NEW TECHNIQUES FOR MECHANICAL MEASUREMENTS IN THE SUPERCONDUCTING MAGNET MODELS

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Abstract

Force transducers based on strain and capacitive gauges have been developed and used for monitoring the coil pre-stress during assembly and excitation of magnet models. This paper will summarize and compare the new techniques of mechanical measurements used at CERN for the New Inner Triplet Project. Furthermore the paper will give a comparison of the gauge performances (Creep effects, temperature effects, etc.) and will present the performances of the new data acquisition system developed at CERN to measure simultaneously the strain gauges, the capacitive gauges and other external parameters for the magnet.

INTRODUCTION

To constrain the superconducting cables in a stable position, it is necessary to ensure that during magnet excitation the cables are always under pressure. The measurement of pressure between the cable and the collar can be realized with strain gauges glued on the collars. This requires a long preparation of the measuring and data analysis setup, the machining of the collars and the gluing of the gauges and some complication in dealing with a large number of connections. Furthermore the limitation in gauge size does not allow to carry out special measurements like the radial pressure distribution over the coil width.

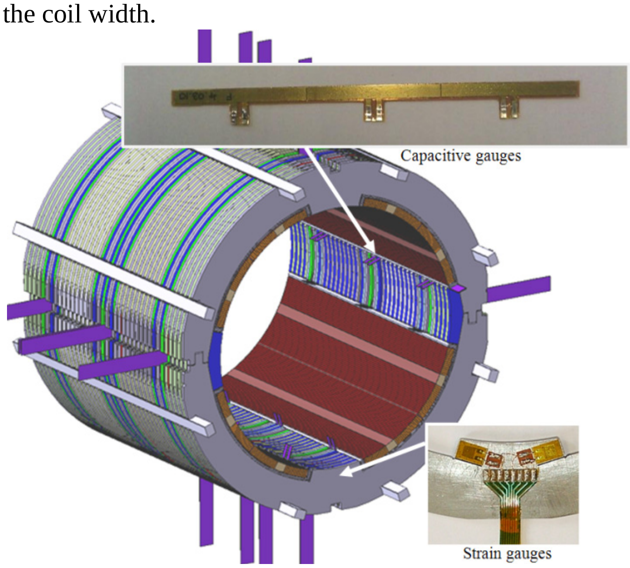

Figure 1: 150 mm model instrumented for the new inner triplets of LHC.

To overcome the above limitations and to set up a more economic and user friendly general purpose method for measuring pressure between contact surfaces with thin devices, special capacitive transducers have been developed at CERN [1]. These transducers have not replaced strain gauges, but they allowed carrying out a number of special tests difficult to perform with strain gauges. Magnet instrumentation with both systems allows having a crosscheck. As e.g. for stress measurements during assembly and cool down to 1.9 K of the 150 mm and 2 m models of new inner triplets of LHC.

This paper presents the performances of the new data acquisition system developed at CERN capable to measure simultaneously the strain gauges, the capacitive gauges and other magnet parameters.

STRAIN GAUGES

The strain gauge has been in use for many years and is the fundamental sensing element for many types of sensors, including pressure sensors, load cells, torque sensors and position sensors. The strain gauges are used in the magnet models in several Wheatstone bridge configurations to compensate the magnetic field and temperature effects. Strain gauge materials (Grid and support) are selected to be compatible with the external effects.

All the details concerning the strain gauge measurement techniques can not be described in this paper and the reader is referred to [2] [3].

CAPACITIVE GAUGES

Basic Principles

The simplest capacitive gauge has two parallel plane electrodes of area S with dielectric material of thickness δ and electric permittivity ε in between. The capacitance C, without considering fringe field effects, is given by:

$$C = \frac{\varepsilon . S}{\delta} \qquad (1)$$

In a capacitor type force/pressure transducer, the capacitance can change by varying either the plate area or the thickness of the dielectric material. Taking the strain of the dielectric material into account, we may rewrite the capacitance equation as:

$$C = \frac{\varepsilon . S}{\delta . \left(1 - \frac{\sigma}{E}\right)} \qquad (2)$$

Where σ is the applied pressure and E is the elastic modulus of the dielectric material. The linearity of this transducer mostly depends on the mechanical properties of the dielectric material. To increase the yield limit and to limit the Poisson's deformation of the dielectric, the design of the transducer must be made such that the dielectric material is put under hydrostatic stress condition. This can be achieved by gluing the dielectric material between rigid electrodes in order to minimise the pressure flow of the dielectric.

