HBK HOTTINGER BRÜEL & KJÆR

WHITE PAPER

Strain Gauge Measurements Beyond the Bending Beam

Western Regional Strain Gauge Conference, October 2021

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Standard training for strain gauge applications often includes laying a sensor on a semi-rigid beam that can be easily loaded to show the resulting strain. While this is ideal for demonstrating instrumentation techniques and best practices, it can be very far from applications that many engineers face in daily practice.

This paper will highlight some of the more unique and challenging strain gauge projects that have been undertaken by the authors, the tools and techniques used and what was learnt from them. The projects to be shared include telemetric measurement of force on a rotating axle differential, real-time and long-term monitoring of stress and crack propagation on a bridge, and explanation of the forces observed on a divining rod.

TELEMETRIC MEASUREMENT OF FORCE ON A ROTATING DIFFERENTIAL CASE

Computer Aided Engineering (CAE) is a critical part of product design in the automotive industry, both for vehicle companies and suppliers. In many cases, Finite Element Analysis (FEA) is used to predict the operating mechanics and forces in a given system. This is often used in the design and development of both powertrain and driveline systems. Having and using these tools are only effective when models have been properly built and validated with real-life test data.

Force is often derived through measurement of strain combined with material properties of a part or structure. Proper application of strain gauges is a skill that quickly grows in complexity for rotating components. This adds difficulty when making measurements on parts such as axle shafts, propeller shafts and wheels. The task becomes even more challenging when the measurement needs to be performed in a confined space. It is for this reason that strain or forces for enclosed and/or rotating components are often estimated or assumed to be correct in models. It is far less common for test groups to instrument a rotating component in a confined space and calibrate the strain gauge to enable force measurements. Such is the case for axle manufacturers who need to measure dynamic forces on differential components.

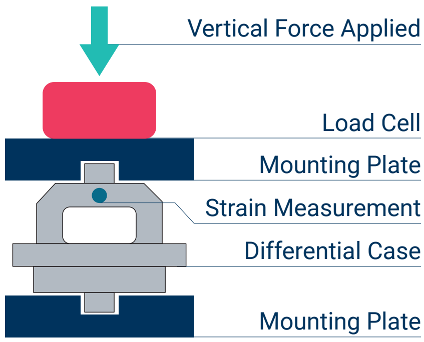

Figure 1: Force calibration process

HBK undertook such a project to measure the force on an open differential axle while being operated on a test stand. A strain gauge could be cleanly applied to the surface of the differential case, or 'diff case'. Because force was ultimately required, the strain output would need to be calibrated under a known load, as depicted in Figure 1. Mounting plates were constructed of steel and designed to directly seat the trunnions of the differential. The fixture and differential were placed on a hydraulic press with a load cell between the top mounting plate and hydraulic piston. While the system is being pressed, the output from the load cell and strain gauge are used to create a calibration, or strain per unit force.

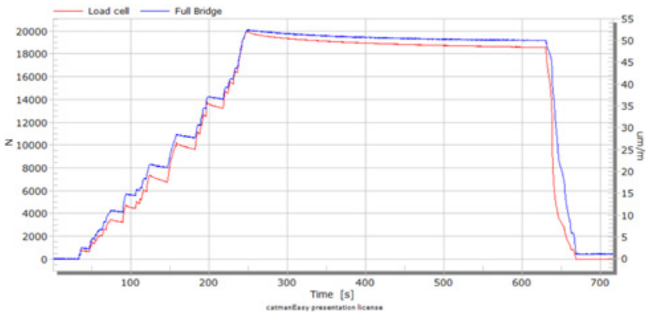

Figure 2: Strain and resulting force during calibration

Because the differential case rotates within the axle housing during operation, a telemetry system was used to enable wireless measurement. The constraints of applying such a device include package space and mounting of the antenna for optimal signal fidelity. Because the operation of the axle could be performed at low speed and short duration, oil was not required. This enabled the oil fill plug to be removed during operation, making a suitable aperture for the telemetry system antenna. The telemetry system includes a transmitter which connects to the strain gauge and requires a DC power source. The transmitter was connected to a plate that was mounted over the aperture on one side of the diff case, and a battery holder was mounted on the opposite side. This provided the required packaging space and offset any imbalance effects during rotation.

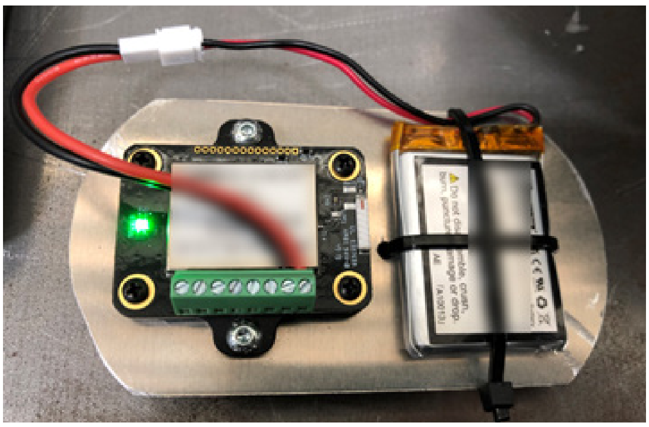

Figure 3: Telemetry transmitter mounted to cover plate for aperture

After confirming clearance during manual rotation of the differential, the axle was assembled and loaded onto a test stand.

