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Research Article

Study of the Supporting System for the clic two-beam module

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Abstract

The Compact Linear Collider (CLIC) study aims at the development of a Multi-TeV e+ e-collider. The micro-precision CLIC structures will have an accelerating gradient of 100 MV/m and will be aligned on so-called girders. The girder construction constrains are mainly dictated by the beam physics and RF requirements. The study of such girders is a challenging case involving material choice, mechanical design as well as prototype fabrication and experimental testing.

Keywords: CLIC, girder, supporting system, V-shaped support, V-support, SiC, mineral cast, epument, base, alignment, actuator, stabilisation

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1. Introduction

The CLIC study is focused on the design of an e- e+ linear collider at colliding beam energy of 3 TeV with a luminosity of 2·1034 cm-2 s-1. A design is deduced at a lower energy, set to 500 GeV and the same luminosity for comparison with the alternative International Linear Collider (ILC) [1] technology. The required luminosity can be reached with powerful beams (14 MW each) colliding with extremely small dimensions and high beam stability. The accelerated particle beams have dimensions of 45 nm in the horizontal plane and 1 nm in the vertical plane at the interaction point. These small dimensions can only be obtained with extremely small emittances.

CLIC is based on the innovative two-beam acceleration scheme, in which the RF power is extracted from a low energy but high-intensity drive beam (DB), and transferred to a high energy accelerating beam, called main beam (MB). The accelerating structures of the MB operate at 11.9942 GHz with an accelerating gradient of 100 MV/m. The two linacs are equipped with two-beam modules, housing all the main RF and focusing components (Figure 1). The overall length of each linac is about 21 km. The RF components have specific alignment requirements to make the first collision happen. Afterwards, the alignment will be continuously based on the feedback provided from beam position monitors (BPM). Since the RF structures are mounted on girders the value of the deformation accepted for them is 10 μm. The two-beam module has a length of 2010 mm, which defines the maximum girder length. For the DB the girder length is fixed to 1946 mm. The MB girder types are different, due to the different lengths of MB quadrupoles required to fulfil the optics requirements. The focusing magnets might replace one or few pairs of accelerating structures (AS). For example, type 1 two-beam module has the shortest MB quadrupole, Therefore the required girder length is about 1.5 m. The type 4 two-beam module, by having the longest magnet, it does not require any girder. The MB quadrupoles are supported separately due to their stringent stability requirements (1 nm at above 1 Hz).

Each girder has an outer cross section of 320 mm × 150 mm. The girder dimensioning is the result of an overall design optimisation which also takes into account the CLIC tunnel constraints. The decelerating structures of the DB are the power extraction and transfer structures (PETS), which are linked to the AS of the MB via a complex waveguide network, connecting several RF components such as choke mode flange, hybrid, high-power loads and splitters.

For the MB the filling factor is about 79%, which is the outcome of several beam optics and mechanical integration optimizations.

2. Technical Specification

The girders shall support and allow for alignment of the RF structures, which must form a non-interrupted chain all along the linac. Damping and isolation of the dynamic behavior of the CLIC two-beam modules are additional requirements for the girders so as to maintain the alignment of the beam in a range of a few micrometers.

The main requirements for the girders are summarized hereafter:

Maximum vertical and lateral static deformation of 10 μm;

Maximum girder weight of 240 kg;

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Maximum girder length is almost 2 m;

Maximum sustainable dead weight of 400 kg/m;

Maximum cross section of 320 mm × 150 mm;

Tolerance for flatness of reference surfaces of 2 μm all along the longitudinal girder axis;

Resistance to high radioactive background aging effects.

