen
- Enable/Disable reduce the current in stand still to reduce heating feature

DC Power Supply should provide a DC voltage that the Drive is rated for, plus it should be capable of providing the necessary current to the drive (or multiple drives) it is connected to. In step motor applications, the DC power supply power capacity is usually sized to meet the per phase current requirement of the motor.

There are two major types of Stepper Drives (Fig. 4):

1. Unipolar Drive
2. Bipolar Drive

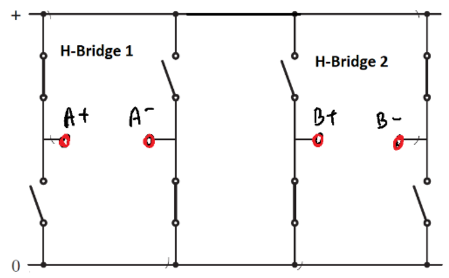
Unipolar drive power stage is such that current in each phase is controlled by two transistors. Each phase is center tapped to either supply voltage Vcc or ground (GRN). Then the other two leads of the phase winding is connected to Ground (GRN) or supply voltage Vcc via a transistor each. At any given time, only one of these transistors are turned ON, and the other one is turned OFF. Current direction is opposite when the pair of transistor ON/OFF states are switched. At any given transistor state (one ON, one OFF), only half of the winding is used to conduct current. For a drive to support two phase unipolar stepper motor, the unipolar stepper drive has four transistors. The two phase motor has 6-wire leads; A, A- and Center, B, B-, Center wires. Unipolar drives are used much less than bipolar drives.



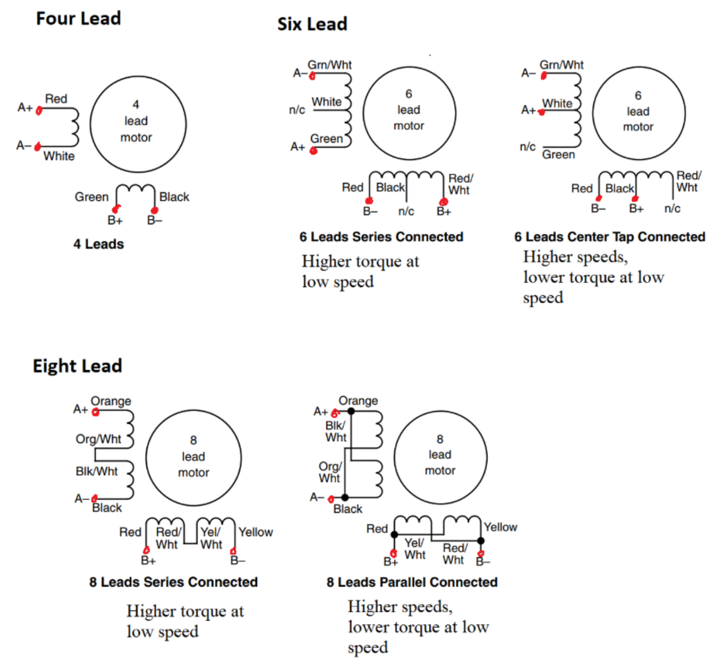
Unipolar Stepper Drive and Motor Phase wiring and current control

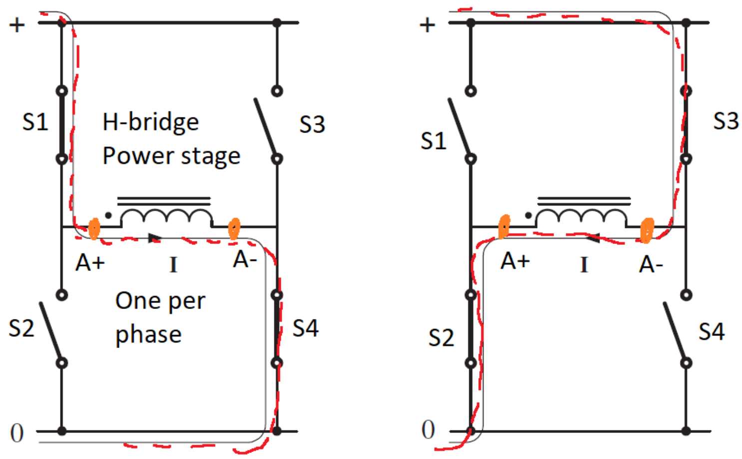
Bipolar drives use an H-bridge for each phase of the stepper motor. Using H-bridge, the current direction (+ or – directions) can be controlled, in addition to magnitude. For a two phase stepper motor interface, the bipolar drive has two H-bridges, one for each motor phase.

Stepper Drive: Bipolar, Two Phase



Stepper Motor: Two Phase, Bipolar





H-bridge (four transistors) controls current direction by operating transistor pairs (S1 & S4, S2 & S3) and magnitude by operating the transistors in proportional (linear) range.

