InstaSPIN™ solutions for designing three-phase motor control applications
# Table of contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>Overview of TI InstaSPIN™ Motor Control Solutions</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Explore InstaSPIN-FOC</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Explore InstaSPIN-MOTION</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>FAST™ Software Encoder</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>PowerWarp™ Software</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>Design Tools and Software</td>
<td>17</td>
</tr>
</tbody>
</table>
InstaSPIN™ Solutions for Designing Three-Phase Motor Control Applications is intended as a valuable quick guide, outlining TI's InstaSPIN-enabled real-time controllers. This e-book allows you to easily explore InstaSPIN solutions and software, and compare differing advantages and applications of the market leading motor solutions.

You will find content on the following two breakthrough technologies:

- InstaSPIN-FOC—the motor ID and auto tuning solution
- InstaSPIN-MOTION—maximum control with minimal effort

You will also find material on C2000™ real-time control MCUs, as well as trainings that are useful to further your understanding of InstaSPIN technology.
Chapter 1  Overview of TI InstaSPIN Motor Control Solutions

TI InstaSPIN sensorless, three-phase motor solutions make designing motor control applications easier whether you have a simple application or a complex design. TI's InstaSPIN-enabled MCUs provide expertise to designers of sensorless (velocity and torque) or sensored (position, velocity and torque) motor control applications and are enabled by a special library on select C2000 microcontrollers.

See InstaSPIN-enabled C2000 MCUs

Compare InstaSPIN solutions

<table>
<thead>
<tr>
<th>InstaSPIN solutions</th>
<th>Control technique and motor support</th>
<th>Required feedback</th>
<th>Motor parameters</th>
<th>Key features</th>
<th>TI-supported devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>InstaSPIN-FOC</td>
<td>FOC torque controller using TI's FAST™ software encoder (observer) for ACI, PMSM, IPM, BLDC</td>
<td>Voltage and current (2–3 shunt or phase)</td>
<td>Motor parameters automatically identified</td>
<td>Automatic current loop tuning; Full torque start-up; Stable at and through 0 speed; Max torque per amp; ACI PowerWarp™ Enhanced start-up, zero and slow speed capability with Initial Position Detection (IPD) by High Frequency Injection (HFI)</td>
<td>F280049C F280048C F280041C F280040C F28069F F28068F F28062F F28054F F28052F F28027F F28026F</td>
</tr>
<tr>
<td>InstaSPIN-MOTION</td>
<td>Accurate speed and position using SpinTAC™ and FAST software encoder (observer) or rotor sensor for ACI, PMSM, IPM, and BLDC</td>
<td>Voltage and current (2–3 shunt or phase)</td>
<td>Single variable speed/position loop tuning—tune your motor in minutes</td>
<td>Robust speed and position control; Cancels disturbances before they happen; Sustains performance across different speeds, positions and changing dynamics; Trapezoidal, S-curve, ST-curve Motion Profile Generation</td>
<td>F28069M F28068M F28054M F28052M</td>
</tr>
</tbody>
</table>
Chapter 2  Explore InstaSPIN-FOC

The motor ID and auto tuning solution in all variable-speed, variable-load motor applications

TI InstaSPIN-FOC (field-oriented-control) technology enables designers—even those with limited motor control experience—to identify, tune and fully control any type of three-phase, variable speed, sensorless, synchronous or asynchronous motor control system in just minutes.

This new technology removes the need for a mechanical motor rotor sensor to reduce system costs and improve operation using TI’s new software encoder (sensorless observer) software algorithm, FAST (flux, angle, speed and torque), embedded in the read-only-memory (ROM) of C2000 devices. This enables premium solutions that improve motor efficiency, performance and reliability in all variable-speed and load-motor applications.

InstaSPIN-FOC Applications

InstaSPIN solutions are being used in a wide variety of three-phase motor control applications:

- Compressors (**HVAC** and **refrigeration**)
- Fans, blowers, pumps
- Spindles, winders, feeders
- Lifts, door / gate openers
- **General-purpose drives**
- Elevator, escalator controls
- **UAV**, drone, hobby propulsion
- **Tools** (consumer, industrial, and oil and gas including drills, drivers and torque wrenches)
- **Laundry / Washing machines**
- **Traction applications** (e-bike, pedelec, e-scooter, carts, forklifts)
- **Medical pumps, respirators, ventilators**, dental tools, surgical tools
Chapter 2: Explore InstaSPIN-FOC

InstaSPIN-FOC Benefits

Replace mechanical encoders and resolvers in a “sensorless” Field Oriented Torque Controller (FOC)

