Contactless Torque Sensor based on shaft torsion measurement, compatible with existing shafts

Eng, Christophe Benoit, Cedrat Technologies, France
Eng, Alexandre Pages, Cedrat Technologies, France
Dr, Frank Claeyssen, Cedrat Technologies, France

Abstract

The torque measurement usually comes from strain gauges bonded on a shaft. The main concern in this measurement is due to the fact that these gauges are also rotating and the integration of electronic on rotating parts is definitely a blocking point.

To overcome these limitations, the architecture of our device is mainly composed of two targets, two position sensors, a proof body and a compact body. In its working principle, the angular shift between two rotary targets along the shaft is converted by the proof body into amplified axial shift between the targets. Only one sensor is required to measure the target motion. However two sensors perform a differential measurement in the stationary frame for temperature compensation. This new generation of contactless sensor has been developed and patented to capture the torque in a stationary axle or rotating shaft. The measurement is done with stationary electronic components. This unique compact structure measures torque with low-cost standard eddy current sensor..

1 Introduction

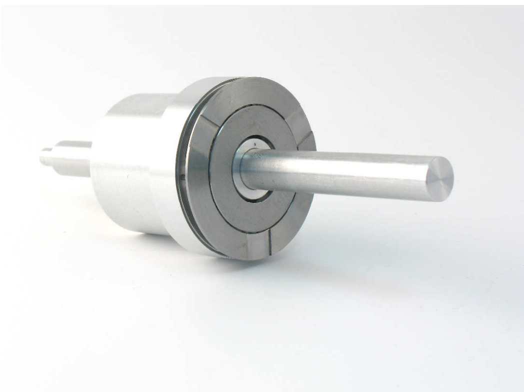

Figure 1 Realisation of a CTS presenting two kinds of targets

The torque measurement on a rotating shaft is a common need that until now is mainly fulfilled thanks to the use of strain gauges bonded on the shaft. One drawback of this technology is it is not suitable to design a sensor that can be in the same time reliable, cost effective and robust. The main concern in this measurement is due to the fact that these gauges are also rotating and the integration of electronic on rotating parts is definitely a blocking point. Other solutions based on magnetic effects, such as magnetostrictive or Hall effects exit, but they have strong limitations such as they require a magnetic shaft, have a limited speed, limited resolution…

Moreover, very few solutions are able to provide in the same sensor the torque and the speed, or the torque and the shaft's position.

To overcome these limitations and to answer customers' needs, Cedrat Technologies has developed the CTS, a new contactless mechanical sensor. The word mechanical sensor is used because the CTS can measure the torque and additional characteristics. The main principle of this sensor is to use the normal shaft torsion under load as the sensor. This becomes possible thanks to CEDRAT's knowhow in small displacement control and amplification. More explanations will be given in the next chapter, but one can already say that this structure offers lots of benefits for the customer:

First, it can be easily integrated in the customer system, as it is compatible with every shaft materials. Most of the time, it can even be mounted on an existing shaft with no need of a new shaft design. The main consequence is it is easy for the customers to retrofit some application by integrating the CTS. This concerns for example the machine tooling systems, electric power generators, power plants and so on.

Secondly, as the sensor is made of a small number of parts, it is a cost effective solution for mass production. One of the most demanding industries on the cost of a solution is the automotive industry. And the CTS's design has convinced the well known automotive manufacturer PSA to support this development and be co applicant with Cedrat in the CTS's patent.

Thirdly, as all the electronic components are in the static part, the CTS is reliable and robust. This makes the CTS compatible with very harsh and polluted environments. This sensor can work for example with dust or sand, oil, water, chips. It can bear the same over torque as the shaft on which it is mounted. This is why this sensor is a good candidate for a machine tooling supervising system where the goal is to detect over torque and improves predictive maintenance. Thus, the CTS sensor design includes thermal or mechanical misalignment compensation mechanisms, allowing an easy mechanical integration. More explanations will be given in the next chapter on how it does work.

Last advantage, and maybe the most innovative, if the CTS sensor is basically a contactless torque sensor, it can offer lots more. In addition with the torque measurement, this sensor can first provide the rotation speed. Torque plus speed, this is very useful to have with only one sensor the measurement of the mechanical power transmitted by a shaft. As another optional measure, the CTS can provide the absolute position information. This becomes very useful for example for the command of synchronous motor. Another application where this multiple measure is very welcomed is the robotic domain. By allowing reducing the number of sensors, the CTS allows saving space and weight and complexity, which is very important for most of robotic applications.

