ANALYSIS OF TURBOCHARGERS & TURBINES

APPLICATION NOTE – OPTICAL SENSORS SOLUTIONS FROM OPTEL-TEXYS

1. Introduction

OPTEL-TEXYS fibre optic tachometers are used in a wide range of applications in the automotive industry, covering the areas of engine and accessory tuning during bench or vehicle testing.

Among the recurring use cases, the characterisation and qualification of turbochargers have naturally called on the optical technology we offer, as it has several advantages. Another application well known to specialists who develop and test turbo machines is 'Tip-Timing' or blade deformation measurement

The legitimate question that the measurement technician asks when presented with the OPTEL-TEXYS solution is often: "But what are the advantages of this solution for my use case?

The aim of this note is to answer these questions through "customer" examples to which we have provided the answer adapted to their needs. However, some examples cannot be supported by photos or diagrams as we must respect their confidentiality.

As a preamble, we would like to remind you that our measurement solution consists of two main elements: the sensor (or amplifier) and the optical probe.

The sensor, an optoelectronic element, is where the near infrared light is emitted and also where the light signals returned by the rotating system are received. The probe, a purely optical element, carries the light via two channels which correspond to the two directions of propagation of the light.

2. Why use fibre optic probes?

There are many answers:

- To extract the sensor electronics from an environment that is restrictive to its proper operation: temperature, EMC, liquid, dust
- To facilitate detection in confined spaces with the design of customised probes (HM4, HM5...)
- To create products allowing detection in the presence of liquid, or with additional optics to increase detection distances.

a. Rough environment

The first answer, which is to expose only the optical probe to the constraints of the measurement environment, applies regardless of the probe manufactured by OPTEL-TEXYS.

The very nature of the optical fibre used makes it immune to electromagnetic fields, thus avoiding altering the measurement signal. It is suitable for applications where magnetic fields are high, such as electricity generation and electric mobility.

Customer case: for the measurement of the speed and especially the position of the turbo during balancing, a customer detects one top per revolution on a magnetised nut. In this case, the fibre optic sensor replaces the inductive sensor because the latter is disturbed by the surrounding magnetic field and cannot ensure flawless detection. The probe is used instead of the sensor.

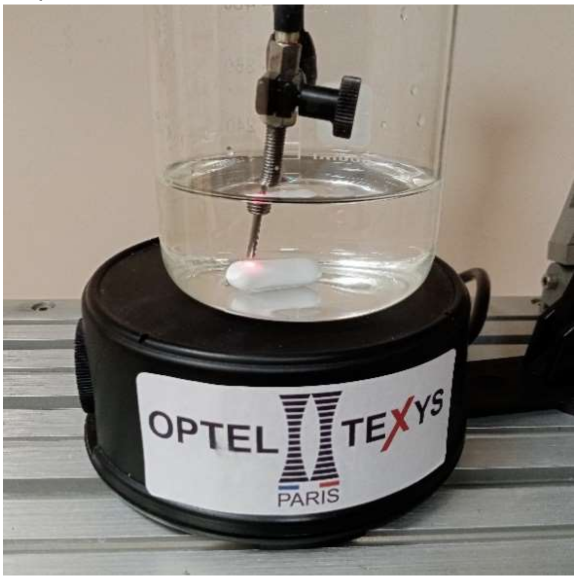
The exposure temperatures are higher than the electronics could withstand. They will therefore cover applications such as automotive turbocharger testing and aeronautical turbomachinery, even if the maximum temperatures are found to be over 1000°C in some cases.

Customer case: This case study couples two requirements, which are to have an EMC insensitive transducer in a temperature sensitive environment. The customer's question was how well our probes would hold up at temperatures above 200°C. We proposed a probe capable of withstanding 200°C continuously and 600°C occasionally.

As the sensors are not completely sealed against liquids and dust, the solution is to place the probe in the presence of these disturbing elements. The judicious placement of the probe within the turbine propelling the liquid or through which it passes allows the detection of the blades. The speed of the turbine can thus be measured more precisely and optimise flow measurements, particularly for water consumption management.

