Torque Sensor for Automotive Applications

An investigation of torque sensing techniques for drivetrain integration

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***Abstract*—The purpose of this project is to increase torque measurement accuracy in BorgWarners AWD coupling. A torque sensor concept which utilizes the effect where a materials magnetic properties changes in response to mechanical stresses was developed. A series of test were conducted to measure the sensors response and sensitivity. The test result clearly shows the torque induced variations of the magnetic field. The proposed solution demonstrates the potential of making a compact sensor with few components with possibilities to be integrated in BorgWarner products.**

Keywords—Torque sensor, Magnetoelastic, Polorized band.

I. INTRODUCTION

Drivetrains are becoming increasingly complex, the ability to measure the torque applied to the wheels are of increasing importance. The ambition at BorgWarner TorqTransfer Systems AB is to increase torque accuracy to optimize their powertrain solutions. Better torque measurement will allow for a more accurate control and greater weight and strength optimization of the components.

The goal of the report was to provide suggestions for solutions that are tailored for high volume production and integration in the coupling. The focus of the investigated methods were on fitting them inside the coupling and measure the torque directly on the shaft.

This study will present the results of the development and test process of a torque sensor concept. The goal is to improve the accuracy and reliability compared to the current method for torque measurement.

II. CONCEPT DEVELOPMENT

Different methods of measuring torque inside the coupling was investigated. The harsh environment inside the coupling with the automotive industries high demands on robustness and low costs placed high requirements on the sensor. This excluded ideas such as strain gauges and SAW sensors where the specimen has to be glued to the shaft as well as the addition of sliprings or electronics on the shaft to transfer the signal.

A promising option was using a magnetoelastic sensing technique, were the torque can be measured by non-contact means on any solid shaft. The selected design was the polarized band sensor with its few components and its low power consumption.

A. Polarized band sensor

This kind of transducer consist of a ferromagnetic sensing element with magnetostrictive properties together with a magnetic field sensor. The sensing element is circumferentially magnetized, creating a circular polarized band. The design for this sensor uses the configuration seen in Figure 1. The two remanent magnetic fields M_{R1}, M_{R2} will rotate under applied torque. The right side of M_{R1} gives rise to the same magnetic polarization as the left side of M_{R2} creating a magnetic pole in the centre of the ring and two opposite poles at the edges of the ring [1].

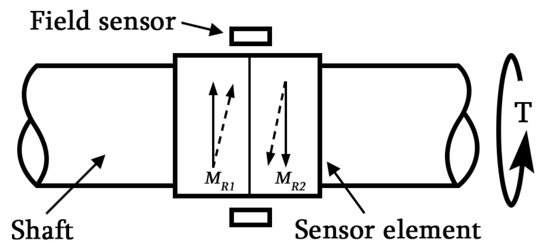

Figure 1 - Polarized band sensor

One or more magnetic field sensors are placed at close proximity to the centre pole, sensing the magnetic field generated by the sensing element. The strength of the generated field is linearly dependent on the applied torque[2].

The performance of the sensor depends largely on the properties of the sensor element. The shaft itself can be used as the sensing element, otherwise an external element can be attached to the shaft e.g. a ring that is pressed onto the shaft. The sensing element needs to be ferromagnetic with high remanence in order to contain the circumferentially magnetized field. Additionally the material needs a high magnetostrictive constant λ_s, which directly affect the sensitivity of the sensor.

B. Prototype

The sensing element was made of a martensitic stainless steel which have good magnetoelastic properties. To prevent the magnetic field from taking the path through the shaft rather than to the field sensor, an isolating ring was used. It separates the shaft and magnetoelastic ring which increases the reluctance path through the shaft which makes more magnetic flux reach the sensor.

Two shafts were made for the tests. One where the rings was press-fitted onto the shaft with only friction transferring the forces to the rings. To ensure a physical lock, the rings were welded on the sides to the second shaft. This shaft was also weakened to make it less torsionally rigid.

AMR sensors were used to detect the magnetic field. Since they were measuring in three directions, all orthogonal to each other, it was possible to measure the magnitude of the magnetic field in axial, radial and circumferential directions.

The sensor was mounted inside a BorgWarner Gen V coupling, Figure 2.