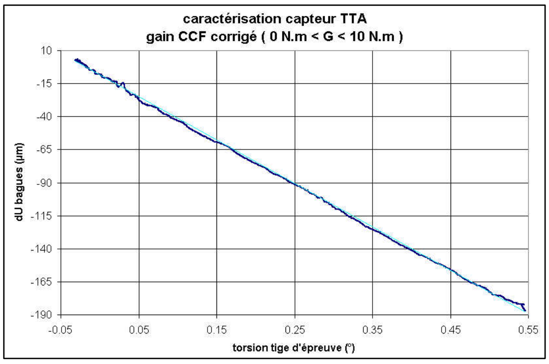

Figure 2 Sensor characterization

2 Working principle

When a torque is applied on a shaft, torsion occurs. The idea is to measure this natural torsion to measure the torque. But there is an issue. Most of the time, for short shafts, the torsion is very small, and cannot be efficiently directly measured. Some optical solutions exist, but not fully answer the sensor needs. To solve this blocking point, the solution is first to transform torsion deformation into linear displacement, because linear displacement can easily be measured. In the same time, if an amplification of the displacement can be created, the sensor sensitivity is increased. This is summed up in the sketch presented figure 3.

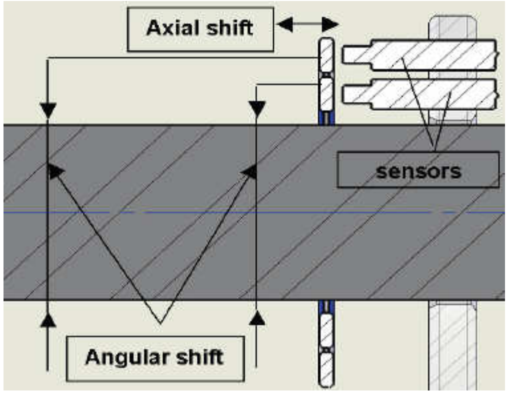

Figure 3 Sensor principle: conversion from torsion to linear displacement

2.1 Technical solution for the conversion

The problem of torque measurement manly becomes how to convert a small angular shift into significant axial shift. The solution is coming from our knowhow acquire with the design of piezoelectric actuators. Indeed, piezoelectric material such as PZT has a strain capability of roughly 0.1%. That means that a 10 millimeters length piezo-stack produces only 10 microns of free displacement. Most of the time this small displacement has to be amplified by mechanical means. We have developed a solution thanks to our APA™ technology [1].

2.1.1 Controlled deformation

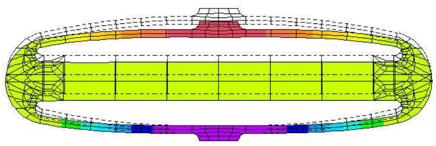

Figure 4 Atila simulation of an APA™

As shown on the Atila simulation presented figure 4, the elliptic shell offer displacement amplification along its short axis when the ceramic actuates along the long axis. The shape of the shell has to be well designed to get the expected performances. With this architecture, the amplification ratio can reach 20, and APA™ can have a stroke up to 1 millimeter. As nowadays, a large range of APA™ has been designed and tested, CEDRAT has developed its skill in dealing with structure controlled deformations.

Figure 5 examples of standard APA™

2.1.2 Application to CTS

This skill in designing amplification mechanisms is used to develop one of the CTS most important parts, the converter. The methodology to design this part is the same as for every new APA^{TM}, or any other system based on controlled deformation. It begins with finite element simulations (figure 6) allowing a fast optimisation and a sharp control of the stress in the material. This stress is calculated to be inferior to Wöhler curve of the material. This requirement is essential to control the sensor reliability.

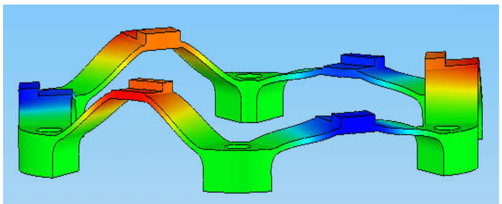

Figure 6 converter alone simulation

The converter is usually a rotating part. That mean its design has to take into account the centrifugal force and the associated deformation. One other constraint is the resonant frequency of this part. It has to be compatible with the bandwidth the sensor has to measure.

