Fermilab

TM-1195
2280.000

Motor Control and Position Sensing Standards
A Selection Guide and Suggestions For New Designs

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June 11, 1983

The purpose of this text is to attempt to outline and describe the standard drive and readout methods which are available as systems or modules that can be used to control motor driven devices.

Selection of a Motor:

Three types of motors are currently in use. The type of motor used depends mostly on the application. Applications requiring precise position control are best done with a DC STEPPING motor. An example would be a small primary beam target requiring accuracy to perhaps a thousandth of an inch, with an equal accuracy of repeatability. A positioner with more relaxed tolerances would use an AC STEPPING motor. Although an AC stepper could probably do an adequate job to position a small target by using a large gear ratio, AC motors are more suited to lesser precision movers. An example would be a collimator or a moveable scintillator hodoscope where positioning to several thousands of an inch is desired. The most common AC stepping motors have a fixed 72 R.P.M. shaft speed. Designs requiring variable drive speed must use a DC stepper. In an application where a device is to be moved from point A to point B, and as long as it gets close that's good enough, a FOUR LEAD AC PERMANENT SPLIT CAPACITOR GEARMOTOR is the best choice. They are less expensive, easy to control, and have a good choice of shaft speeds making the mechanical design simpler. An example would be a rotating lead radiator, a SWIC positioner (with precise mechanical stops), or other device with only two operating positions. Naturally with careful mechanical design, a less expensive motor can be used to operate a precision device, but this usually comes at the expense of long travel times.

Selection of a Position Readback Device:

Position readback devices are selected using some of the same criteria for motors. A precision device requires a readback device with a high resolution. That is, a very small increment in movement should be easily measured and displayed. Repeatability should also be good. When it is desired to move a device to a position it has occupied in the past, the readout device should be able to display the same reading it did the last time the device was in the same place. Depending on the mechanical design, and the environmental factors, (radiation level, temperature, mechanical shock) several devices are available. An INCREMENTAL type SHAFT ENCODER is frequently used for high accuracy measurment. An incremental encoder contains a set of one or more switches that are alternately opened and closed as a connecting shaft is rotated. For a single complete rotation of the shaft a given number of switch closures will be performed. The number of closures per rotation is said to be the resolution of the encoder. The more closures the better the degree of accuracy can be measured with the device. The number of switch closures is counted as the device moves, and the position is represented as a numerical value. The accuracy also depends on the mechanical design of the mover. If the encoder is connected to a drive shaft where a great many turns of the shaft causes only a small movement of the device being positioned, then the position can be measured very closely. Most encoders have only one set of contacts and are called 'single phase' encoders. By counting the pulses from a single phase encoder it is impossible to tell which direction the encoder is rotating. In a control system, you already know which direction you told the device to go, so you use that information and assume the device is travelling the same way. You direct your position counter to count in the same direction as the commanded motion.

The disadvantage of this is that if the device should move from some other means like gravity or a fat finger pushing on it, the counter will count in the direction it defaults to which may not necessaraly be the right one. Most of the time this really is not a problem. If the mechanical design requires that the motion be measured when the device moves by other means, then a different encoder must be used. An encoder with two or more switches is called a 'MULTIPHASE' ENCODER. This type has several switches that open and close just as in a single phase encoder, but they operate in sequence, never all at once. It is then a simple matter to measure the sequence of switch closures (the phase rotation) to detect the direction of travel. The multiphase encoder usually has a higher resolution just because there are more switches to count. The standard type 044 CAMAC modules that interface to shaft encoder read devices can only read single phase encoders, therefore multiphase encoders should only be considered as a last resort. The 044 module has a maximum count range of 65536 counts. This should be taken into account when the encoder is selected and the mechanical design is done. The maximum number of counts required from limit to limit must not exceed this number. Several types of incremental encoders are available. Some use reed switches, some use optical switches, others use pin or brush contacts that slide on rotating contact disks called 'encoder wheels'. The most common type in use is the reed switch type, probably because of its resistance to radiation and because somebody ordered too many and had to use them up. It should be pointed out that since the reed type operate magnetically, they will not work in an area where there are strong fringe fields from nearby magnets. If radiation is not a problem, an optical type is an alternative.