- Uses the FAST software encoder as a superior rotor flux sensor

Control system design accelerated

- Built-in motor parameter identification
- Automatic closed-loop current control tuning
- Fully tuned observer and stable torque controller in minutes

Full InstaSPIN-FOC control system available in ROM

- Select C2000™ devices
- Software API and multiple example projects through MotorWare™ software

Voltage and current filtering ensure quality sampled signals to the system

- One time hardware and software calibration
- Offset compensation

Solving the start-up challenge:

FAST software encoder stability at zero speed enables:

- Zero speed start-up feature provides 100%+ torque at start and closed-loop control with FAST providing angle in less than one electrical cycle
- Full closed loop from zero speed ready—just supply electrical starting angle from additional Initial Position Detection algorithms

Motor Identification

- No datasheet required!
- One-time parameter identification based on simple motor nameplate data (max voltage, current)
- Optional Rs online feature can track resistance changes and provide compensation during operation

FAST Software Encoder

Universal three-phase motor software encoder

- Rotor flux observer / estimator
- Synchronous (BLDC, SP, IPM)
  - Rotor flux compensation for salient IPM motors
- Asynchronous (ACI) motors
- Unique, high quality feedback signals for use in control systems

Control Loop Tuning

FOC current controllers automatically tuned:

- Gains calculated from parameters
- User may adjust
- User may use own controllers
- Minimum current used to meet torque requirements of load

Generic speed loop is provided for initial evaluation:

- User must tune for mechanical inertia
- User must tune for use across operating conditions
**PowerWarp™ technology:**
- Optional mode for induction motors
- Produces minimum current use at all times
- Trade-off with dynamic torque response
- Never before seen energy savings occurring during partial load situations

**System Flexibility**

**InstaSPIN-FOC**
- Created for any three phase motor system
- Simple API interface
- Full customization for expert users

**Flexibility for different use cases:**
- FAST software encoder as a feedback sensor (ROM memory)
- InstaSPIN-FOC as a torque controller
  - User adjusted (ROM)
  - Fully customized (user memory)
- InstaSPIN-FOC as a cascaded speed and torque controller
  - User adjusted (ROM)
  - User customized (user memory)
- FAST software encoder is the only portion that MUST be run from ROM.
- All other portions are in ROM with source provided in the MotorWare software.
Chapter 2: Explore InstaSPIN-FOC

Software Architectures
The flexibility of the library allows for a variety of configurations including: using the library only for feedback; a fully abstracted sensorless FOC torque or torque and speed loop with only minor user control adjustments; or a fully customizable control system.

Feedback Sensor Only
FAST™ software encoder
- Feedback to programmable logic controller
- Redundant to mechanical sensor for high safety applications
- Low-cost replacement for mechanical speed and torque sensors
- Motor health sensors

User-Adjusted FOC
TI InstaSPIN-FOC Torque Control
- User controlled torque applications
- Transit: E-bike, lifts, scooters, traction
- Tools: drills, saws
- Hobby: cars, helicopters
- Valves, solenoid replacement

User Customized FOC
InstaSPIN-FOC Torque Control
- User-controlled torque applications
- Transit: E-bike, lifts, scooters, traction
- Tools: drills, saws
- Hobby: cars, helicopters
- Valves, solenoid replacement

TI InstaSPIN-FOC Speed and Torque Control
- Variable speed, variable load
- Washers / Dryers
- Compressors
- Pumps
- Fans / Blowers
- Treadmills, escalators, elevators

InstaSPIN-FOC Speed and Torque Control
- Variable speed, variable load
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- Compressors
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- Treadmills, escalators, elevators
Chapter 3  Explore InstaSPIN-MOTION

TI InstaSPIN-MOTION is powered by SpinTAC from LineStream Technologies. SpinTAC provides robust control across dynamic speed, position and load ranges of the system. SpinTAC significantly slashes setup time by replacing hard-to-tune PID controllers with simple, single-parameter tuning. InstaSPIN-MOTION is ideal for applications that require accurate speed and position control, minimal disturbance and for applications that undergo multiple state transitions or experience dynamic changes.

**InstaSPIN-Motion Applications**

TI InstaSPIN-MOTION can be used in many applications with the various characteristics: accurate speed and position control, minimal disturbance, undergoes multiple state transition/dynamic changes. Specific examples are identified below for each characteristic.

