Abstract

To reach the required luminosity at the CLIC interaction point, about 2000 quadrupoles along each linear collider are needed to obtain a vertical beam size of 1 nm at the interaction point. Active mechanical stabilization is required to limit the vibrations of the magnetic axis to the nanometre level in a frequency range from 1 to 100 Hz. The approach of a stiff actuator support was chosen to isolate from ground motion and technical vibrations acting directly on the quadrupoles. The actuators can also reposition the quadrupoles between beam pulses with nanometre resolution. A first conceptual design of the active stabilization and nano positioning based on the stiff support and seismometers was validated in models and experimentally demonstrated on test benches. Lessons learnt from the test benches and information from integrated simulations using measured stabilization transfer functions lead to improvements of the actuating support, the sensors used and the system controller. The controller electronics were customized to improve performance and to reduce cost size and power consumption. The outcome of this R&D is implemented in the design of the first prototype of a stabilized CLIC quadrupole magnet.

Stabilization strategy

Stability margins for a vibration isolation system with a seismometer, a reference mass and the positioning controlled with a fixed gantry, in function of the first mode of the system.

Seismometer

Inertial reference mass

Nanoposition control

Seismometer

Inertial reference mass

Nanoposition control

Absorbs vibrations due to external forces

Compatible with alignment system

Lockable for transport

Allows fast nano-positioning

Measures the error $\Delta(s)$ between the requested quadrupole position $R(s)$ and the actual relative position $y(s)$ of the magnet

Limited by the pole of the first mode

In order to increase stability a low pass filter at 40 Hz is added.

The actuator elongation is given by $y(s) = (s+k)(s+1)\Delta(s)$, where $k$ is a PI controller.

Controller architecture

Local hybrid stabilization controller designed to be placed next to every magnet

Analog signal path

Low latency massasive to radiation, digital components:

Flexible

Simplicity

Digital local infrastructure

Remote control centre

< 5 m

< 20 m

several km

$\sum$

Stabilization on type 1 quadrupole

Latency classification of signals

Critical latency

Best effort delay

Critical latency signals

Best effort delay signals

Input

$\Delta$ (s)

Emergency stop

Configuration parameters

Output

$\Delta$ (s)

Error signal

m/s vibration level of magnet

Performance figure

Results achieved

The prototype of the CLIC stabilization system has been tested on two test benches (see below). Results look promising. Attenuation between ground and magnet can be configured for wider bandwidth or deeper factor according to the machine needs (see top left). Root Mean Square r.m.s. value of vibrations above 1 Hz for stabilized magnets is below requirements for all test benches and under different levels of vibrations. 0.3 nm and 0.5 nm vertical values are achieved for small mass on 1 degree of freedom and 100 kg on 2 degrees of freedom test benches respectively, well below the 1.5 nm originally required (see top right).

A test with stabilization on 2 d.o.f. test bench has been performed over 2 days, demonstrating feasibility of long term functionality (see bottom left). Preliminary results of nano-positioning system seem promising. Precision of 2 nm is achieved, although work is ongoing to improve speed of the steps (see bottom right). To conclude a 100 kg mass has been stabilized to 0.5 nm above 1 Hz. For reference a DNA molecule is 2 nm wide.

Transmissibility ground to magnet

r.m.s. vibration levels for different test benches and conditions

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