

# Carbolite Gero: High Temperature Furnace for Heat Treatment of Superconducting Magnets at CERN

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The key for further improvements of particle accelerators in the field of high energy physics is given by the superconducting magnet technology. The base material for future magnet coils is based on NbSn alloys. This alloy is transformed into superconducting Nb<sub>3</sub>Sn material due to a complex reaction heat treatment. These coils can currently achieve fields of 11 T. CERN/CH has launched a special development project to further increase these fields up to 16 T.

## Introduction

The high temperature furnace GLO 10 000 KE/09-1G from Carbolite Gero/DE is tailored for the heat treatment of superconducting coils for CERN. The plant, which is going into full operation at the CERN site in the middle of this year, was introduced in detail to the technical press on 18 March 2016 by Carbolite Gero at its site in Neuhausen.

## Plant description

The coils have a total length of up to 8 m. Three different dwell temperatures of 210, 400, and 650 °C respectively must be exactly reached at a uniformity of  $\pm 3$  °C for more than 2 days. Because of the coils dimensions, the usable volume inside the retort is 10 m<sup>3</sup>, with an inner diameter of 1 m and a heated length of >10,5 m. Prior to heat treatment, the retort must be evacuated to perform the heat treatment at the lowest possible oxygen partial pressure. The pumping unit consisting of a combination including a roots pump with a pumping speed of 4400 m<sup>3</sup>/h and a single stage rotary vane pump with a pumping speed of 630 m<sup>3</sup>/h evacuates the whole retort down to the fine vacuum range, within a few minutes. Afterward the retort is flooded up to atmospheric pressure. After starting of

the reaction heat treatment, Ar is continuously supplied. A defined volume rate of the process gas is analyzed with an O<sub>2</sub> sensor. This allows logging the gas composition throughout the entire heat treatment process. The sensor is precisely calibrated for the gas mixture O<sub>2</sub> in Ar in the low ppm-range, because oxidation of the coils must be prevented.

The preparation of the gas measurement is based on a condensate trap and filtering prior the O<sub>2</sub> sensor. This allows protecting the sensor from contamination of outgassing compounds. In each segment of the program, the sensor can be switched on or off.

To fulfill the required uniformity during all dwell times, the Ar is circulated within the retort. This is done by a fan with an outer diameter of 630 mm, with 2000 rpm at most generating an inert gas flow of 18 000 m<sup>3</sup>/h. Together with the special design of the gas guiding plates, a turbulent flow around the coils towards the fan is generated.

With the help of finite element simulations for the whole gas guiding, the system was optimized to the effect of achieving the nominal temperature as fast as possible and to achieve the best possible uniformity during the dwell time.

The uniformity is achieved with the inert gas circulation mainly in the low temperature range. In addition a total of 16 heating zones gain the possibility for optimum adjustments.

The combination of the fan with the 16 heating zones, secures the heat treatment further against a possible failure of one heating zone. In the unlikely case of a power failure of a heating zone, the gas circulation generates the required temperature equalization and the heat treatment can be continued.

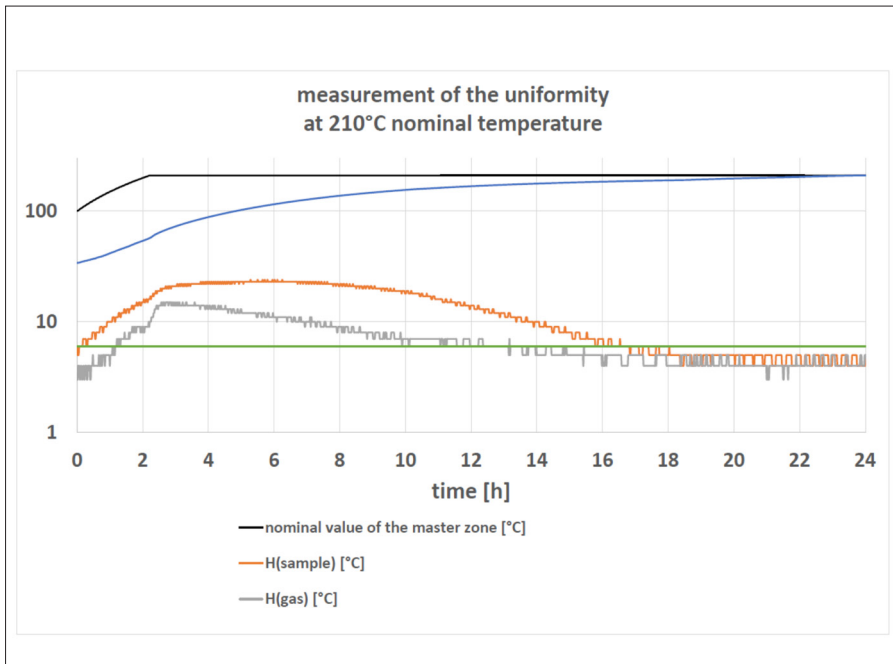
The heating elements are divided from top to bottom. 60 % of the total power is installed at the bottom heating zones and 40 % is installed in the top heating zones. The total power adds up to 400 kW to heat up the whole system including load to 900 °C at most with a heating rate of 50 K/h.

