KOLLMORGEN

Because Motion Matters™

Selecting the Proper Cables for Your Stepper or Servo System

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Engineers devote a lot of time and effort designing highly efficient, reliable, and economical stepper or servomotor positioning systems. They select a motor, a controller, appropriate feedback circuits, and an amplifier to satisfy the specific motion system's needs. Unfortunately, however, the signal and power cables connecting the components are often neglected until the project is nearing its end or worse yet, handed off to an electrician who lacks the proper training. Overlooking critical cable selection factors can deliver a system with lower than expected accuracy, frequent failures, low immunity from electromagnetic interference, and adverse affects on neighboring equipment.

BASIC CABLE CONSTRUCTION

Cables are designed and manufactured with characteristics intended to service a specific application for peak performance. Each element in the basic cable construction plays a unique role. All cables contain some or all the following elements: single or multiple conductors of proper ampacity, insulation with appropriate voltage breakdown specifications, an overall shield or multiple shields for individual conductors or pairs, and a jacket to protect the cable from mechanical, chemical, and environmental influences. Additional cable elements might include a drain or grounding wire used with foil shields, binding tapes, embedded steel-support wires, and fillers to give the cable a uniform circular, cross-sectional shape.

SELECTION CRITERION

Cable selection begins with characterizing the operating conditions that affect the cable during service such as temperature, moisture, chemical exposure, abrasion, flexing, and expected life. The proper type and thickness of the insulation selected depends upon working voltages. The number of conductors and current requirements are specified by the motor and drive manufacturer. Possible options include separate feedback and power conductors or one composite power and feedback cable. Electromagnetic interference affecting signals in the cable and other equipment adjacent to the cable determines the need for shielding. Interference may exist between conductors of the same cable and between the cable and its surroundings. The major coupling factor and contributor to the interference is the inductance. If the area between conductors is too great, alternate paths for the signal will be found. These unintended paths result in the coupling to the alternate signals. To further decrease the tendency of coupling, reducing the area between the intended path conductors is accomplished by twisting the pairs. Up to four turns/inch are recommended.

Some applications require stationary cables, such as in systems where the motor and the drive are fixed relative to each other. In these situations, cable trays and conduits are frequently used to route the wiring. Moreover, cables carried in trays are extremely flame resistant, and in order to be marked Type “TC” or “CT” the cables must pass special Vertical Tray Flame Tests (UL) or Vertical Flame Tests (CSA). In case a conduit (metallic tubing) is used, Table 1, Chapter 9 in the National Electric Code® (NEC®) Handbook must be consulted to find the maximum number of conductors allowed inside one conduit depending on the conductor size and temperature.

Other applications may involve occasional, non-repetitive movement of servo system components, and in other machines, the motor might be constantly moving with relation to the rest of the system such as a robot arm. Required cable flexibility plays a huge role in the selection of every cable component – conductors, insulation, shield construction, and jacket material.

INSULATION and JACKET

One specific material provides the conductor insulation and another provides the jacket; each plays a different role in a cable structure. One type of insulation electrically isolates individual conductors or pairs in a cable. By comparison, the jacket provides the cable "skin" and protects the conductors, insulation, and shield from the environment, mechanical impact, and chemically aggressive substances. Some products, such as conventional hook-up wire and consumer-product power cords have only a single layer of insulation that acts primarily as a physical protective jacket. However, most industrial grade cables contain both. Jacket material is the major source of friction within the moving tracks and the selection of the material is tantamount to success or failure of the system.

The environment, including the ambient temperature and heat created by the current flowing through the conductors, determine the maximum operating temperature of the insulation material. In general, the temperature rating can be interpreted as the maximum temperature of the conductor that can be safely sustained by the insulation. This is especially true for power cables. However, if any cable (even a feedback cable) is routed near a heat-generating machine the ambient temperatures must be taken into account.

A typical, nominal rating for power and control wiring is 600 V. This rating relates only to the conductor insulation, not to the jacket. This is the maximum working voltage that can be applied between the conductor and any adjacent part such as another conductor, shield, or a conductive object located outside the cable. UL® does not recognize the jacket insulating properties as part of the voltage rating. It is considered primarily a mechanical protective and binding element of the cable.

HIGH FLEX AND CONTINUOUS FLEX CABLES

In many motion control applications the motor, feedback device, or both, frequently or constantly move relative to the controller. This arrangement requires special high flexibility cables. High-flex and continuous flex cables contain a combination of specially selected conductors, insulation material, shields, and jacket allowing them to withstand the mechanical impact.