**Common Applications:**
- **Elevators and escalators**
- **Fans, blowers, pumps**
- **Tools** (consumer, industrial, and oil and gas including drills, drivers and torque wrenches)
- **Laundry / Washing machines**
- **Traction applications** (e-bike, pedelec, e-scooter, carts, forklifts)
- **Medical pumps, respirators, ventilators**, dental tools, surgical tools
- **Surveillance systems**
- **Medical robots**
- **Conveyer systems**
InstaSPIN™ Benefits

**Robust speed and position control**
- Controller provides more accurate compensation, both in steady state and in situations varying speed, position and load
- Motion Engine easily calculates the reference signal (with feedforward) based on current reference, target, acceleration, deceleration, and jerk

**Compensation for real mechanics of the system**
- Estimates and cancels system disturbance, in real-time.
- Eliminates recalibration—Works over the ENTIRE operating range

**Simplified control tuning**
- 1-variable “gain” allows for instant tuning
- Single tuning parameter for position and speed

**Easy design and execution of complex motion sequences**
- Motion Profile Generator creates time-optimal curves within specified acceleration, deceleration and jerk limits.
- Supports trapezoidal (ramp), s-Curve and LineStream’s proprietary st-curve. The st-curve provides additional smoothing of the trajectory.
- Motion Sequence Planner operates user-defined state transition maps.

**Identify Inertia**
SpinTAC uses Inertia to provide the most accurate system control. The SpinTAC inertia estimator automatically measures system inertia by spinning the motor and measuring feedback.

**in·er·tia—noun**
1. Motor’s resistance to change in velocity
2. More inertia = more torque to accelerate/decelerate

The SpinTAC controller can tolerate a wide range of inertia change

**Simple Tuning**
With single coefficient tuning, InstaSPIN-MOTION allows you to quickly test and tune your control from soft to stiff response. This single gain (bandwidth) typically works across the entire variable speed, position and load range of an application, reducing complexity and system tuning time in multi-variable PID-based systems. A single parameter tunes both position and speed. These systems often require a dozen or more velocity, position and load-tuned coefficient sets to handle all possible dynamic conditions. See Figure 1.
Disturbance Rejection

SpinTAC controller automatically rejects disturbances caused by:

- Cycle transitions
- Changing loads
- Environmental disturbances

SpinTAC estimator maximizes control—recovering more quickly than a PI controller, with less oscillation and with minimal over/undershoot. See Figure 2 and Figure 3.

Execute Motion Profiles

SpinTAC provides an easy way to smoothly transition from one point to another. As opposed to pre-defined lookup tables, SpinTAC runs on the processor to create smooth configurable trajectories between two positions / speeds.

The Motion Engine automatically generates the best curve to satisfy the user-entered jerk and acceleration constraints for each move. These constraints will be applied to the curve type selected by the user:

- Standard trapezoidal (constant acceleration, infinite jerk)
- S-curve (smooth, bounded jerk)
- Proprietary st-curve (smoothest, continuous jerk)

Plan Trajectories

SpinTAC will help you plan your trajectories in minutes. SpinTAC trajectory planning allows you to quickly build various states of motion (point A to point B) and tie them together with state-based logic (hold for time, wait for interrupt, move to state C or D based on logic, etc.).

The trajectories are directly embedded into the C code on the microcontroller. See Figure 4 and Figure 5 on the following page.

![Figure 2. Speed control comparison with load changes.](image)

![Figure 3. Position control comparison with load changes.](image)
Chapter 3: Explore InstaSPIN-MOTION

Figure 4. State machine plan for washing machine example.

Figure 5. State machine plan for elevator example.
SpinTAC Controller

TI InstaSPIN-MOTION features SpinTAC precision speed and position control, unattainable by other methods.

SpinTAC Control Features:

• **SpinTAC Identify**: Estimates system inertia according to the applied torque profile and the measured velocity feedback

• **SpinTAC Control**: Regulates speed and position loops according to velocity reference, position reference, feedback, and acceleration reference

• **SpinTAC Move**: Generates a speed or position profile based on reference, target, and configured system limitations for acceleration and jerk

• **SpinTAC Plan**: Generates sequential setpoints and system limits (acceleration and jerk) according to a user-defined state transition map

• Tuning is accomplished in minutes vs. days

• Single tuning parameter typically works across all speed, position and load ranges

• The controller automatically compensates for system disturbances

• System inertia is automatically identified, and used to maximize control

![Figure 6. SpinTAC features.](image)

![Figure 7. Tuning interface.](image)
Chapter 3: Explore InstaSPIN-MOTION

Software Architectures

TI InstaSPIN-MOTION example projects are available through MotorWare software. The projects rely on modules and an interface library included in MotorWare, as well as the core SpinTAC™ features (identify, control and move) residing in on-chip ROM. The projects are designed in a modular structure to demonstrate the flexibility of adding InstaSPIN-MOTION features to your application. SpinTAC is available in conjunction with FAST on select Piccolo™ microcontrollers, identified by a trailing “M” (ex: TMS320F28069M). See Table 1.