Another type in use is the ABSOLUTE SHAFT ENCODER. The absolute encoder is a multiple switch device that generates a unique binary code for each angular position of the shaft over one or more rotations. The biggest advantage of the absolute encoder is that it never forgets its position. There are no counters to keep track of where the device is.

The position is directly readable from the encoder. There is a price to pay for this luxury. These encoders are much more expensive than incremental types, and they have a maximum number that they will accomodate before they overflow to zero. Incremental counters can count to as high a value as you can afford to by counters for. For these reasons there are very few applications that use absolute encoders, and their use is not actively encouraged.

The readout device that is the most commonly in use is the LINEAR MOTION POTENTIOMETER. The linear pot is always mechanically connected directly to the device that is moved. For this reason, it must be reasonably matched in length to the total travel from limit to limit. A voltage is applied to the potentiometer end terminals, and the voltage from the wiper to common is measured as an indication of the position of the device. Since the linear pot is an analog device, it has a greater tendency than the shaft encoder to be effected by electrical noise. The linear pot, like the absolute encoder, does not lose the position information with a power failure. Linear pots are used in devices of all precisions. They are used mostly in devices of medium to low precision because the higher precision controllers tend to be all digital designs. Linear pots cannot usually stand much radiation and are not very good for primary target position readouts. Collimators, and moveable hodoscopes are usually read with linear pots.

Another type of readout device is the LINEAR VARIABLE DIFFERENTIAL TRANSFORMER, or LVDT. The LVDT is a very special form of electromagnetic transformer. It is a cylinder shaped device with a hollow center like a pipe. Inside the cylinder, circling the center bore, are three windings along the axis. The primary is wound in the center section along the axis, and the two secondaries are wound at opposite ends. A moveable rod of magnetic material is inserted into the bore forming a complete transformer. The transformer measures position by using the variation in magnetic coupling from the primary to the two secondaries by the position of the core.

The two secondary windings are connected in series, electrically out of phase. That is, they are connected so that the voltage produced by one winding is opposed by the voltage on the other winding. When the two voltages are equal they exactly cancel each other and the net is zero. To measure position, an alternating current is applied to the primary winding in the center. Depending on the position of the core, a voltage will be produced in the secondaries. If the core is exactly in the center of the transformer, both secondaries will get an equal amount of coupling to the primary, and they will have equal voltages induced in them. Since they are opposing each other, the net output voltage will be zero. If the core is moved out of the bore, the front winding will get a little more magnetic flux, and the back will get a little less. The voltage will now be a little higher in the front winding than the back so the net voltage will go up to some value depending on how far the core was moved. If the core is moved into the bore past the center, the flux to the back winding is now greater than to the front. The back winding now has more induced voltage than the front. If the core was moved an equal amount below center as it was above center, the level of the voltage will be the same. The amplitude of the output voltage indicates the distance of the core from the center. The position of the core with respect to the center, whether it was pushed in or pulled out, is determined by the phase of the output signal. Since the two secondaries are connected opposite to each other, the output of one is in phase with the primary, and the other is out of phase. The phase of the output voltage will be the same as the secondary with the highest output. The phase and amplitude of the LVDT are easily measured simultaneously with a synchronous amplitude modulation detector much like the ones used in television sets for video detection. The position is read as a DC voltage proportional to displacement, and polarity determined by direction. The LVDT, like the linear pot, must be sized to the desired measurement distance, and does not forget position with a power failure. They are especially good for measuring very small distances.

Since LVDT's operate on an AC voltage with a frequency much higher than the power frequency, they are less prone to interference than the linear pot. They are rugged, there are no parts to wear out, and can be made to withstand extreme temperatures and intense radiation. Their linearity is comparable to linear pots, but they are more expensive. The application of these devices is usually limited to very harsh environments or special applications and are not generally in use.

Here are a few examples of how a motor and readout device might be configured.