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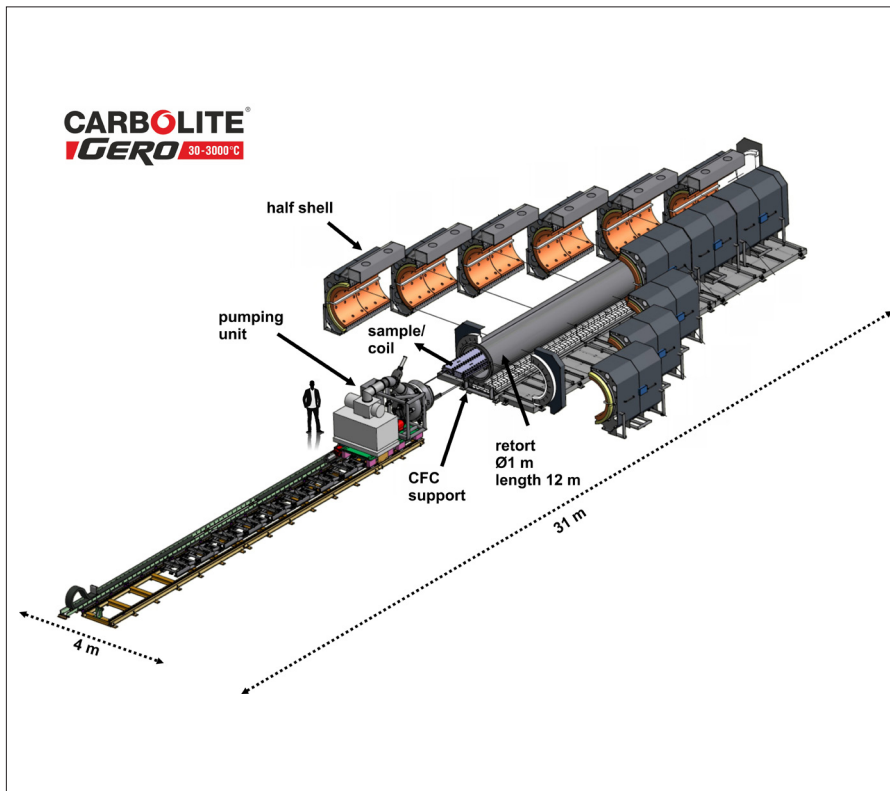
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**Fig. 1** Nominal value of the master zone; uniformity/homogeneity of the sample thermocouples located in the solid; uniformity/homogeneity of the sample thermocouples located out of the solid and hence measuring the gas temperature and the average temperature of all 40 sample thermocouples; the required uniformity is achieved after 13 h of dwell time and afterward underrun



**Fig. 2** Explosion drawing (CAD): the complete pumping unit and the CFC-support are automatically movable for loading and unloading; the likewise automatically moving half shelves are shown in the explosion view, and hence the retort is visible

The retort is heated by 14 zones from outside. The two remaining heating zones are located directly inside the retort. They are inevitable to compensate for the temperature drop towards the water cooled door. At the water cooled flange, the water cooled door is mounted, which can be automatically opened and closed. The vacuum unit is connected by a DN250 flange including vacuum the valve to the door.

After the heat treatment process an increased cooling rate can be achieved by moving the half shelves radially away from the retort. The retort is cooled down from outside by an air flow. The availability of the plant is increased.

After the heat treatment, the coils are removed automatically on a >10 m long CFC- (Carbon Reinforced Carbon) support out of the retort. The graphite rolls inside the retort and the hinged metallic rolls outside of the retort are specially designed for a load up to 7000 kg to be moving free of vibrations (<20 mm/s<sup>2</sup>) with the lowest bending (<0,1 mm) and lowest accelerations (<20 mm/s<sup>2</sup>).

The software visualization is tailored for the requirements of the heat treatment. The furnace is classified in class 1 of the AMS standard. All temperatures are logged with an unforgeable writer. T

he values are transferred to the touch panel. The entire signal chain from the tip of the thermocouple up to the display is calibrated to achieve the best possible accuracy. For temperature uniformity measurements, 40 sample thermocouples are available to characterize the usable volume. The uniformity ( $H(t)$ ) of all 40 thermocouples is calculated after constant time steps and visualized on the screen.

Additionally the positions of the sample thermocouples onto the sample is visualized. The thermocouples with the highest and lowest temperature is marked with different colors. Hence, the user has a compact overview of the actual status of the temperature distribution available.

Time consuming evaluation steps after the heat treatment can be omitted. Further a control track is available which only starts the dwell time, after the uniformity criteria  $H < 6$  °C is achieved.

$$H = H(t) := \max [|T(\vec{r}_i, t) - T(\vec{r}_j, t)|]$$



**Fig. 3** The fully assembled plant in Carbolite Gero, which can be operated from the front automatically by means of a touch panel



**Fig. 4** Roland Geiger (3<sup>rd</sup> f. l.) starting the plant: Oliver Korz, Major Neuhausen, Enzkreis; Dr Friedrich Lackner, CERN; Roland Geiger, Managing Director Carbolite Gero; and Dr Timm Ohnweiler, Head of Project Management Carbolite Gero (f. l. t. r.)

The uniformity/homogeneity ( $H(t)$ ),  $i$ , and  $j$  are the temperatures of the 40 different sample thermocouples inside the retort. An algorithm evaluates live the uniformity during the heat treatment.

### Outlook

The first experimental results and tests of the plant showed full conformity with the simulation results. The required uniformity was measured during three dwell times. At nominal temperatures of 210, 400 and

650 °C respectively, the uniformity of  $\pm 1,5$  and  $\pm 3$  °C respectively, was experimentally measured. With further optimizations of the heating zones, improvements are expected.