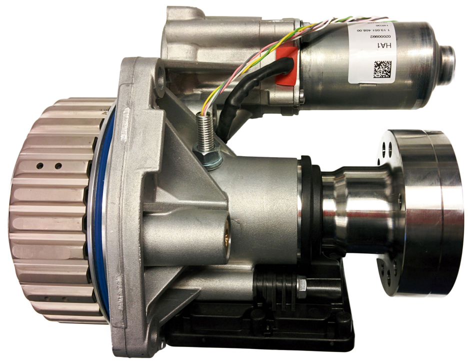

Figure 2 - Gen V coupling with the sensor mounted inside

III. Results

The test of just the magnetoelastic ring shows a linear relationship between applied torque and magnetic field, Figure 3. The slight unevenness came from the inaccuracy of the applied torque.

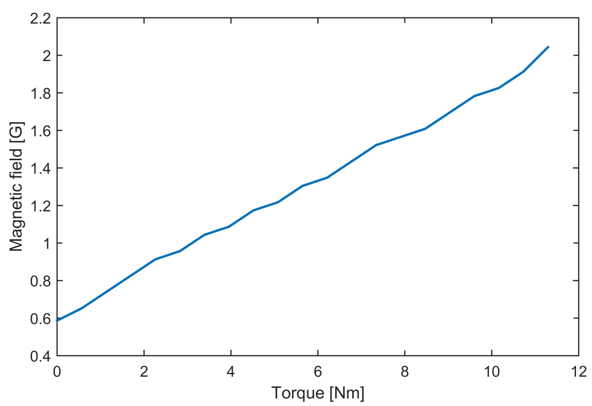

Figure 3 - Static torque test

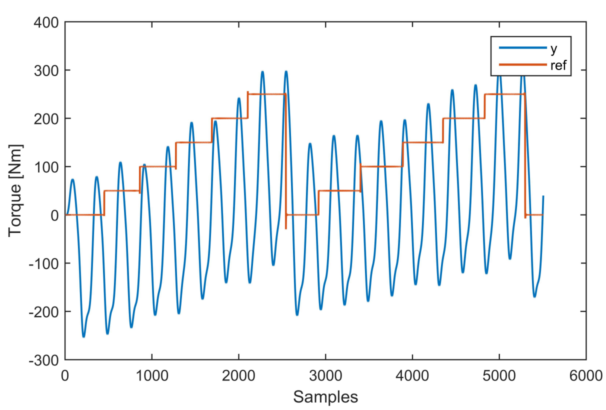

Figure 4 - Test in coupling

Further tests were preformed with the rings mounted inside the coupling and the shaft was rotated at a constant speed of 10 RPM. The tests where the rings were secured with just frictional bond did not give any result where the output signal could be correlated to the actual toque. This was a result of the stresses not being transferred to the magnetoelastic ring to the extent of which would cause measurable changes in the magnetic field.

The result of the tests with the rings secured to the shaft with welds can be seen in Figure 4. A variation in the magnetic field can be seen around the circumference of the sensor element. Each period corresponds to one revolution. These variations are an effect of the magnetization process where it did not managed to order the magnetic domains uniformly in the sensor element. In Figure 4, the magnetic field was measured in the axial direction, similar oscillations could also be seen in the circumferential and radial direction but of less magnitude. When torque is applied the strength of the magnetic field increases. Due to hysteresis it does not return to its original level when the torque return to zero.

IV. Conclusions

The benefit of the magnetoelastic torque sensor is the wireless nature of the technique as well as the sensor assembly can be less complex compared to other measuring techniques. If the shaft is made of an magnetoelastic material the only additional sensor part would be the field sensor.

The torsional rigidity of the rings have to be reduced to allow stresses to go through the isolating ring and reach the magnetoelastic. The risk of slip in the interference between the ring and shaft increases with the torsional resistance. By making the isolating ring thinner it would make the assembly less torsional resistant and less prone to slip. Improvements can also be made to the attachment of the rings to the shaft. A press fit can be improved by using retaining fluid which glues the rings to the shaft, or by making a physical lock by e.g. using splines.

To reduce the amplitude of the peaks and improve the remanent magnetic field in the rings an electromagnet could be used. It would allow for better control of the magnetic field as well as greater field strength, compared to the permanent magnets used during the magnetization in this report.

The tests show the sensor has potential of measuring torque on a rotating shaft. However, improvements have to be made to both the magnetization as well as the attachment of the rings.

References

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[2] Ivan J. Garshelis, *Investigations of Parameters Affecting the Performance of Polarized Ring Torque Transducers* IEEE Transactions on Magnetics, Vol. 29, IEEE International, 1993.