Sophisticated MB91580 Series MCUs Can Simplify Hybrid and Electric Vehicle Motor Control Designs
Motor Control MCUs for Hybrid and Electric Vehicles

All-electric vehicles that function entirely without an internal combustion engine need safe, cost-effective and high-capacity energy-storage systems. Efficient software algorithms, powerful microcontrollers (MCUs) and highly efficient electric motors can make maximum use of available energy. A high level of integration enables leaner and cost-effective motor control systems. New generations of highly integrated MCUs developed specifically for hybrid electric (HEV) and electric vehicles (EV) include timer structures that generate motor control signals along with various I/O ports and interfaces. The new MB91580 series is part of the Fujitsu FR family of 32-bit RISC architecture microcontrollers, which incorporate embedded flash memory and feature optimized, high-performance peripherals for EV and HEV 3-phase inverter motor control. Applications include EV/HEV motor and electric generator control, as well as generic, high-performance, electric motor control.

An Overview of HEV and EV Motor Functionality

Before detailing how these new MCUs operate, it is useful to review how HEV and EV motors function. Figure 1, above, shows the broad classifications of HEV and EV vehicles. A central element of hybrid and electric vehicles is the electric motor in the powertrain, which is deployed in combination with a conventional internal combustion engine in hybrid cars or as an independent source of power for electric vehicles. Selecting the motor requires careful analysis of the dimensions, weight, reliability, robustness, required torque and total efficiency.

There are two basic types of these motors. Asynchronous motors are robust and reasonably priced in part because they do not require magnets made from rare earth elements. Their properties are easily controlled with software algorithms, and maintenance is not required. Compared with synchronous motors, asynchronous motors are slightly less efficient (about 90 percent), require lower torque at start-up and weigh more.

The other choice, the permanent magnet synchronous motor (PMSM), features high torque coupled with compact dimensions and high efficiency (about 94 percent). Synchronous motors cost more because they are built with expensive materials from rare earth elements, which are required for the permanent magnets. Brushless versions of both motor types mean that brush loss is not an issue. PMSMs, which offer a better dimensions/torque ratio and higher efficiency, are currently the first choice for use in the powertrain of electric and hybrid electric vehicles.

Motor Control

Energy efficiency and optimal performance come from using the best control algorithms executed on a fast CPU, in tandem with the appropriate peripheral blocks. Together, the algorithms and peripheral blocks provide accurate and fast motor rotor position feedback and output optimized driving signals.

One of the prerequisites in designing EV and HEV powertrain systems is efficient motor control, as these brushless motors require more effort for commutation. It is important to find the perfect balance of motor, power electronics, the MCU, and the control software running on it.

The algorithms must be adapted to the respective motor and application so that the electronic controller commutates the motor optimally at all times. Failure to adapt the algorithms correctly can lead to undesired effects such as irregular running...
and excessive noise, which together have a negative impact on the degree of efficiency that can be achieved. Motor control combines various control algorithms depending on the application. Figure 2 shows field-orientated control (FOC) combined with proportional integral derivative (PID) regulation systems for controlling rotor speed, torque and flux.

In FOC, the Clarke/Park transformation is used to transform the phase currents measured (at least two must be continuously recorded) from a stator-based, three-dimensional system to a rotor-based, two-dimensional system. These transformed variables — the current rotor position and a target position specified by the application — or a target rotational speed, are taken as starting points for the control algorithms. Due to their fast, precise and overshoot-free control characteristics, PID regulators are ideal for bringing complex systems into a stable state.

By means of inverse Park/Clarke transformation, the system is transformed into a rotor-based vector system and the voltages to be set are transmitted to the motor via the power electronics by means of pulse-width modulation. The current rotor position can be either directly determined with a sensor or estimated using a complex calculation system. The latter method — also known as sensor-less angle detection — is based on the logging and evaluation of two actively controlled phases. This method can be subject to deviation of several angular degrees and is not currently used for motor vehicle applications.

Sensor-based rotor-position detection can be conducted with various sensor systems. The following section gives a brief overview of the most common sensor types. However, it can generally be said that the detection of the rotor position is essential for precise motor control. As a key component, the rotor position sensor has significant influence on the performance and efficiency of the motor system.

Hall sensors are based on the Hall Effect, in which a voltage is induced by changing the magnetic field around a current-carrying conductor. With the help of a magnetic ring attached to the rotor and a sensor unit affixed to the stator, the Hall Effect sensor is an inexpensive, easy way to detect angles. The greater the number of magnetic poles and Hall elements, the higher the resolution and accuracy susceptible to magnetic interference.