Because the device under test was calibrated with load, this measurement resulted in force observed on the differential case during operation. This could ultimately be used to validate the force at the same location in a CAE model under similar conditions, which could then be exercised under other conditions for an accurate understanding of the forces in a driveline system.

CRACK PROPAGATION AND REAL-TIME MONITORING OF A BRIDGE

The infrastructure of many countries and municipalities includes several large structures, often used for transportation. These include roadways, bridges, tunnels and several other constructions. In all of these cases, accurate strain measurements are critical; not only during construction to validate designs and confirm proper load cases, but also during the operating life of the structure to ensure safety and longevity without incidents. It is for this reason that structural health monitoring (SHM) systems are used.

These systems often include strain gauges, temperature sensors, displacement transducers, accelerometers, and inclinometers, which are monitored immediately following commissioning. In many structures or substructures built with concrete, it is not uncommon for cracks to form under the stress of real-life use. These cracks are often not problematic but must be monitored over time to avoid costly repairs or, even worse, catastrophic failures. Such was the case with a bridge installed in Norway.

Figure 4: Herøysund bridge, Norway

An 'omega sensor' is a strain gauge-based transducer in the shape of 'Ω', whose purpose is to monitor the expansion of a crack. The sensor is usually installed on top of an already developing crack, with one 'leg' placed on each side of the crack. Civil engineers can monitor the propagation of cracks with this device to predict long-term durability of the structure.

Figure 5: Omega sensor installed at existing site of crack

While these transducers and standard strain gauges are common, the unique facet of this application was the real-time monitoring of the installed system. This gives instant access and collection of the data for engineers who may be monitoring the structure and ensures that the transducers have not encountered installation faults over the course of time.

The data below shows the output from six strain gauges and two omega sensors over the longitudinal axis of the bridge. Peaks in the amplitude can be observed while traffic passes over the top deck roadway. Heavier vehicles, such as commercial trucks, create higher-amplitude peaks. The relative offset in time can be observed as vehicles cross the bridge and pass over each transducer.

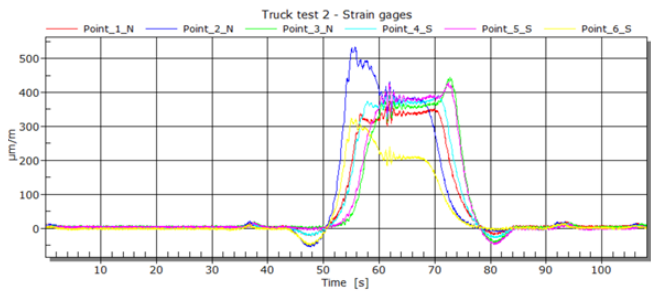

Figure 6: Strain at strain gauge sites

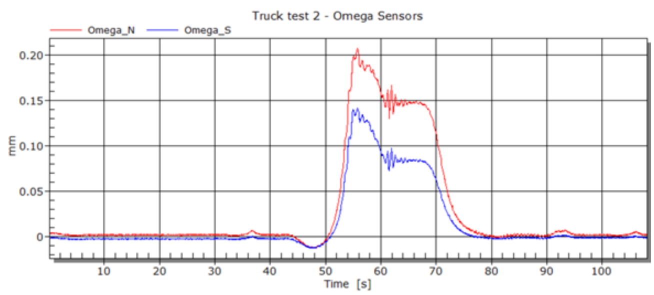

Figure 7: Crack propagation at omega sensor sites

EXPLANATION OF FORCES ACTING ON A DIVING ROD FOR DETECTION OF MATTER

Dowsing has been documented in cultures as early as the sixteenth century[2]. Also referred to as 'divining', this is the act of an individual using a y-shaped stick to locate underground deposits of substances like gemstones, ores, oil, or water. Several instances recorded in European regions were first thought to be blasphemous or an act of occultism. Today, dowsing is considered a 'pseudo-science' that carries both scepticism and intrigue. It is sometimes said that only a small percentage of the population have this ability, leading to even more doubt of its validity. HBK staff set out to help identify the force that apparently pulls the stick, or 'divining rod', to help locate these subterranean resources.

When the rod is held by a dowser, it is said to be pulled toward such sources. Users claim that feeling the rod bending in the centre section of each leg is outside their influence. In this experiment, a wooden divining rod was instrumented with strain gauges on each leg of the handle as seen in Figure 8. Wooden rods were positioned orthogonally at each handle to confirm that the user was not intentionally 'dipping' the device toward the ground. If their claim was accurate, the rods would remain in the same position, and strain should be observed beyond the handle on each leg.

Figure 9: Divining rod instrumented with strain gauges

In this experiment, our customer was experiencing health issues which were said to be uncurable by medical professionals. His own holistic research showed that such medical issues could be caused by energy fields and might be mitigated by disrupting the field with copper wire. The divining rod pulled with great torque and showed that such a field existed in his home. Instrumentation of the rod proved that torque and bending on the rod were detectable at this site.

He was ultimately able to disrupt the field that was present in his home and alleviate his symptoms.

SUMMARY

Real-life applications are often more complicated than testing of a beam in bending. With careful planning and creativity, the principles of strain measurements can be applied to create unique transducers or tests to solve complicated challenges.

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2: Wikipedia contributors. (2021, September 28). Dowsing. In Wikipedia, The Free Encyclopedia. Retrieved 15:25, October 8, 2021, from: https://en.wikipedia.org/w/index.php?title=Dowsing&oldid=1046976196

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October 19th 2021