Application Brief

Current Sensing in Collaborative and Industrial Robotic Arms

Kyle R. Stone

Introduction

Collaborative robots and Industrial robots are the dominant robot technologies driving factories toward automation and increasing efficiency and throughput of the factories. Factories are able to build their end products at an ever-faster rate to meet the demand of the customers by implementing these semi- and full-factory automation technologies.

Collaborative Robots

Collaborative robots are human-assisted robots that typically work only with human interactions. These robots assist humans in lifting payloads in the range of 6 kg to 25 kg and greater to help reduce human fatigue, while increasing production speed. The collaborative robot is typically operating at voltages lower than 80 V, with most systems operating in the 48-V to 50-V range due to direct human interaction. These systems are sometimes isolated and requirements are based on the system design. Typical current ranges for these systems are between 10 A to 30 A depending on the circuit node. Current sensing in collaborative robots is typically used for motor control within the axis, where a device is monitoring the in-phase current of the electric motors as shown in Figure 1.

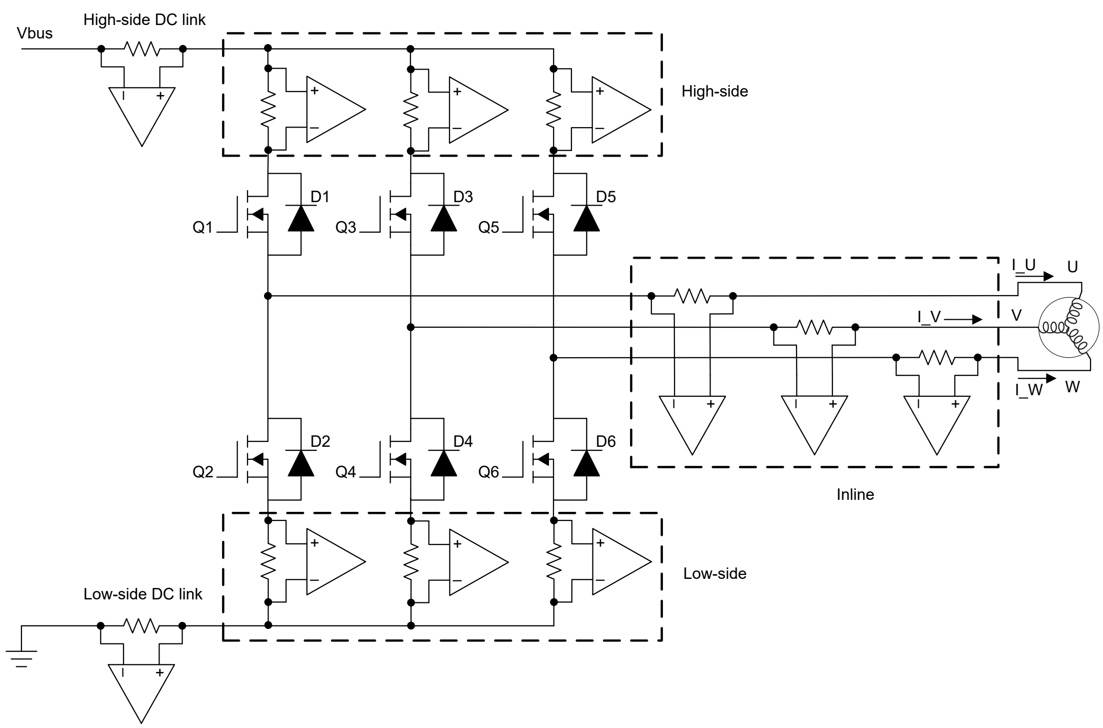

Figure 1. Methods of Motor Current Sensing in Collaborative and Industrial Robots

An accurate phase current sensing is critical in motor control. Poor current sensing can lead to large torque ripple, audible noise, and inefficiency. There are three methods of motor current sensing with their own positives and negatives as shown in Table 1. The best location to measure the motor current is directly inline with each phase due to the continuity of signal measurement and direct correlation to the phase currents. In-line current sensing comes with the challenge where each motor phase is subjected to common-mode voltage transitions that can switch between large voltage levels over very short time periods. Current measurement in other locations, such as the low-side of each phase, requires recombination and processing before meaningful data can be utilized by the control algorithm.

Table 1. Current Sensing in an H-Bridge

Current Measurement	Advantages	Disadvantages
High-side	Detect shorted load from battery for diagnostics	High-voltage common-mode amplifier
Inline	Direct motor current measurement, low bandwidth amplifier	High dv/dt signals. PWM settling time.
Low-side	Low cost, low common-mode voltage	Unable to detect shorted load

Board space is highly constrained in collaborative robots, so a small-footprint device is desired. Since isolation is typically not a requirement, a device such an the INA241A is an excellent choice for an in-line current-sensing application because the INA241A offers high CMRR and enhanced PWM rejection allowing for minimal error in switching systems in a collaborative robot. The INA241A is packaged in a small SOT-23 (DDF) 8-pin package measuring 2.95 mm × 2.95 mm (8.70 mm^2) with the leads. If the application does require isolation, then a device such as the TMCS1108 (a Hall-effect current sensor), provides functional isolation up to 100 V.

Industrial Robots

Industrial robots are very large robots that are found in car factories and other manufacturing facilities where heavy lifting is required to pick and place large products. Industrial robots help bring a level of safety to a manufacturer because these robots are moving very large items without the need for human interaction, and can be done in a very controlled manner. The industrial robots typically operate in the AC domain with voltage levels between 400 V to 600 V, which are common AC voltage levels in large manufacturing facilities. The current levels generally range from 35 A to 250 A dependent upon what the robot is moving around the facility. Current sensing is typically done within a cabinet near the robot, so space is less of a concern in these systems. The current monitoring is usually done in-phase with the motors controlling the robot. Given the high-voltage present in industrial systems, isolation is generally required to separate the high-voltage levels that are dangerous to the low-voltage circuit systems and to humans. Today, current sensing is typically done with a hall-effect current sensor or isolated amplifiers such as the TMCS1123 or AMC1306.