A typical continuous flex cable might have conductors comprised of numerous extra-fine, bare copper strands covered with special, extra-flexible PVC insulation and a polyurethane jacket. Reverse spiral shields provide superior flexibility compared with the braided shields, which is important for high and continuous flex applications. However, copper braided shields have improved electromagnetic noise immunity and in combination with band clamps considerably simplify grounding. Some cables contain dry lubricant to reduce sliding friction between the insulation of individual conductors, shields, and jacket during small-radius flexing.

Linear-flex rated cables can only be bent in one direction and should not be twisted, which is considered a two-directional flex. Widely used power tracks keep the cable oriented in such a way that it only flexes in one direction. Machine builders are often forced to decide on inter-cable connectors when the cables must be flexed two axes or greater.

Bend radius requirements are an often overlooked specification. Bend radius determines the service life of a continuous-flex cable. The smaller the radius, the shorter the life. The minimum allowed cable bend radius is specified as a factor N multiplied by the cable outside diameter, for example "12 X cable diameter," where N = 12. Properly selected and installed continuous flex cables have a life expectancy of several million flex cycles. Special flat cables have been developed to decrease the limit on the dynamic bend radius. Standard cables with static bend radius of 10 times the diameter and dynamic (moving) bend radius of 12 - 15 X the diameter would result in a machine that would be obtrusively high. The added real estate is a cost and shipping factor to be considered as well as a usability issue. These flat flexible cables are critical to the final envelope requirements of the manufacturer.

TERMINATION
Any cable can fail prematurely, especially in a high-flex application, when it is not properly terminated. Termination-related loss of an electrical connection is one of the most common causes of system failures. Connector contacts should be rated for the wire size of the cable. If machine crimping is not available, use the proper hand tools to make reliable electrical and mechanical connections between the conductor and the contact. Loose crimps can corrode and lose electrical connection. Also, over crimping tends to cut wire strands, which weakens the conductor and creates hot spots caused by the higher current density. Typically in "Flyable Hardware" or Life Support applications, you see soldered terminations to avoid these pitfalls.

Straight and right angle connectors provide a choice of attaching cables to motors. Larger motors often require round metal-shell or molded plastic connectors. Many small motors use smaller plastic rectangular connectors or have non-terminated wires. Bulkhead connectors are used for in-line connections through an enclosure wall or metal cabinet wall. Many servomotor and stepper motor drives come with terminal blocks for power cable termination. Alternately, a large number of stepper systems come with IDC connections. These must be limited to static applications, as motion will compromise the connector.

Proper shield grounding is required to reduce emissions, increase immunity, and to prevent personal injury caused by ground currents. Standard practices recommend bonding shielded motor cables to the back panel of the drive with metal cable clamps.

Installing cable that is "only long enough" puts unnecessary stress on cable termination points and can form extremely sharp bends that reduce cable reliability. On the other hand, excessive length of cable (beyond the necessary layout requirement) increases the overall system cost and might degrade performance. Longer than necessary feedback cables degrade signals due to their inherent resistance, inductance, and capacitance, and they increase crosstalk. Excessively long, coiled power cables reduce drive voltages at the motor terminals and act as antennas, which radiate electrical noise interference.

Conductor insulation and jackets made from the most commonly used insulation material, Polyvinylchloride (PVC), are suitable for many motion-control applications, including continuously flexible cables. Machine tools, robots, pick-and-place equipment, material handling equipment, and cable tracks are just a few examples. Many PVC formulas are suitable, but a typical PVC jacketed cable typically has a static temperature range from –30 deg. C to + 70 deg. C. A flexing requirement narrows the lower temperature range to about -5 deg. Multiple conductors also reduce the thermal area for dissipation and thus reduce the power for a given wire size.

Ethylene Propylene (EP) is less resistant to Benzene and various oils, but has excellent UV and ozone resistance. Polyurethane (PU) jackets are applied to many continuous-flex cables. The material is rugged, extremely flexible, and provides superior protection for cables that contact chemicals such as acids, alkalines, solvents, and hydraulic fluids. The temperature range is wider than PVC, and many formulas used are flame retardant and boast superior self-extinguishing characteristics.

On the downside, however, polyurethane jackets and insulation are difficult to cut, strip, and terminate, especially by hand. Combining PVC insulation for individual conductors with a polyurethane jacket eases cable fabrication and maintains excellent protection.