Example 1: Target Shuttle

Motor: DC Stepping Motor
Superior Electric Model M063-FD06R (radiation hardened)

Readout: Single Phase Incremental Shaft Encoder
Disc Instruments Magnetic Reed Type, Model 110

Limit Switches: Ceramic Case SPDT
Micro Switch Model V3-1301, with JV-5 actuator

CAMAC Interface 044 Module

Example 2: Collimator

Motor: AC Stepping Motor
Superior Electric Model SS400

Readout: Linear Potentiometer
Vernitech Model 111, 5000 Ohms, 4 Inch

Limit Switches: Plastic Case SPDT
Micro Switch Model V3L-111-D8

CAMAC Interface 154 Module

Example 3: Collimator

Motor: AC Permanent Split Capacitor 4 Wire
Bodine Model NCI-13D3

Readout: Single Phase Incremental Shaft Encoder
Disc Instruments Magnetic Reed Type, Model 110

Limit Switches: Plastic Case SPST
Micro Switch Model V3L-111-D8

CAMAC Interface 044 or 154 Module

Example 4: SWIC Mover

Motor: AC Permanent Split Capacitor 4 Wire
Japan Instruments URM 8P20, with 8G90H-25 Gear Head

Limit Switches: Plastic Case SPST
Micro Switch Model V3L-111-D8

CAMAC Interface 014 Module

The official configuration for target movers is a DC stepping motor with a single phase incremental shaft encoder readout.

The official configuration for a beamline collimator is an AC motor of either type with a linear pot or shaft encoder readout.

Devices Officially Supported

Motors

Any SLO-SYN AC Synchronous Stepping Motor (Permanent Split Capacitor 3 Lead) up to 3 amps at 120 VAC
I.E. Superior Electric SS50, SS150, SS250, SS400, X1500

Any Permanent Split Capacitor 4 Lead motor up to 3 amps at 120 VAC
I.E. Bodine Series N-1D gearmotors, Japan Servo "M" Series Instrument Motors.

Any Four Phase DC stepping motor up to 5 amps per winding.
I.E. Superior Electric M062-FC03, M063-FD06, M112-FJ-08
Bodine 2000 Series DC Stepping Motors

Readouts

Any Single Phase Incremental Shaft Encoder
I.E. Disc Instruments Model 110, 111
CAMAC Control by 044 Module or 154 Module depending on precision

Any Litton Absolute Shaft Encoder with Binary Output up to 13 Bit Resolution
CAMAC Control by 154 Module

Any 5000 Ohm Linear Potentiometer
I.E. Vernitech Model 111, Litton 9000 Series, Gamewell Model 20TC-1590, Duncan PT-100 Series
CAMAC Control by 154 Module

Any Schaevitz AC Linear or Rotational Variable Differential Transformer
CAMAC control by 154 Module

Typical Components and Their Sources

Motors, AC SLO-SYN Stepping, DC Stepping:
Superior Electric Co., 799 Roosevelt Rd., Glen Ellyn, Il. (312) 858-2960
(Newark Elec. 2711B, Curtiss St., Downers Grove, Il., (312) 969-9440)

Motors, Permanent Split Capacitor:
Bodine Electric Co., 2500 W. Bradley Pl., Chicago, Il. (312) 478-3515

Japanese Products Corp., 7 Westchester Plaza, Elmsford, NY, 10503
(914) 592-8880

Shaft Encoders:
Disc Instruments, 666 Industrial, Elmhurst, Il., (312) 530-7775

Litton Encoder Division, 20745 Nordhoff St., Chatsworth, Ca., 91311
(213) 341-6161

Linear Potentiometers:
Vernitech Div. Vernitron Corp., 300 Marcus Blvd., Deer Park, NY.
(516) 586-5100
Litton Potentiometer Div., 750 S. Fulton Ave., Mt. Vernon, NY., 10550
(914) 664-7733
Duncan Electronics Div. Systron-Donner, 2865 Fairview Rd., Cosa Mesa, Ca.
92626 (714) 545-8261

LVDT's:
Schaevitz Engineering, U.S. Rte. 130 & Union Ave., Pennsauken, N.J.
Mail Address: P.O. Box 505, Camden, N.J. 08101
(609) 662-8000

Limit Switches:
Micro Switch Div. Honeywell, 1460 Renaissance, Park Ridge, Il.
(312) 296-0710