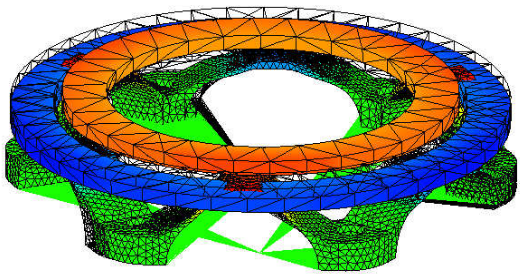

Figure 7 Converter and the 2 targets meshed

To explain the role of the converter in few words, the shaft's torsion is transmitted to the converter. This creates deformation of one half of the converter's arches in one direction, and the other half in the opposite direction. Thus the goal is reached, the converter transforms angular shift into significant axial shift and there is only targets that have to be mount on the converter. Now to measure the torque one simply needs to measure the linear displacement of the 2 targets

The choice of having two targets is to compensate thermal dilatation or mechanical tolerances. Indeed, as the CTS mounted on the shaft, rotating with it, its axial absolute position is linked to the shaft position. In the same time, the position sensors are linked to the frame. By making the difference between the two sensors, any thermal shift is compensated.

Once all the optimisation process is ended and the requirements are met, the next phase is the manufacturing of the converter.

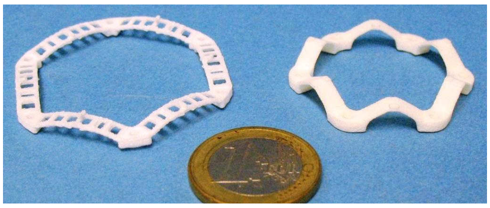

Figure 8 Example of converters

2.2 Displacement measurement

Concerning the linear sensors, several solutions are possible, and customers are free to use their own linear sensors if they want. But we suggest a good solution is to use eddy current sensors [2]. That is why in the frame of the CTS development, we are developing eddy current sensors too. By keeping in mind we want to offer a cost effective CTS, we decided to design eddy current sensors integrated in a PCB.

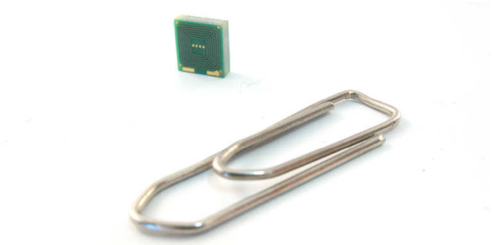

Figure 9 Eddy current sensor

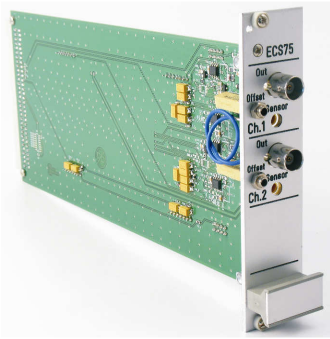

Figure 10 Electronic conditioner card for eddy current sensors

Eddy current sensor integrated in PCB offer elegant and low cost opportunity for an efficient integration. But this requires the capability of designing on request planar coils [3] and associate electronic drivers.

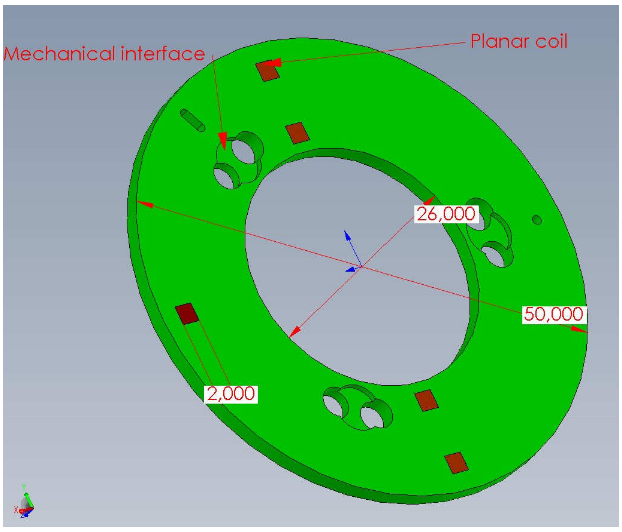

Figure 11 Fives ECPS on a 50mm diameter HDI PCB in contactless Force sensor application.