<table>
<thead>
<tr>
<th>Sensorless Speed Control</th>
<th>Sensored Speed Control</th>
<th>Sensored Position (Servo) Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>InstaSPIN-MOTION Speed Control with FAST Software Encoder</td>
<td>InstaSPIN-MOTION Speed Control with Mechanical Sensor</td>
<td>InstaSPIN-MOTION Position Control with Mechanical Sensor and redundant FAST Software Sensor</td>
</tr>
<tr>
<td>• Accurate speed control</td>
<td>• Accurate speed control</td>
<td>• Accurate position, speed and torque control</td>
</tr>
<tr>
<td>• Minimal disturbance</td>
<td>• Minimal disturbance</td>
<td>• Combined position and speed 1-variable tuning</td>
</tr>
<tr>
<td>• Multi-state transitions</td>
<td>• Multi-state transitions</td>
<td>• Inertia identification and automatic current-loop tuning</td>
</tr>
<tr>
<td>• Dynamic changes</td>
<td>• Dynamic changes</td>
<td>• Motion trajectory curves and state-based planning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Minimal disturbance across multi-state transitions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• FAST Software Encoder for redundancy</td>
</tr>
</tbody>
</table>

Table 1. Three-phase motor control software architectures.
Chapter 4  FAST Software Encoder

Universal 3-phase motor software encoder supports
• Synchronous (BLDC, SPM, IPM)
• Asynchronous (ACI) motors
• Unique, high quality feedback signals for use in control systems

Performance
• Stable estimations
• Tracks below 1 Hz
• Tracks through zero on speed reversals
• Stable feedback to control system when rotor is at zero speed

Motor Parameters
• Relies on fewer parameters than other observers
• Off-line commissioning learns the needed electrical motor parameters
• Optional online observer tracks parameter changes to insure estimation accuracy over time and temperature

Tuning
• No tuning of the observer required

Included in ROM on select Piccolo MCUs, with software API

Rotor FLUX
• High-quality Flux signal for more stable flux monitoring and field weakening and boosting applications

Rotor Flux ANGLE
• Best rotor flux Angle estimation accuracy over widest speed range
• Provides reliable angle tracking within one electrical cycle of rotation
• With quality sense inputs can track at under 1-Hz frequency
• Angle tracking is completely robust under dynamics and FAST recovers and re-locks after an over load stall event
• Typical angle accuracy within ±1 count of a 1024 mechanical encoder steady state
• Angle estimate for induction machines is independent of rotor resistance

Shaft TORQUE
• Accurate rotor shaft torque signal for load monitoring
• Use in custom control systems for flow rate monitoring, unbalanced load detection and motor health diagnostics

Rotor Flux SPEED
• Mechanical and electrical rotor speed estimations (including slip for induction)
• Without position derivative quantization seen in standard observers
• Reduces phase lag in control systems
• Best speed input into the control system
PowerWarp software is a capability of InstaSPIN-FOC designed to improve induction motor efficiency at partially applied loads.

**PowerWarp Software Savings**
- Automatically adjusts current usage of induction motors to minimum possible at all times
- Benefits greatest when load (torque demand) on the motor is lowest
- Only works because FAST encoder is so robust and stable when dynamically tracking the rotor flux angle
- Algorithm is an industry first based on reducing motor copper losses in the stator AND the rotor!

Motor efficiency is boosted dramatically at lower loads, with a trade-off in dynamic torque and speed response, though the control system remains stable.
Chapter 6  InstaSPIN Design Tools and Software

MotorWare
The software and documentation package for developing InstaSPIN-FOC or InstaSPIN-MOTION solutions for F2806x, F2805x and F2802x series.

MotorControl SDK
The latest software and documentation package for developing InstaSPIN-FOC solutions for the F28004xC series.

SDK InstaSPIN Universal GUI
This GUI instruments the common variables in any MotorControl SDK InstaSPIN-FOC project.

InstaSPIN Universal GUI
This GUI instruments the common variables in any MotorWare project and is useful during evaluation and development.

InstaSPIN-FOC and Insta-MOTION GUI
A static demonstration GUI that shows many of the general features and capability for MotorWare-based InstaSPIN solutions.

Additional Resources
InstaSPIN training videos:

Motor drive and control blog:
http://e2e.ti.com/blogs_/b/motordrivecontrol

InstaSPIN e2e™ support forum:
http://e2e.ti.com/support/microcontrollers/c2000/f/902

C2000 motor control:

C2000 overview:

TI Worldwide Technical Support

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Technical support forums
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