Neoprene (Polychloroprene or PCP) performs well under extremely harsh conditions. It remains flexible to –40 deg C, and, being a thermoset material, does not melt under high heat. Neoprene jackets do not age when exposed to sunlight and oxidation, and are resistant to abrasion, crushing, and cutting.

Teflon® allows for a very high temperature but can typically be difficult to work with due to its high memory and tensile strength. In the case of high thermal conditions of greater than 100° C, the choice would require Teflon. The manual cable fabrication with Teflon may be one of the most difficult.

In dynamic conditions, work hardening of certain polymers is not well documented. There are basic rules of thumb, but UV-light, heat, humidity and chemical exposure are variables that effect the equations. Ignorance of these factors can lead to premature failure.

Table 1. Insulation and Jacket Material Comparison Table

Property	*Insulation and Jacket Material*				
	PVC	Ethylene Propylene	Neoprene	Polyurethane	Teflon
Abrasion Resistance	G	VG	VG	E	E
Tear and cut Resistance	VG	VG	E	E	E
Low Temperature Flexibility	G	VG	VG	E	P
UV Resistance	VG	E	E	E	E
Ozone Resistance	E	E	VG	E	E
Water Resistance	E	VG	E	E	E
Transformer Oil Resistance	VG	F-G	F-G	E	E
Gasoline Resistance	P	F	G	E	E
Kerosene Resistance	P	G	G	VG	E
Bleach	F	E	VG	F	E
Ethylene Glycol	G	E	VG	F	E

E = Excellent, VG = Very Good, G = Good, F = Fair, P = Poor

CONDUCTORS

A cable can contain a single conductor or multiple insulated conductors arranged in pairs that carry current for both power and control circuits. Copper is the most commonly used material for wires and cables. Aluminum or steel conductors usually are not used in modern motion systems. Conductors can be solid (one copper wire) or stranded where the composite conductor is made of several smaller, solid, twisted strands.

Tin plating improves the corrosion resistance and solderability of conductors and individual wire strands. Silver or nickel plating protects conductors at even higher temperatures -- 200 degrees C for silver or 450 deg. C for nickel, but they are rarely used. Bare copper oxidizes rapidly at these temperatures, but such temperatures are not typically encountered for stepper and servomotor wiring. When maximum flexibility is needed, as in continuous-flex cables, a cable made with bare copper conductors containing a high number of fine strands is the best choice.

When selecting a conductor size, consider its location and the presence of other conductors. For a given current, a conductor located inside the enclosure of a heat-generating machine must be larger than a conductor exposed to the open space in an air-conditioned facility. According to specification "NEC 75 deg. C" shown in table 310-16, the conductors in a cable connecting the motor to the drive shall have an ampacity of no less than 125% of the motor's full-load current. Ampacity is defined as the maximum current that a conductor can carry before exceeding the temperature limit. Rating factors must be used for insulation materials with lower or higher temperature ratings and for applications with elevated ambient temperatures.

Table 2 Recommended Conductor Ampacity for Motor/Drive Cables

Conductor Size AWG or MCM	Conductor Cross Sectional Area, mm^2	Ampacity per 75°C NEC Table 310-16, A
20	0.5	5
18	0.8	7
16	1.3	10
14	2.1	15
12	3.3	20
10	5.3	30
8	8.4	50
6	13.3	65
4	21.2	85
2	33.6	115
1	42.4	130
1/0	53.5	150
2/0	67.4	175
3/0	85.0	200
4/0	107.2	230
250MCM	126.6	255
300MCM	152.0	285
350MCM	177.4	310
400MCM	202.7	335

SHIELDING

Often, the purpose of a shielded cable is misunderstood. Shielding can be applied over individual conductors, pairs, and over the entire cable. In most cables, a jacket covers the shield. The combination of an overall shield and twisted wires helps reduce electromagnetic radiation from the cable. The shield also prevents external radiation or electrostatic fields from entering the circuitry and disrupting normal signal transmission. This is especially critical for cables carrying feedback and other low-level signals.

Resolver cables and other feedback cables often have several levels of protection against electrical interference. First, individual pairs are twisted to reduce electromagnetic radiation from analog and digital signals. Then each twisted pair is placed inside a shield to reduce crosstalk between adjacent pairs. Ferrite beads, clamp style ferrite cores, and capacitors are sometimes required to alleviate EMI. A final ferrous-type overall shield may provide top-level protection against electromagnetic and electrostatic interference and cut down emissions in critical applications. These are typical involving aviation, defense or life support, but are also showing up in modern industrial equipment to maintain compliance to the Electro-Magnetic Compatibility (EMC) directives for industrial equipment.