Customer case 1: the main difficulty is to make a SLIT probe that can detect on the edge of the blade and to ensure a position and orientation at an adapted distance thanks to the screw thread of the ending.

Customer case 2: design of a probe for installation in the slot for a PT1000 probe.

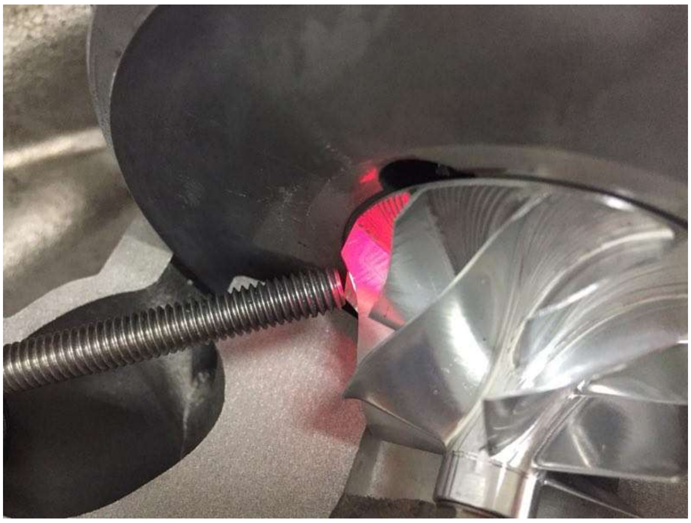


b. Integration

The probe construction is based on small diameter flexible optical fibres that can be easily shaped: spiral probe body, various tip lengths and diameters, external thread, in-line or 90° outlet.

For turbocharger applications, we have developed probes with M4 and M5 threads to customer specifications for easy integration into the part and distance adjustment.

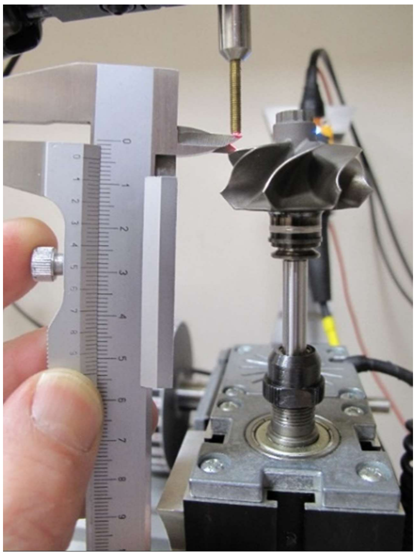
Indeed, the lengths of these probes and the threading (standard or fine pitch) give a sufficient degree of freedom to manage the approach of the ending to the blades or splitters.

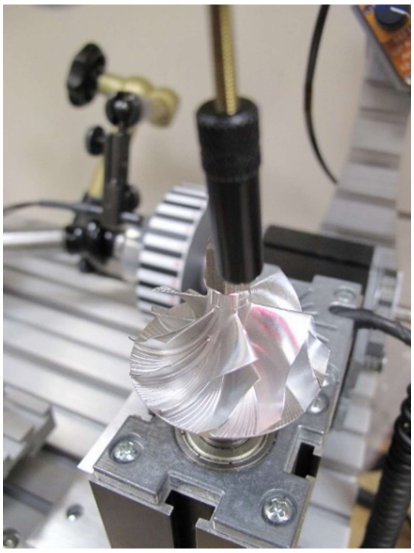


Depending on the environment and customer requirements, there are cases where the probe is not installed in the turbocharger body but at the outlet or inlet of the compressor.

