

Development of Magneto-Elastic Torque Sensor for Automatic Transmission Applications

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ABSTRACT

Progress in the design and application of the magneto-elastic torque sensor to automotive drivetrain systems has taken the technology from the concept level to the point where it is considered production feasible. The latest generation of the sensors shows promising results regarding both the capabilities and applications to powertrain controls. Sensor designs, electronics and packaging layout are maturing. Well-defined component specifications and requirements are becoming available. The sensor utilities for real-time shift analysis and friction element control are established through vehicle-level investigation to demonstrate the production feasibility of the technology for transmission torque sensing.

CITATION: Pietron, G., Fujii, Y., Kucharski, J., Yanakiev, D. et al., "Development of Magneto-Elastic Torque Sensor for Automatic Transmission Applications," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):2013, doi:10.4271/2013-01-0301.

INTRODUCTION

Progress in the design and application of the magneto-elastic torque sensor to automotive drivetrain systems has taken the technology from the concept level to the point where it is considered production feasible. The latest generation of the sensors shows promising results regarding both the capabilities and applications [1, 2]. Sensor specification, location, material selection, packaging, manufacturability, FMEA, and use in powertrain controls are investigated, specific to automatic transmission applications. This paper presents sensor design considerations, operating characteristics and performance, followed by the feasibility assessment of torque-sensor based control concepts.

Prototype sensors were designed and fabricated for the input shaft of a step-ratio FWD transmission with a torque converter. The sensor design was driven by powertrain control requirements, demanding an accurate and reliable signal. Bench testing was conducted to characterize and verify sensor functions using a static load test stand and an environmental chamber. The same sensor was implemented in a test vehicle, which was equipped with strain gauge type torque transducers on the transmission half shafts as a reference signal. Thorough verification of sensor function was conducted in the vehicle for accuracy, linearity,

resolution, uniformity, repeatability, response time, hysteresis, and zero offset. Additional dynamic response study was conducted in a proving ground to establish real-world transient characteristics in comparison to the reference sensor.

To gain insight into the use of the sensor in powertrain controls, fixed accelerator pedal tests were conducted. The torque sensor measurements and other sensory data were combined together to construct a transmission-internal load map, including clutch torque during both synchronous and non-synchronous shifts. The study indicates the feasibility of torque-based closed-loop clutch control that improves shift quality and reduces calibration effort.

BASIC SENSOR FUNCTION

The magneto-elastic torque sensor (ME sensor) relies on a well-known property of permanently magnetized materials. The magneto-elastic effect causes a finite rotation of magnetic domains when a magnetized shaft is placed in torsion. The rotation of the field is proportional to the applied torque, and remains linear until the magnetic yield point is reached, beyond which the magnetic field rotation is non-linear with torque [3]. To utilize this physics in a torque sensor, several components are required: a magnetized shaft,

a magnetic flux sensor, and electronics to drive the sensor and create a useful output signal.

The shaft must be made of a permanently magnetizable material with large enough magnetostrictive coefficient such as a nickel alloy steel (SAE 4340 or 9310) and heat treated to obtain at least 95 percent martensitic structure. The shaft shape should be of constant cross section and be long enough to contain all magnetized regions. The magnetic field shaping and direction can be controlled to provide desired properties such as external magnetic field cancellation, and to minimize hysteresis. Typically the shaft is circumferentially magnetized within a band, and the application of torque to the shaft results in the opposite magnetic poles forming on the opposite edges of the band, with a toroidal field being generated above the surface of the shaft, that can then be detected by a flux gate sensor [4].

The flux gate includes a core which is easily saturated by the combination of a driven reference signal (a square wave), and the magnetic field generated by the magneto-elastic effect. The electronic system drives the square wave signal to the flux gate, compares it to the reference signal utilizing a wheatstone bridge, and amplifies the measured voltage difference from the bridge. A thermistor is located near the shaft to compensate for the change in the magnetoelastic effect caused by varying temperature. This gives the electronics the additional task of driving the thermistor, reading the temperature, and adjusting the output signal for the temperature.