Fabrication

In order to increase the capacitance of the gauge a "sandwich" consisting of stainless steel foils interleaved with polyimide films is glued together.

Wide temperature range, magnetic field, high pressure cycling are typical of superconducting magnet applications. To fulfil these conditions the following materials were chosen: non-magnetic AISI 316L stainless steel foils for the electrodes, H-type Kapton™ film as the dielectric and the high-performance epoxy resin M-bound 610™.

The fabrication technique consists of three steps: preparation of the gauge components, the gluing process and curing under a constant pressure. After the fabrication, the gauge needs to be pre-cycled at a pressure 20 % higher than the operating one with a certain number of thermal cycles in liquid nitrogen afterwards. After this training, the creep and non-linearity of the gauge are reduced.

The initial capacitance of the unloaded gauge depends on the surface of the gauge and on the number of layers. The sensitivity (Capacitance to pressure ratio) of the gauge does not depend on the number of steel foils, but depends on the elastic modulus and on electric permittivity of the dielectric. Furthermore, the initial capacitance and the behaviour of the gauge under pressure is influenced by many other parameters such as materials, thickness of the layers, alignment of the layers, curing pressure and time. Linearity of the gauges depends on the thickness of the glue layer and its distribution over the foil surfaces as shown in figure 2 and 3.

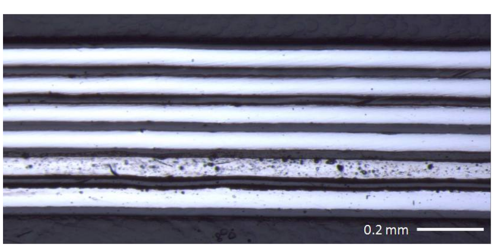

Figure 2: Metallurgical section of a linear capacitive gauge.

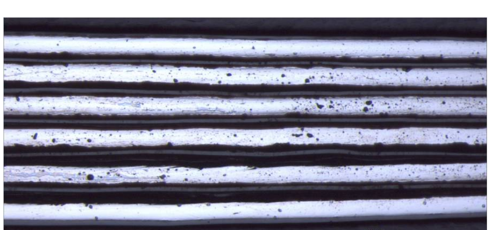

Figure 3: Metallurgical section of a non linear capacitive gauge.

Acquisition

The signal provided by the capacitive gauges under pressure corresponds to 0.5 nF for 200 MPa. During the LHC prototyping phase, a multichannel data acquisition system based on an LCR meter, analogue multiplexer and a PC with a Labview® program was used. This system was not able to measure simultaneously the strain gauges, the capacitive gauges and other external parameters like the current or the temperature.

For the New Inner Triplet Project, a new measurement interface was developed in order to:

- Measure simultaneously all the signals.
- Increase the resolution of the measurements.
- Increase the number of channels and the sampling frequency.
- Have a user friendly software interface for measurement and analysis.

The MGCplus® system from HBM™ was chosen for data acquisition. A special connection box has been developed to be able to acquire signals from capacitive gauges. This box contains a printed circuit containing two stable and precise resistances of 350 Ω connected in half-bridge configuration. The capacitive sensor is connected in parallel to one of the resistances as shown in figure 4. The half bridge is supplied with a carrier frequency at 4.8 kHz

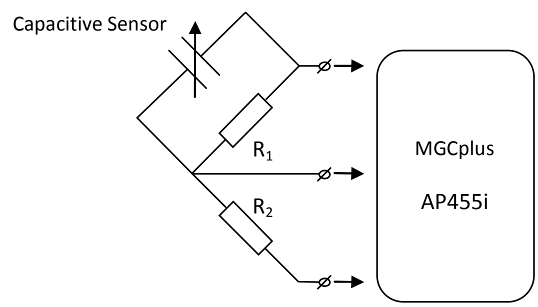

Figure 4: Electrical connection of the capacitive gauge

Applying a pressure to the capacitive sensor will cause a change of the gauge capacitance. Consequently, the current flowing through the gauge will be changing and unbalances the measuring bridge. Such measurement technique allows to synchronize both measurements: using strain and capacitive gauges.