One frequently used sensor is the incremental encoder. This is available in a wide range of designs, featuring both mechanical and optical scanning to determine the current angular position. To measure an angle, an incremental encoder must be based on zero or a reference position. For the MCU, actual angle determination only involves detecting the direction of rotation and counting the pulses emitted. The angular rate can be calculated by simply measuring the intervals between two pulses. The insensitivity to magnetic interference is beneficial; any mechanical friction losses and susceptibility to dirt are disadvantages in the case of optical systems.
**Resolver**

The resolver is a robust sensor often used in the automotive industry. The resolver is not at risk from magnetic interference and dirt, or subject to friction losses during angle detection. It consists of the rotor, which is permanently attached to the motor shaft (= motor rotor), and the ring-shaped stator, which is permanently attached to the motor housing. The stator consists of at least one excitation coil and two sensor coils. Higher resolutions can be achieved by increasing the number of pole pairs.

Figure 3 shows a resolver. The excitation coil is fed with an analog sinusoidal signal. The analog signal is transmitted to the two sensor coils, set at 90° to each other, via the magnetic coupling (induction). Evaluation of the analog sinusoidal and cosinusoidal signals returned by the resolver requires a resolver-to-digital converter (RDC), which is used to determine the angular position and rate from the analog data.

Resolvers may not be superior to the competing technologies in terms of performance and precision, but they are more robust and offer better protection against dirt and extreme temperature conditions. Resolvers are also able to detect the motor's absolute position at any time, even when it is not moving. Incremental encoders and hall sensors cannot perform that function.

![Figure 3: Schematic and mechanical structure of a resolver](image-url)
Inverters in vehicles

In the simplest case, the motor controller consists of an MCU, a power-output stage, the motor in conjunction with a rotor position sensor (resolver) and the RDC, which is usually implemented as a discrete circuit. This generates the resolver signal and determines the rotor position and rate as quickly and precisely as possible based on the sinusoidal/cosinusoidal information returned.

This information must be forwarded to the microcontroller so that it can be taken into account in the motor control algorithms as described. External RDCs are usually linked to the MCU via a serial peripheral interface (SPI) or, depending on the system’s design and the manufacturer of the RDC, via other serial or parallel ports. These solutions suffer from a serious disadvantage in that the MCU does not have constant access to the rotor data, and must instead always request it from the external RDC. This is relatively slow, and a potential source of errors that can negatively impact the functional safety of the entire system.

![Motor control diagram](image)

Figures 4a and 4b: Motor control with external and integrated RDC
Motor control MCUs simplify the system architecture

With its new MB91580 32-bit microcontroller series, Fujitsu is taking an entirely different approach (see Overview of the MB91580 Series below). In a 144-pin package, a powerful 32-bit MCU with 150 D-MIPS computing power offers up to 1 MB of flash memory with 128 KB RAM, numerous I/O ports, powerful timer structures to generate all the motor control signals, and ample communication interfaces such as Controller Area Network (CAN), Local Interconnect Network (LIN) and FlexRay. The integration of the RDC results in a significantly simplified system architecture. Rotor position, sinusoidal and cosinusoidal values as well as the angular rate are available to the MCU at all times and can be read out from dedicated registers every 100 ns. The block diagram in Figure 5 gives an overview of the on-chip resources available.

Motor controllers are often developed using a model-based method; new and powerful software tools generally work with floating-point numbers. In order to transfer the algorithms developed in this way to a conventional microcontroller, the floating-point numbers must be converted to integers. The integrated floating point unit in the MB91580 series increases the computing power and reduces the amount of work needed to port from models to the application itself.

Overview of the MB91580 Series: 32-bit Motor Control MCU for Electric (EV) and Hybrid Electric Vehicles (HEV)

The new MB91580 series, a part of the Fujitsu FR family of 32-bit RISC microcontrollers (http://us.fujitsu.com/semi/mcu/FR), offers 3-phase inverter motor control and an embedded resolver interface for electric and hybrid electric vehicles. The MCU series offers high performance combined with optimized peripherals for electric and hybrid electric vehicles. The MB91580 series was designed to provide special features for efficient loopback control. The device offers a 12-bit Analog to Digital Converter (ADC) and a 12-bit Resolver to Digital Converter (RDC) to detect motor current and position at high speed and with high resolution. The electric angle of the revolver, which is calculated by the RDC, is latched into dedicated registers and synchronized with the three-phase current detected by the ADC. Control algorithms will benefit from the floating point Unit (FPU) and will speed up vector conversion and calculations by 10-15% using decimal point numbers compared to standard integer processing.

The MB91580 series features Fujitsu’s advanced flash memory technology, including dedicated program memory and a separate work flash for E²PROM emulation storage.

For more information about the MB91580 series, visit http://us.fujitsu.com/semi/mcu/HEV-EV.