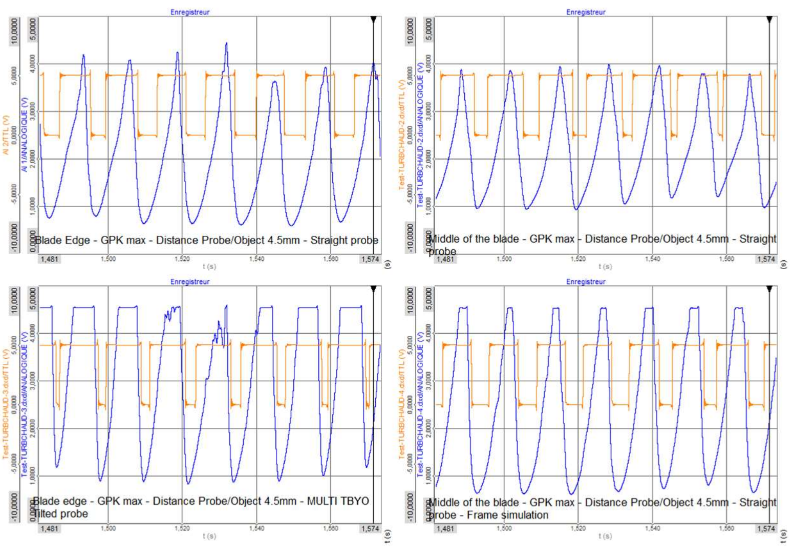
For a test centre dedicated to turbocharging, we have tested several distances using a conventional probe and a probe with an additional lens.

The customer's goal is to avoid contact between the probe and the blades due to the problem of axial displacement in the turbo. The aim was to avoid damage to the probe and the turbo.



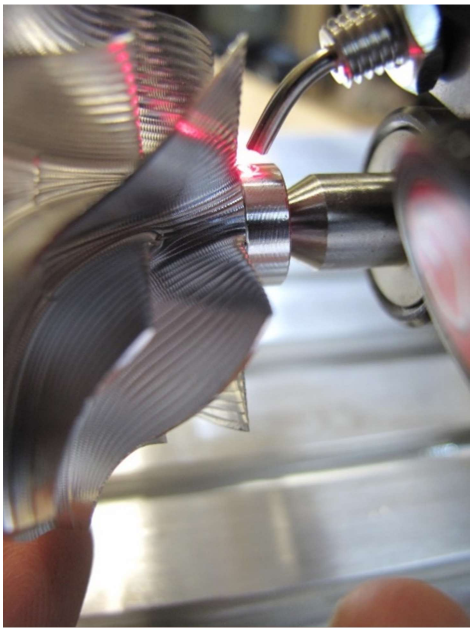


We managed the sensor setting with the potentiometer at the same time as the distance between the blades and the probe. As our tests were carried out at low speeds, we needed to obtain pulses at the passage of the blade with a width sufficient to have a duty cycle of about 80/20 (Figure below). This would allow operators working at higher speeds to obtain a duty cycle closer to 50/50 or even 20/80 in order to provide the acquisition system with incoming signals that are easier to process.



In the same spirit, another adaptation with a bended probe for detection on a specific point of the turbo was carried out for a car manufacturer. Tilt tests allowed the customer to propose the desired definition.

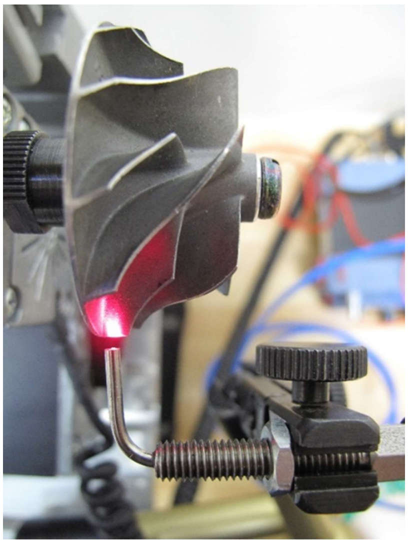
For more than 10 years, the customer has been using a customised probe with an elbow of about 45° and a thread for fixing to the balancing bench.



To complete the subject of probes, OPTEL-TEXYS's know-how allows us to shape the tips and the overall shape of the probe according to the installation and the detection point.

The example above shows a so-called "SLIT" probe, capable of detecting blades or splitters with a thickness of about 1mm on the edge.

The 90° bended probe with a thread, called MULTI TBYO 52, can be inserted in a space where the rest of the probe must be installed perpendicular to the rotating elements.



3. Do I need such high performance for my measurement?

This will depend on your goals in terms of detection accuracy, reliability and handling. The primary quality of our sensors is to provide signals with metrological characteristics adapted to measurement rather than control.