The ML455 multi-channel amplifier from HBM® is used to acquire the signal from capacitive gauges. This amplifier has the following parameters: accuracy class 0.05, carrier frequency 4.8 kHz, bridge excitation voltage 2.5 V, measuring range ± 4 mV/V.

Calibration

As mentioned above, capacitive gauges have to be thermal-cycled in liquid nitrogen. The "zero" signal of the gauge is shifted at 77 K. This is the apparent signal. It was noticed that after three thermal cycles, the apparent signal remains the same and is well reproducible. This value should be taken into account for the application at cold.

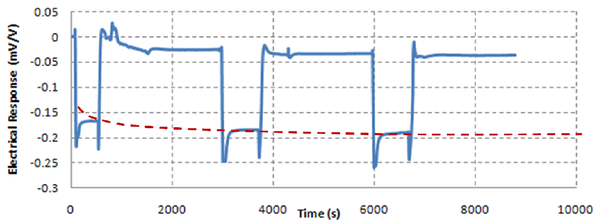

Figure 5: Thermal cycles at 77 K

A hydraulic press is used to calibrate the gauges at ambient temperature. Four load cycles are applied to the gauge up to 100 MPa. After each cycle the transducer is repositioned. A typical calibration curve is shown in figure 6.

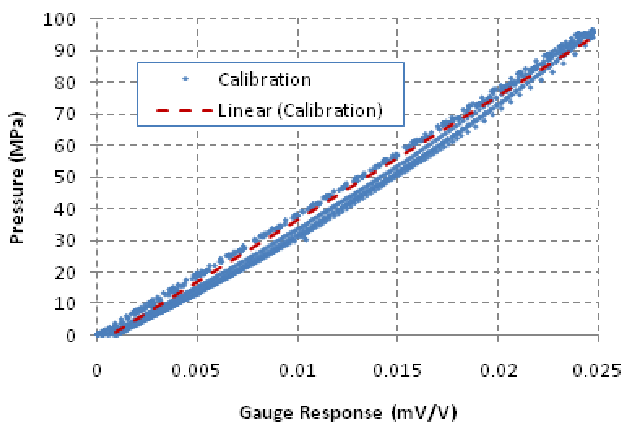

Figure 6: Sensitivity of the capacitive gauge

The calibration curves have some hysteresis during load-releasing cycles due to non linear the behaviour of dielectric. The linear approximation of the calibration gives an error of ± 5 % over the measuring range.

The stress relaxation test has been performed on one of the capacitive gauges on a 250 kN load frame UTS tensile machine. The force of 200 kN was applied via compression plates. A stroke displacement with accuracy of 1 μm was fixed for 17.5 hours. The force degradation after that time was about 2.5 kN.

A specific tooling adaptable to the UTS tensile machine will be developed for the calibration at 77 K. The system will have to be rigid enough to balance with the calculated deformation of the gauge at 200 kN.

CONCLUSION

The simultaneous use of capacitive and strain gauges for monitoring pressures up to 200MPa from ambient temperature to super fluid helium is possible now with a new generation of data acquisition system. This system allows correlating the measurements performed with both gauges in order to increase the measurement reliability. Metrological characteristics of the gauges are summarised in table 1.

Table 1: Characterisation of the gauges

	Capacitive Gauges	Strain gauges
Range	200 MPa	200 MPa (*)
Accuracy	3 % after 10 MPa	5 %
Linearity	5 %	0.3 %
Resolution	0.06 MPa	0.02 MPa

(*) Characteristics for MQXC magnet model

The first 150 mm magnet model for the New Inner Triplet Project will be equipped with up to 28 capacitive and up to 100 strain gauges. All the probes will be connected to the same data acquisition system. Other external parameters, like temperature and the excitation current can be synchronized with the mechanical stress measurements. All the physical values will be recorded and visualized on a user friendly front panel.

REFERENCES

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