Translator implements the following table in Half/Full step mode: that is which power transistors to turn ON or OFF for a given step and direction pulse. For each step pulse, we move one row on the table. Direction of move is determined by the "direction" signal (Fig. 6). In micro-stepping mode, the table simply have more rows and that the transistors controlling the phase currents are partially (proportionally) turned ON/OFF, not just fully ON/OFF. Table below is shown for a stepper motor with 200 full steps/revolution (400 half steps/revolution) with 50 teeth. In other words, there are 8 states in half step mode per tooth. That 8-state per tooth repeats for 50 teeth per revolution.

Step Table
(half stepping)

Step	A+	A–	B+	B–
0	open	open	+	–
1	+	–	+	–
2	+	–	open	open
3	+	–	–	+
4	open	open	–	+
5	–	+	–	+
6	–	+	open	open
7	–	+	+	–
8	open	open	+	–

DIR=1 cw (downward)

DIR=0 ccw (upward)

Step 0 is the Power Up State

Fig. 6 – Step table implemented in the stepper drive's "translator" module: convert each "step" and "direction" pulse into a transistor state as shown in the table.

Stepper drive is customized (configured) for a particular matching stepper motor. That means the drive is capable of supporting different stepper motor sizes. We then configure it for a specific application using either driver's configuration software (provide by the drive Supplier) or by hardware DIP switches. The example below shows how the drive is configured using nine (9) DIP switches. Increasingly, these configurations are done through software instead of DIP switch settings (Fig. 8).

The configuration decisions are

- Select the maximum current per phase (match the motor size)
- Select number of Steps/Rev (microstepping)
- Enable/Disable 50% Standstill (Idle) current reduction mode
- Turn ON/OFF a Self Test mode

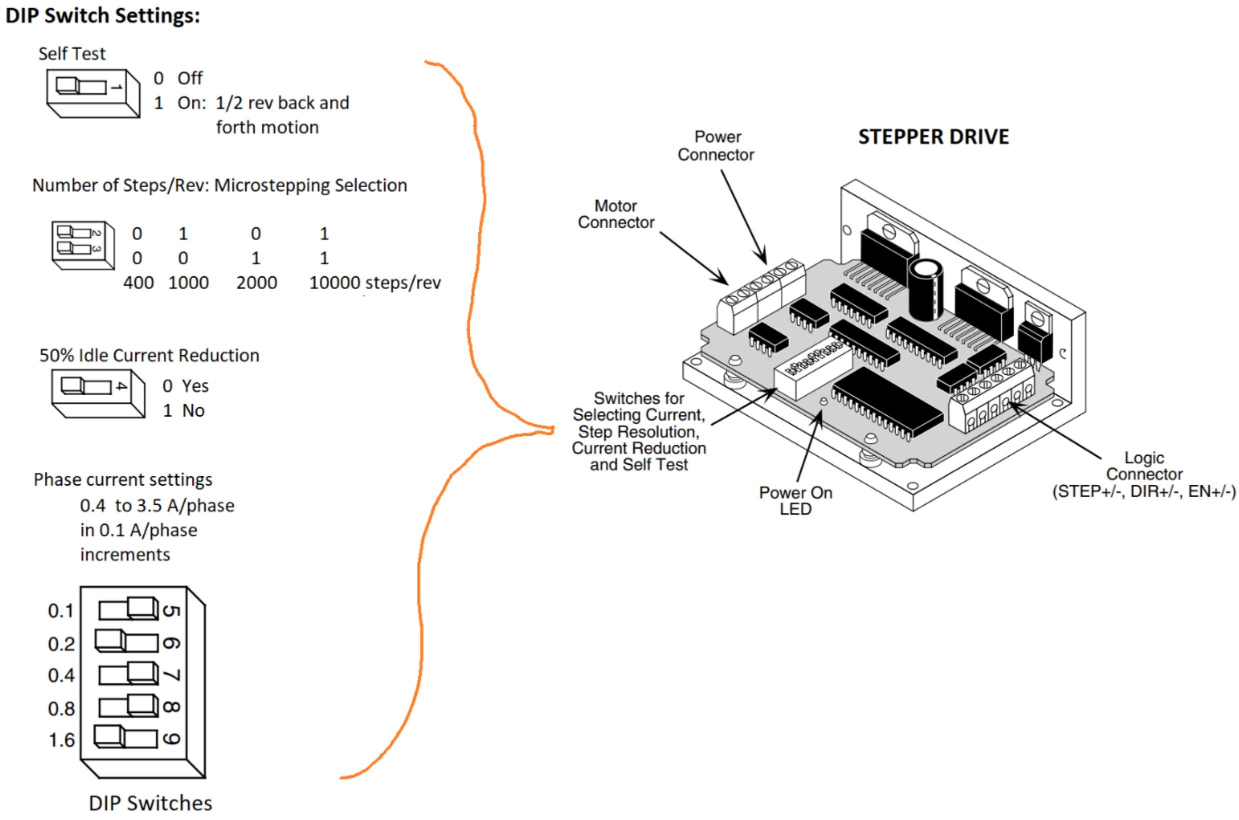


Fig. 8 – An example of DIP switches used to configure a stepper drive.