Figure 5: MB91580 series microcontroller – block diagram
Resolver diagnosis increases functional safety

The MCU can identify a failure or malfunction of the motor relatively easily. For example, the phase currents may not correspond to the expected values, or the expected speed may not have been reached. In these cases, the MCU can set the system to a defined state – without compromising vehicle safety. But how is the resolver monitored and how are malfunctions diagnosed? The MB91580 series offers a solution here as well. It monitors all signals from and to the resolver via integrated diagnostics and fault profiles such as short-circuits to ground, so cable breakages/interruptions or even short-circuits within the resolver windings can be identified quickly and reliably. If such faults occur, the MCU immediately receives an internal interrupt signal so it can react quickly and in a targeted manner that addresses the specific situation. All this takes place internally with minimal latency. In contrast, systems with external RDCs must signal the failure by means of a slow interface to the MCU.

Since the MB91580 series was developed specially for use in motor vehicles, it offers other powerful functions to increase operational safety. For example, all flash memory and RAM are monitored by means of ECC. A memory protection unit identifies and prevents unauthorized access to prohibited memory areas. An integrated CRC generator (CRC16 & CRC32) and parity bits on the internal buses offer added security.

Application of the MB91580 series in HEVs and EVs

Applications for motor control MCUs, such as Fujitsu’s MB91580 series with integrated RDC, include the inverter for the electric drive motor. The block diagram for an inverter is shown in Figure 6a. For reasons of functional safety, the motor control MCU (master) is supported by a second, smaller microcontroller (slave). Both microcontrollers maintain a constant dialogue and, as soon as abnormal behavior is detected, the slave MCU can initiate a system reset or cut off the power supply to the motor. The master MCU generates the commutation signals for the motor, measures and monitors the phase currents, generates the resolver signals, and determines the rotor position and angular rate via the sine/cosine feedback. The motor control algorithm uses all this data for targeted control of the rotor speed and torque.

The inverter communicates with the battery management system (BMS) via the internal network (CAN or FlexRay) to ensure that the energy required can also be provided.

Economical use of energy is essential in an HEV/EV. Systems that require a constant supply of energy, such as hydraulic power steering, would over the long term put excessive strain on the energy-storage systems. Hydraulic systems run continuously in order to build up the required pressure by means of a servo pump. Refer to Fig 6a for a diagram of an example HEV/EV inverter.
A purely electric power steering (EPS) system only needs energy when in use. Refer to Fig 6b for a diagram of an example EPS control system. In principle, the design is similar to that of the inverter for the powertrain. There are master and slave MCUs, while the power element is different mainly in terms of the power to be regulated. A PMSM is used for this application also, while the resolver functions as described. However, the master MCU must still evaluate a steering input device and a torque sensor. So that the correct steering assistance can be given at all times, the microcontroller needs data such as the speed of travel, which is provided via the internal network (e.g., the CAN bus). This information helps calculate the extra steering torque required and transmit that data to the electric motor on the steering column.

The aim is to reduce the effort expended by the driver and provide dynamic support for steering movement. For example, steering movement requires more support when the vehicle is almost at a standstill, such as during parking maneuvers, than at high speed on the motorway. EPS is intended to increase both driver comfort and safety. It is entirely possible for the electronic stability control (ESC) to actively regulate vehicle stability by means of steering intervention. It is also conceivable for the EPS to be part of a driver-assistance system that could park a vehicle automatically without driver input.

More and more hybrid vehicles are coming onto the market. At the moment, most are comprised of simple start-stop systems. However, the number of full hybrids and plug-in hybrids (PHEVs) is expected to increase substantially in the years to come. Unlike hybrid vehicles, which have a backup gas engine, all-electric engines need safe, cost-effective, and high-capacity energy storage systems.

Here, too, technological development is marching onward, although not as quickly as many would like. Until HEVs and PHEVs become commonplace, maximum use must be made of the energy available in the form of fuel and/or electrical power in hybrid vehicles. Efficient software algorithms, powerful microcontrollers and highly efficient electric motors will make this possible. A higher level of integration leads to leaner and cheaper motor control systems that can be used in applications above and beyond those presented here. Fujitsu's new series of 32-bit motor control MCUs can really help. By integrating RDC on the chip, the MB91580 series offers significant advantages by reducing system cost, offering higher levels of integration, and improving system performance efficiency.

For more information about the MB91580 series, visit http://us.fujitsu.com/semi/mcu/HEV-EV. To learn more about the full lines of 8-, 16-, and 32-bit MCUs from Fujitsu, visit http://us.fujitsu.com/semi/mcu.

Figure 6b: Diagram of an EPS control