Such sensors allow getting nanometric resolution for displacement of hundreds of micrometers, which perfectly cope with the targets' displacement.

3 CTS functions

As explained in the introduction, the CTS first function is to measure the torque. Its second characteristic is that it is possible to design specific CTS to be adapted on existing shafts, whatever the shaft's materials. And obviously, with its own shaft and bearings, it is also possible to design a stand alone sensor.

But the CTS inovative working principle has the advantage to allow adding other measurements in combination with the torque, one can cite the speed measurement, or the position measurement.

3.1 Speed measurement with CTS

To offer additional measures, such as speed or position, specific targets have been designed.

Standard unlined targets allow measuring only the torque. But by adding notch on both targets, you get a speed measure too. When the targets are rotating, each eddy current signal includes the same oscillation in phase created by the notch, while the torque impact is in opposition phase. By summing the signal, the result is an oscillating signal which frequency is proportional to the speed. And by subtracting the signals, only the torque is measured.

The figure 1 is a demonstrator sensor made with the aim to show the two kinds of possible targets. The internal target is a standard unlined target, typically used when there is no need to measure the speed, while the external target is lined with notches, as explained here to measure the speed.

3.2 Position measurement

To measure the position, the solution is to mount the each target with an angle shift and use 2 eddy current sensors diametrically opposite per target (Figure 11).

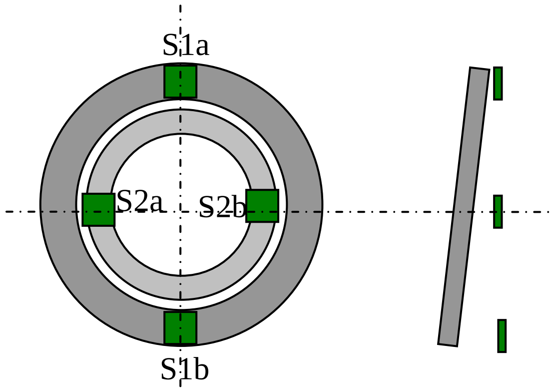

Figure 12 principle for position measurement

In grey are represented the targets and in green the eddy current sensors.

Torque=(S1a+S1b)-(S2a+S2b)
Cosinus(position) = S1a-S1b
Sinus(position)=S2a-S2b

Both speed and position measure is optional, and each CTS are designed to meet the customers requirements.

4 Conclusion

This new sensor coming in the market offers new possibility of integration to the engineers. By its capability to be easily mounted, the combination of torque, speed and position measurement and its compatibility with severe environments, the CTS offers new perspective to engineer in charge of new system design or system retrofit.

Designed to be robust, reliable and cost effective, we think this CTS can be an opportunity for Cedrat Technologies to improve its business. If we are confident in this technology offer, it is because it is coming from customers' demands. A couple of years ago, they were looking for a low cost and reliable solution to measure the torque/speed/position. And at this time, there didn't find products or technologies on the market to meet there requirements. That is where the CTS is coming from.

Nowadays, the CTS is not dedicated to become a standard product, but to be a technology brick to be adapted to each customer's case. As the goal is to facilitate integration, it has to be adapted to the customer shaft material and size, its speed, torque and other characteristics to measure and so on.

In the coming years, the CTS is involved in several collaborative or industrial projects, such as SmartJoint, MMiCST and other that cannot be mentioned due to non disclosure agreements.

5 References

[1] Claeyssen, Le Letty, Barillot, Sosnicki: Amplified Piezoelectric Actuators: Static & Dynamic Applications, Ferroelectrics, 2007

[2] "Non-contact eddy current displacement and distance measuring systems", Website of MICRO-EPSILON Messtechnik GmbH & Co.KG, www.micro-epsilon.com.

[3] Sosnicki et al, Eddy current sensors on Printed Circuit Board for compact mecha-tronic application, to be published in Sensoren und Messsysteme 2010