A multi axis motion control system components using stepper motors is shown in figure below (Fig 9 and 10). Stepper motor and Drive pair are required for each axis. The DC power supply needs to be large enough to support all of the axes. Typically a multi-axis controller is used for the motion control, i.e. a PLC or motion controller. The controller and drive interface can be

1. digital I/O based where the controller and each drive has digital I/O lines for Step, Direction, Enable, Fault (3 Digital Output, 1 Digital Input from Controller view) per Drive. For a three axis system that would require 9 DI, 3 DO at the controller side.
2. EtherCAT based communication where each Drive has EtherCAT Slave mode implementation and commands are sent from the controller to the drives over EtherCAT. In that case, the number of axes that can be supported is up to 64 axes in one EtherCAT chain.

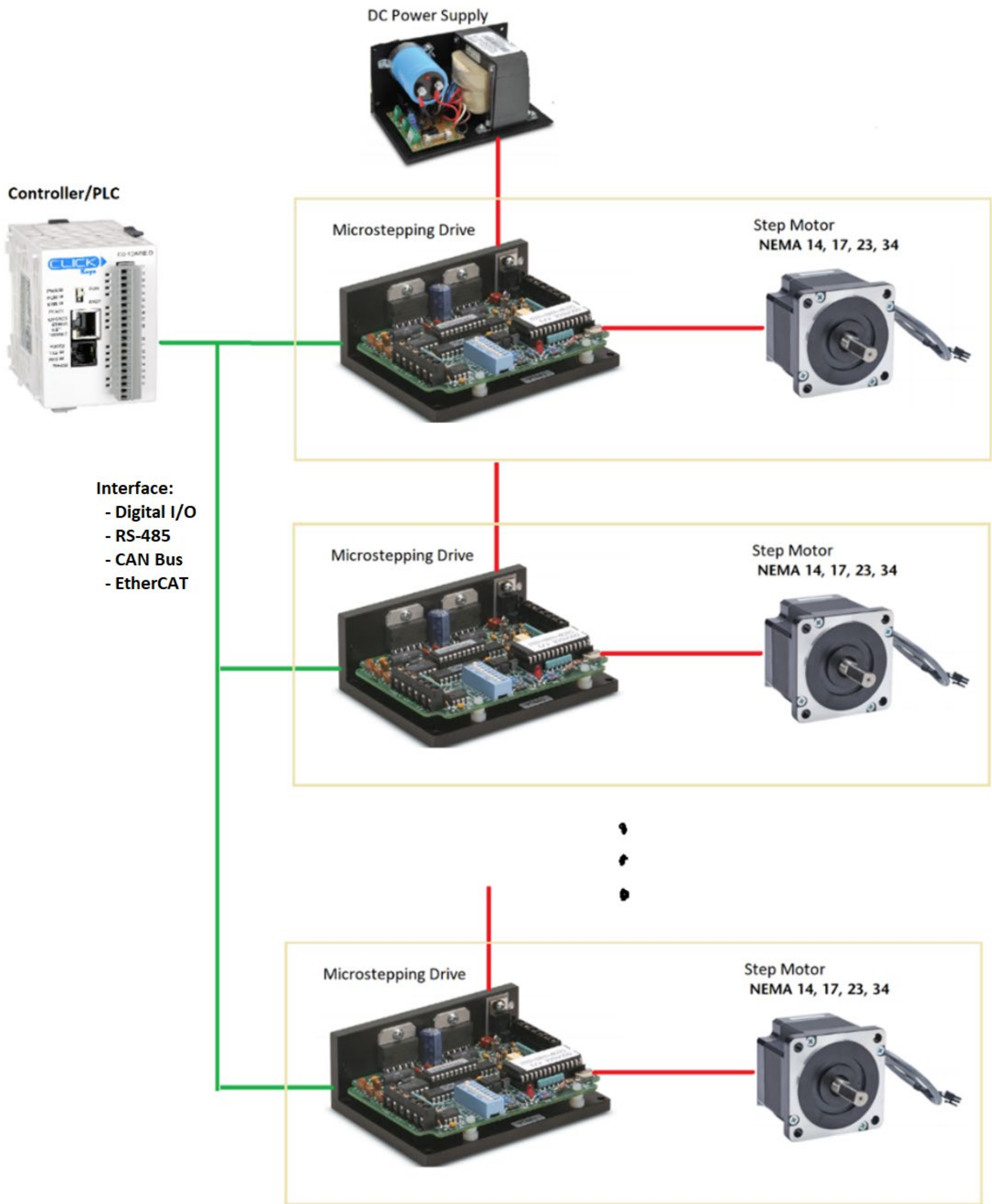
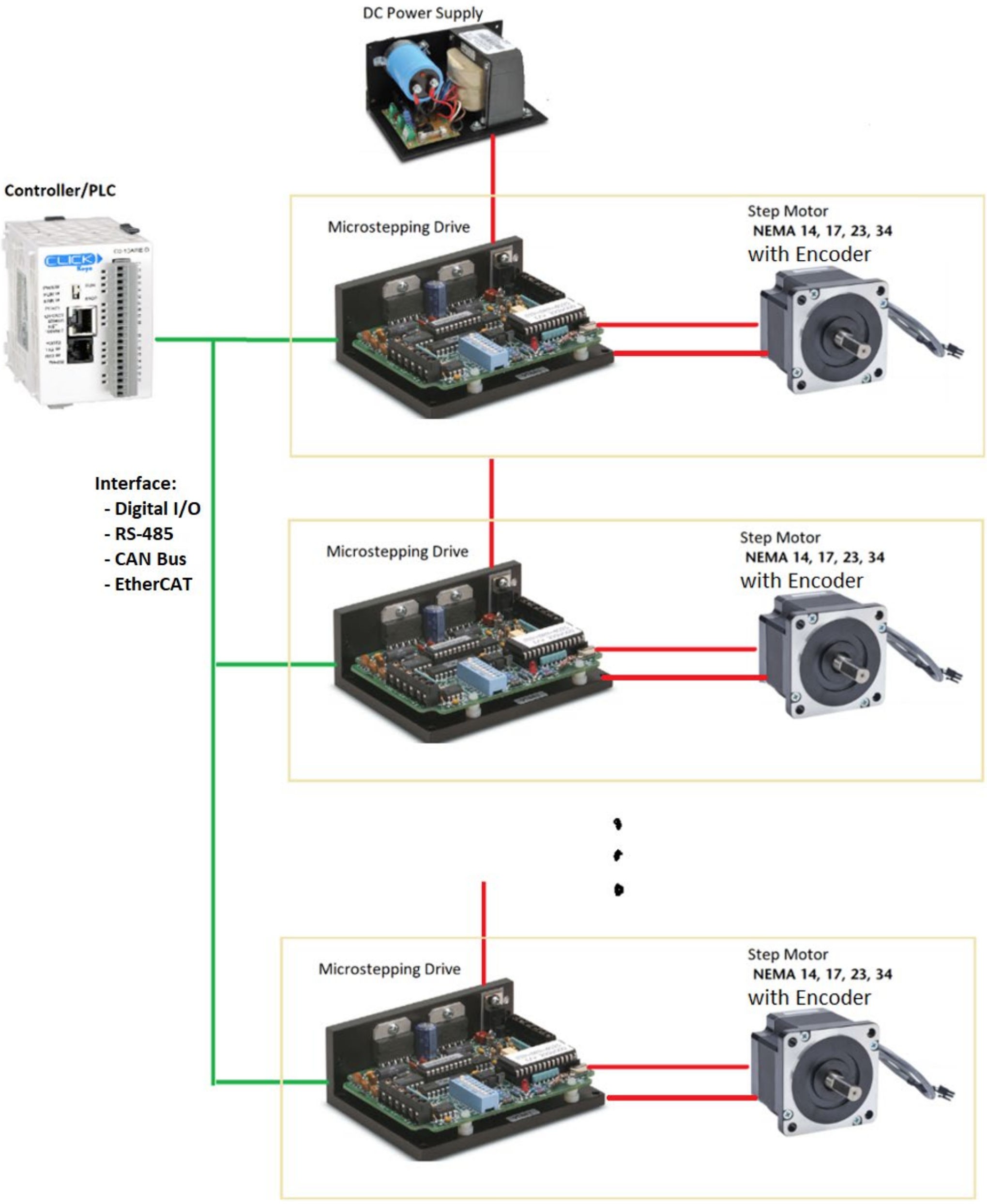


Fig. 9 – Multi axis motion control system using stepper motors: no position feedback.

Closed loop stepper motor systems: If the stepper motor has position encoder and the stepper drive has interface for it for closed loop control, the operation of the system becomes very similar to that of closed loop servo motor control system. The closed loop stepper motor system requires a stepper motor with position sensor and drive which has interface for the position sensor and software to use it in closed loop control. The position information can be transmitted to the controller. The most practical way of achieving that, if needed, is to use EtherCAT interface between Stepper Drives and the Controller/PLC.



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