EVERY CONNECTION COUNTS

WHITE PAPER

ENABLING RAPID-GROWTH HUMANOID ROBOTS VIA SMARTER MOTOR INTERCONNECTIONS

Humanoid robots are rapidly evolving toward higher dexterity, lighter weight, and more human-like motion. At the heart of this evolution lies the low voltage electric motor system – particularly frameless torque motors for loaded joints and hollow cup motors for precise finger motion. Electrical interconnections inside motors have become a critical bottleneck, limiting further miniaturization, reliability, and manufacturing scalability.

TE Connectivity (TE) is continuously expanding its engagement in humanoid robots and electric motor applications by actively monitoring industrial developments, interacting with motor manufacturers and humanoid OEMs, and advancing application-driven interconnecting concepts. With reliable magnet wire solutions and deep expertise in motor applications, TE is empowering motors' design capabilities and transforming electrical bottlenecks into competitive advantages, unlocking the next wave of humanoid robotics.

1. The main types of motor used in Humanoid Robots

Modern humanoid robots integrate dozens of motors distributed throughout the body. Large rotary and linear actuators locate in high-load joints, i.e., torso, shoulders, arms, hips, legs, knees, ankles, typically rely on frameless torque motors.

These motors eliminate traditional motor housing and shafts, allowing direct integration into joint modules together with gearboxes, sensors, and control electronics to achieve compact size to deliver continuous speed and torque.

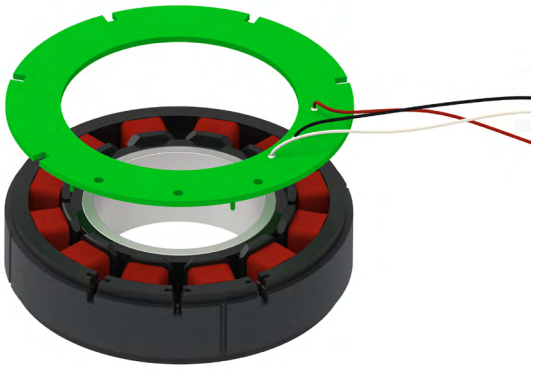
1.1 Frameless torque motors in rotary and linear actuators

In frameless torque motors, they are often tightly integrated with stator PCBs carrying hall sensors, temperature sensors, and power interfaces.

The typical architecture of a frameless torque motor consists of:

- Dozens of magnet wires wrap onto a bobbin forming the stator winding.
- Magnet wires, lead wires, hall sensors and temperature sensors are terminated onto a shared stator PCB.
- Wire terminations are heavily reliant on soldering process.

This typical architecture provides a more compact package which can be embedded directly as a whole unit into the rest of system, but shifting internal electrical connections are a major design constraint, which increases assembly time and labor cost while adding risk of soldering fatigue under vibration and thermal cycling. To eliminate soldering, the effective way is to adopt highly automated terminal solutions based on Insulation Displacement Contact (IDC) technology.



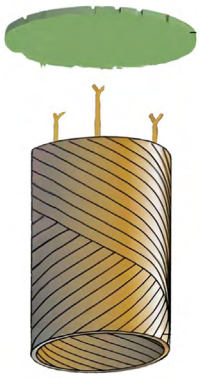
1.2 Brushless hollow cup (coreless) motors in dexterous hands.

For dexterous fingers control, humanoid robots increasingly rely on brushless hollow cup (coreless) motors, which have no laminated iron core inside. Their ultra compact form factor and ultra-fine magnet wires (30AWG for example) enable smooth and precise motion – but also create significant challenges for electrical termination in and out.

The typical architecture of a hollow cup motor consists of:

- Ultra-fine magnet wires form coil winding and bridge at ends by twisting to multiple splices.
- Twisted splices are usually tin-plated to strip enamel layer and establish the electrical connection within winding.
- Splices terminations are heavily reliant on soldering process onto PCB.

As hollow cup motor diameter shrinks within dexterous hands, traditional soldering termination becomes increasingly difficult for this architecture to automate and control within extremely limited space, limiting yield and long-term reliability.



2. Electrical Interconnection Challenges in Humanoids Motors

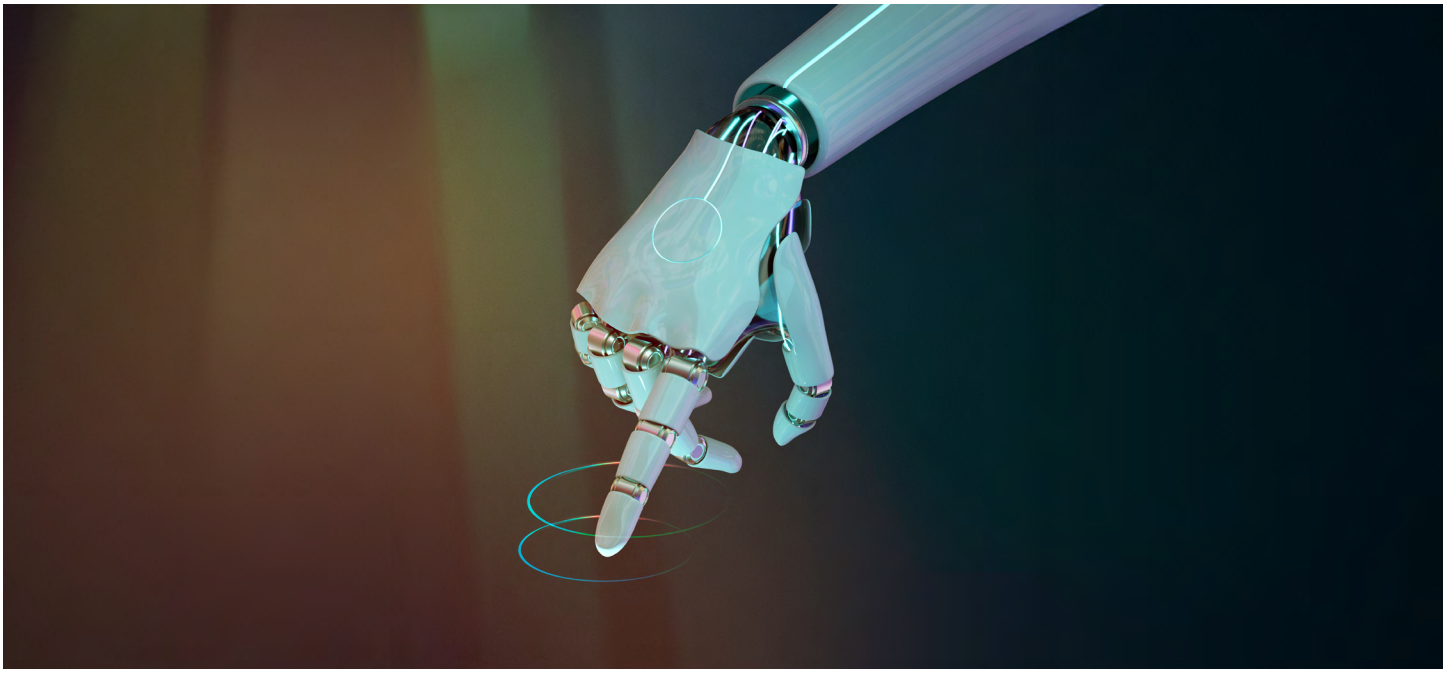
Across both motor types, several common challenges emerge in:

- **Miniaturization vs. Scalable Manufacturability**

As motors become smaller and more integrated, soldering joints bring more difficulties to scale in high volume production. Soldering of dozens of magnet wires per motor also brings higher takt time and increases overall manufacturing costs.

- **Reliability in Dynamic Environments**

Humanoid robots experience continuous motion, vibration, shock, and thermal cycling. Solder magnet wire joints are vulnerable to cracking and fatigue.



3. How TE Connectivity Addresses These Challenges

As humanoid robots move from prototypes to mass production, OEMs face pressure to standardize processes across different production stages. TE's magnet wire termination, splicing and interconnections solutions are designed to support massive and industrialized assembly, reducing dependence on highly skilled manual soldering, supporting faster production ramp up and quality consistency across global manufacturing sites.

The solutions TE offers to mitigate above challenges include, but are not limited to,

3.1 Electrical Connections Within the Motor

- **Smarter Magnet Wire to Board Termination based on IDC technology**

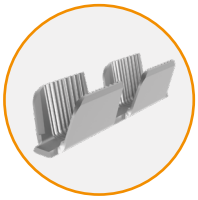
Slim Line MAG-MATE Terminals

For frameless torque motors where magnet wires terminate directly into a stator PCB, Slim Line MAG MATE terminals help to allow solderless magnet wire termination with an Insulation Displacement Contact (IDC) at the bottom and solderless PCB termination through press-fit Multispring or Eye-of-the-Needle (EoN) pin on the top. It supports to replace multiple soldering points with automated production ready solderless connectors.

SIAMEZE Tab Terminals

In applications where a single termination is required to fit for a larger range of wire gauge, SIAMEZE terminals provide a robust and reliable solution, while the soldering tab or press-fit terminal at the other end can be flexibly customized to conduct into PCB in limited spaces.

- **Flexible Magnet Wire to Lead Wire Connections**



AMPLIVAR Splices

For the architecture which magnet wires are not requested to terminate into a PCB, AMPLIVAR splices help enable reliable magnet wire to lead wire crimping, helping minimize number of soldering joints and supporting compact designs for space-constrained motors.

- **Supporting Future Hollow Cup Motor Integration**

Although hollow cup motors push the limits of miniaturization, TE continues to explore integrated magnet wire termination concepts, combining splicing and press-fit based contacts to support future solderless, high volume, automated production approaches.

3.2 Electrical Connections Outside the Motor

- **Motor Power and Signal Interconnection Solutions**

Beyond motor internal connections, TE provides a broad portfolio of solutions to support external power and signal interconnections for humanoids motor architectures. These include EP3.96 and Power Double Lock (PDL) connectors for power delivery, as well as SGI1.5, SGI1.25 and Flexible Printed Circuit (FPC) connectors for signal transmission. A hybrid solution that integrates both power and signal into a single connector is also available as an optional configuration.

3.3 TE's Web-based Savings Calculator – Facilitating the Shift from Manual Soldering

If you are still utilizing conventional methods of soldering or welding for magnet wire applications, TE provides a web-based Savings Calculator to estimate potential annual cost-savings from adopting our comprehensive portfolio of terminals and splices specifically designed for magnet wire applications, requiring only a simple set of user inputs:

- How many units do you produce per month?
- How many magnet wire connections per unit?
- What is your average hourly rate?

Please refer to the following link for more information: Magnet Wire Savings Calculator | TE Connectivity

Note: This information is provided for reference purposes only and does not constitute legal advice.

4. Conclusion – strategic empowering rapid growth of humanoid robot industry

From early-stage concept development to production ready designs, TE Connectivity aligns actively with emerging requirements and partners closely with humanoid OEMs across frameless torque motors, hollow cup motors, and next generation actuator architectures to enhance motor performance, reliability, and manufacturability. With this ongoing focus, TE is able to identify new opportunities early, support evolving design challenges, and develop scalable interconnection solutions that meet the future needs of humanoid robots.

To discuss your specific motor requirements, electrical interconnection challenges, and future humanoid robot performance, contact your TE Connectivity representative or visit www.te.com to learn how TE can support your next generation humanoid designs.

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