One other common place where current sensing is required in industrial robots is in the coil drive brake release unit. Coil drive is used for releasing the brake friction disks once the motor moving the joints has stopped or to provide dynamic stopping in an emergency event. The magnetic field in the coil drive keeps two spring-loaded friction disks away from each other so that rotor can turn freely. When flow of the current stops, the two braking friction disks are pressed against each other with the help of the loaded springs to stop the rotor. Figure 2 shows a low-side current sensing used in a coil drive in a brake release unit. Low-side current sensing gives more choices of current-sensing devices but due to the inductive nature of the coil, inputs of the current-sense amplifier can be subjected to negative voltage during switching. In such an event, a current-sensing device is required to survive the negative input voltage.

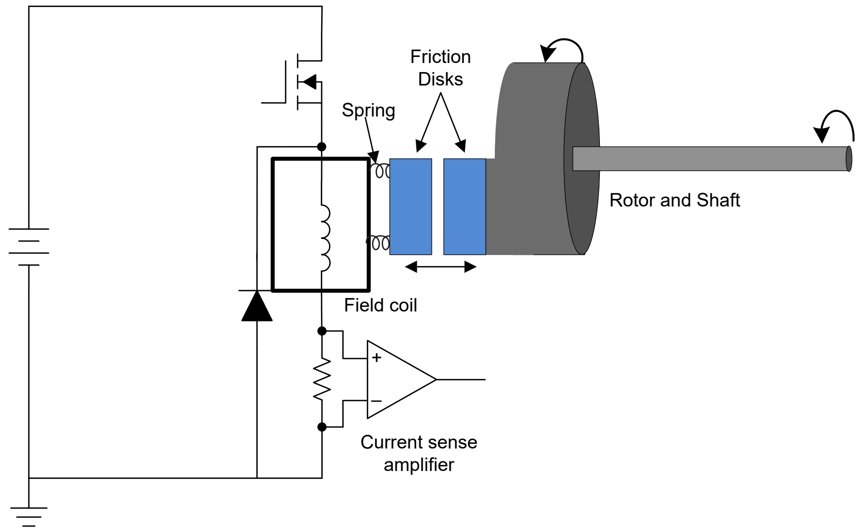

Figure 2. Low-Side Current Sensing in Coil Drive for Brake Release Unit

Conclusion

In conclusion, both collaborative and industrial robots generally both use current sensing to monitor the in-phase current of the electric motor in the various robots. The main differences are the need for isolation, the level of power, and the amount of weight the robot can lift, hence the difference in requirements for current-sensing devices. Industrial robots require current sensing in the coil drive to brake and stop motor. Collaborative robots generally do not need isolation, have power levels that do not exceed 2.0 kW, and typically lift payloads between 6 kg to 25 kg. While industrial robots generally do need isolation, their power levels that can range from as little as 3 kW up to and beyond 125 kW, and lift from 20 kg to a few thousand kilograms.

Alternate Device Recommendations

The INA241B is a high-precision, accurate analog current-sense amplifier. The INA241B can be used in high-voltage bidirectional applications paired with 1.1-MHz bandwidth to offer fast response times with precise control for in-line control within H-bridge applications. The INA241B can measure currents at common-mode voltages of –5 V to 110 V and survive voltages between –20 V to 120 V, making the INA241B an option for many systems.

The INA253 or INA254 devices are ultra-precise, current-sense amplifiers with integrated low inductive, precision 2-mΩ or 400-μΩ shunt and with an accuracy of 0.1% or 0.5% respectively and a temperature drift of < 15 ppm/°C. The INA253 is limited to applications that need < ±15 A of continuous current at T_A = 85 °C, and INA254 is limited to applications that need < ±50 A of continuous current at T_A = 85 °C . The INA253 and INA254 integrated shunt is internally Kelvin-connected to the INA240 amplifier. The INA253 or INA254 provides the performance benefits of the INA240 amplifier with the inclusion of a precision shunt providing a total uncalibrated system gain accuracy of < 0.2% or < 0.5%.

The INA281 can be used in high-voltage applications such as high-side current sensing in a motor. The INA281 can measure currents at common-mode voltages of –4 V to 110 V and survive voltages between –20 V to 120 V, making the INA281 versatile for a variety of applications where voltage can swing negative.

An option for low-side sensing is the INA381. This device is a cost-optimized current-sense amplifier with an integrated comparator which serves to reduce the PCB footprint size and simplify the design.

Table 2. Alternate Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
INA241B	V_{cm} range: –5-V to 110-V Bidirectional	Slightly lower accuracy compared to INA241A
INA281	V_{cm} range: –4 V to 110 V	Unidirectional
INA381	Integrated Comparator	V_{cm} limited to 26 V
INA253	Integrated shunt 2 mΩ, V_{CM} range: –4 V to 80 V	±15-A maximum continuous current
INA254	Integrated shunt 400 µΩ, V_{CM} range: –4 V to 80 V	±50-A maximum continuous current

Table 3. Related TI Application Briefs

Literature Number	Description
SBOA160	Low-Drift, Precision, In-Line Motor Current Measurements With PWM Rejection
SBOA176	Switching Power Supply Current Measurements
SBOA163	High-Side Current Overcurrent Protection Monitoring
SBOA554	Current Sensing in Mobile Robots

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.