SENSOR SYSTEM DESIGN

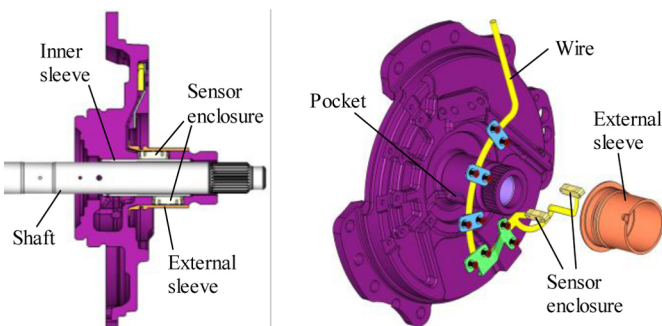


Figure 1. Input Shaft Torque Sensor Design

Figure 1 shows a prototype magneto-elastic torque sensor design for a step-ratio FWD transmission with a torque converter [5]. The transmission system is modified to package the torque sensor without compromising its original functions and load specifications. For example, the reshaping and material changes to the input shaft must not affect strength, and essential geometric features. In this application, the shaft was redesigned to include the constant cross section, as well as material change to 4340 nickel steel alloy. Axial stack-up of the shaft required modifications to align the magnetized region to the location of flux gate sensors. Considerable efforts were taken to maintain uniformity of

martensitic microstructure without reducing fatigue life and to utilize a manufacturing process not significantly different than that for the production shaft.

The transmission front support module has multiple functions that include mounting the torque converter's stator, routing transmission fluid for hydraulic controls, and providing a support for output torque gearing. In the area where the flux gate sensor is placed, additional functions of providing a bushing to pilot the input shaft, a bushing to pilot the torque converter, and a seal for the torque converter fluid are required. To ensure each of these functions, the front support was designed to include an inner sleeve, an outer sleeve, windows for sensor containment, and channels for running wiring to and from the sensor. The inner sleeve provides the journal surface for the shaft, and also seals the fluid flow paths. It is composed of a magnetically transmissible bronze material. The window and channels allow for location and protection of the lead frame wires and sensor enclosure during assembly and operation. The outer sleeve holds the sensor in place, protects it during operation, provides a journal for the torque converter bushing, and accommodates a seal for the torque converter system. It is constructed of soft carbon steel, and also acts as a magnetic shield for the flux gate sensor by smearing the signal from localized magnetic "hotspots" on the torque converter that potentially degrade rotational signal uniformity on the torque measurements.

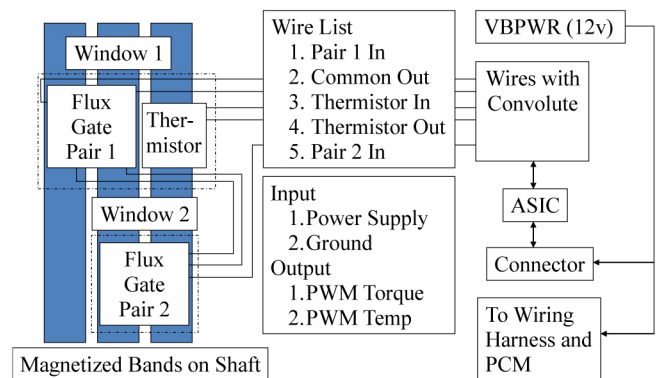


Figure 2. Torque Sensor Electronic Design

The sensor electronics diagram is shown in Figure 2. The system includes three magnetized bands on the shaft, two flux gate pairs and a thermistor near the shaft, and the electronics [4]. The magnetic bands are arranged in alternating polarity, and the flux gates in each sensor window read only two of the three bands. The flux gates and thermistor are enclosed in a capsule to protect against contact with the transmission fluid. They are sized to place the flux gates at a fixed location within the window cut in the front support tube. They are attached together by a lead frame which minimizes the size of the wiring channels, while providing placement of the wires during assembly and operation. The electronics also provide failure mode information, as well as temperature and torque signal to the powertrain control module. Pulse width