The TTL signals are only as good as their very steep rising and falling edges, a few tens of nanoseconds for the fastest: 152G8 and 152M.

And the small phase shift of a few microseconds ensures a temporal positioning that only encoders can provide, but at the cost of detecting hundreds of tops, which is perhaps less easy to achieve and install.

In addition, we have decided to separate the emission and reception of near infrared light. This avoids the sensor having a moment when it is blind, i.e. when it cannot see the light information arriving because it is transmitting. This will never happen with our solution, which is essential at very high speeds to avoid signal loss.

a. Turbocharger balancing

It is therefore not surprising that our sensors are used in turbocharger balancing, where time accuracy is decisive in the adjustment of the turbine mass. Also, the bandwidth is an asset to be able to handle the quantity of detection points entering the sensor.

Taking the example of a turbo with 6 full blades and 6 splitter blades and rotating at 200,000 rpm, the number of pulses entering the sensor can reach 40,000 per second. If enough points are required to describe the measured curve, a minimum coefficient between 2 and 3 should be applied. A bandwidth between 80KHz and 120KHz is therefore necessary to avoid losing detection information.

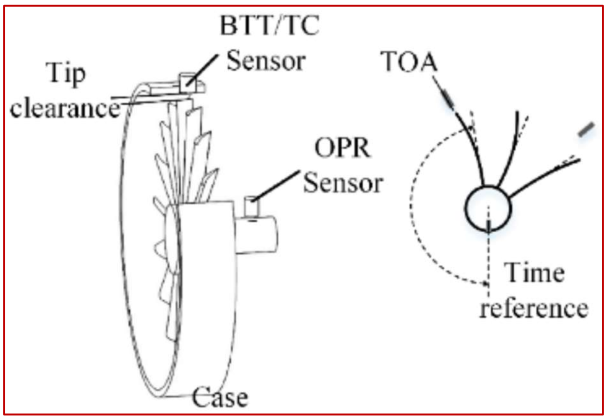
With the 152 G7 sensor with a BP of 260KHz, the user will have sufficient margin for his measurements.

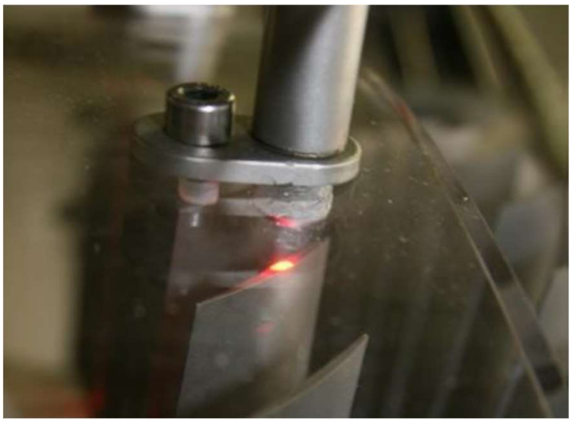
It is also necessary to consider the time taken for the blades to pass in front of the probe as a function of the speed of rotation. For example, if the thickness to be detected is 1 mm, the passage time will be 5 microseconds at 200,000 rpm. In this time, the 152G7 is capable of transferring approximately 15 pulses; the measurement system must then be able to quickly "digest" the incoming pulses.

b. Blade Tip-Timing

This method of characterising blade vibration in turbomachinery is a specific application to turbines and gives rise to numerous studies and research topics. Indeed, these vibrations can lead to blade failures and one can imagine the consequences for the engine and the aircraft.

The most commonly used principle uses a reference sensor (Once per revolution) and one or more sensors at the blade tips as shown in the following figures.





BTT/TC sensor : Blade Tip timing sensor to detect blade passing-by
OPR sensor : Once Per Revolution sensor; time reference
TOA : time of arrival

It is easy to understand the level of time signal accuracy that is required and also the desire to generate a large amount of information without loss.

4. Other advantages?

To complete this overview, we can also mention the following advantages:
- An optical sensor with near IR light that is not dangerous for users
- Interest in ATEX zones by keeping the electronics away by using an optical probe of adapted length.