It is necessary to understand the coupling factors of electromagnetic interference (EMI) noise, and the type of shield required to suppress that noise. Using a foil shield for an inductively coupled noise is ineffective at best, and may worsen the situation should an improperly grounded shield become a radiator. Radiated noise will sometimes only affect another device at over ½ wavelength away, which is why the EMC compliance for radiation begins at 30 MHz. In fact a high powered signal at 30 MHz will be received by any device over 5 meters away if it has an antenna of 1/20th of the wavelength, or 0.5m. The only question is the amount of disturbance.

Other times, the magnetic wave of this frequency may inductively couple at far less. It won't be able to be characterized as a 30 MHz voltage signal, but it is still a problem. To suppress this type of noise, one should use braided shielding of at least 80 – 95% coverage, or a twisted wire shield. All connectors must be metallic (metalized plastic will likely be ineffective). Best practices are to shield the source and the receiver, and disable the coupling method. The proper shield will do that.

It may not be obvious, but even power cables require shields in certain applications. Power cable shields contain the EMI emissions generated in the conductors in order to protect adjacent equipment and wiring. Often, motion controllers drive various types of steppers and servomotors with high-frequency switching currents to minimize losses in the power semiconductors. The parameter of concern is the dv/dt, the ratio of the rise time or fall time of the switching signal to the magnitude of voltage at which the semiconductor is switched. Large and steep dv/dt switching voltages produce currents with high levels of interference around the power cable, which must be shielded. These may easily be capacitive coupled through other systems. The power cable is a major source of EMI that eventually gets inductively coupled to other machinery in the plant environment. The shielding is required to be sufficient to 30 MHz in industrial machinery and higher for medical equipment.

CERTIFICATION AND MARKINGS
The National Electrical Code (NEC) is the main reference source for various types of standardized cables. It requires that tables must have clear printing to indicate conductor size, voltage, temperature, and insulation information, as well as listing marks. The marks applied to cables sold in the United States are the UL (Underwriters' Laboratories Incorporated), the CSA (Canadian Standard Association), or both. Cables intended for Europe must conform to the CE Low Voltage Directives and EMC compliance and be marked accordingly. CE tests for EMI compliance like CISPR 11 require emission control to 1 GHz. This requires cables with braided shields and 360-degree coverage.

The UL mark printed on the cable jacket indicates that UL evaluated and approved the cable. However, the UL only evaluates the cable to ensure its safety for users. Various cable qualities such as ease of stripping, terminating, and soldering, or cross talk between multiple conductors is of no interest to the testing organization. Moreover, the presence of the UL mark on the cable connected to a motor or a drive does not indicate that the motor and drive were tested and listed.

A properly grounded overall shield also provides additional shock protection. If the power cable's insulation is damaged and the conductor is exposed, most likely, it will short circuit to the grounded shield and trip a circuit breaker or a fuse before harming anyone.

CONNECTORS

The selection of connectors effects both the selection of the style cable as well as the overall reliability. For each connection, a reduction in the reliability is the result. Minimizing the number of connectors, yet maximizing the cable life, increasing serviceability, and cost are the variables. In systems that have narrow bend radius requirements, a flat cable is selected. Since most motor connectors do not accommodate connectors for these cables, a compromise must be made. Either the cable must be terminated within the connector for the motor, or an inter-cable connector must be supplied. With a gantry system, typical in cutting applications and electronic assembly equipment, two axes of motion, X and Y, typically require an interconnecting cable assembly that traverses the moving tracks. The narrow bend radius requires a special flat connector that carries data, power, motor current and DC bus voltages for the moving head of the machine. The signals are usually separated at the head by connectors easing replacement worries at a cost of connector expense and reliability reduction.

ABOUT KOLLMORGEN

Kollmorgen is a leading provider of motion systems and components for machine builders around the globe, with over 60 years of motion control design and application expertise.

Through world-class knowledge in motion, industry-leading quality and deep expertise in linking and integrating standard and custom products, Kollmorgen delivers breakthrough solutions unmatched in performance, reliability and ease-of-use, giving machine builders an irrefutable marketplace advantage.

For more information visit www.kollmorgen.com, email contactus@kollmorgen.com or call 1-540-633-3545.