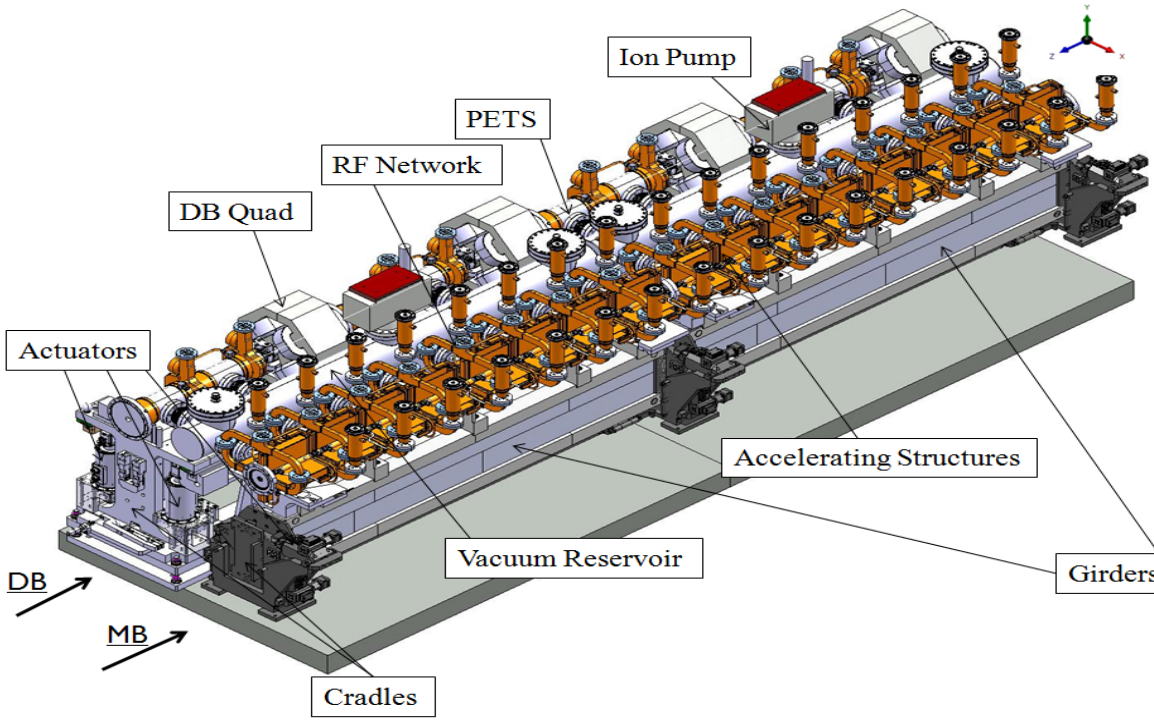


Fig. 1. Two CLIC two-beam modules type 0 in series

3. Supporting System

General Overview

All girders are mechanically interconnected constituting a system called “snake system” (Figure 2). This system allows for the precise alignment on the overall length of the two linacs. Through the “snake system” the girders are position monitored and re-aligned.

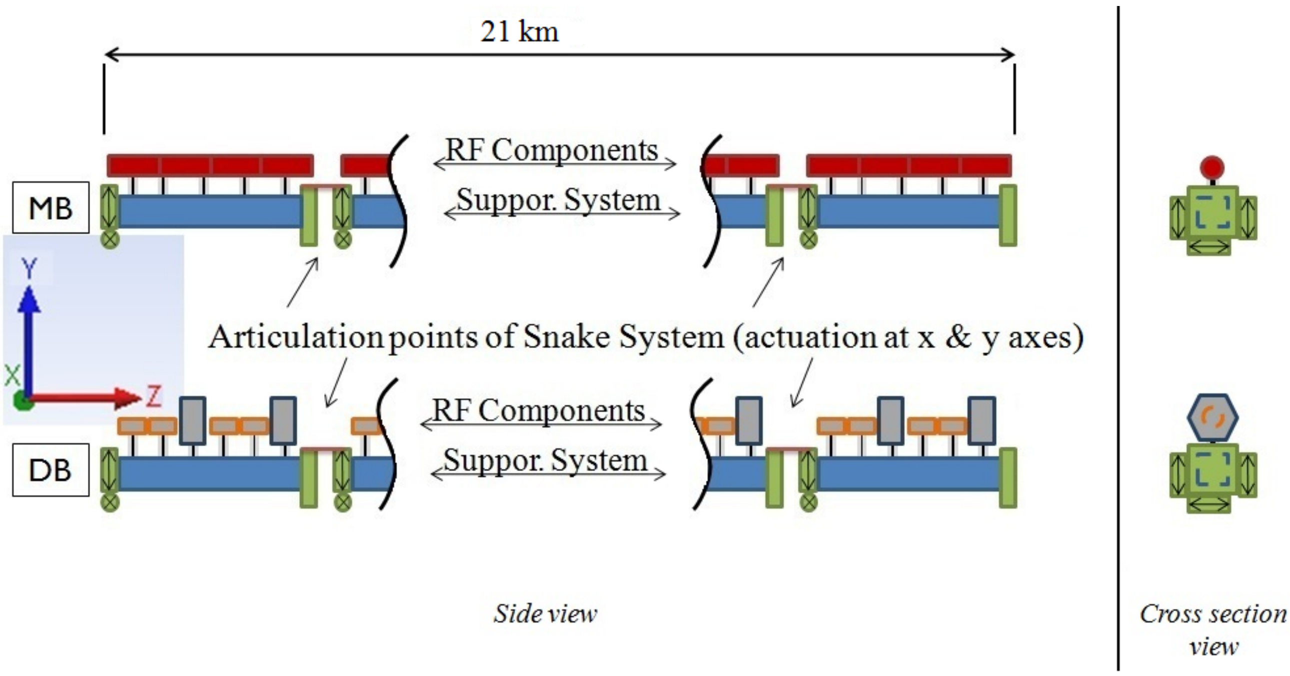


Fig 2. CLIC "Snake System"

The repositioning of the girders is achieved with the help of actuators fixed on each side of the girder. The system is designed to make possible the corrections in three directions at each end of the girder. The actuators are functioning with micrometer precision and nanometer steps. A fundamental issue for the snake system proper operation is the stiffness of the girders and the V-shaped supports. It is expected that the girders and the V-shaped supports will have higher values of stiffness in comparison with other components of the CLIC two-beam modules. Therefore, the possible static deflection of the girders and V-shaped supports are taken into account at the earlier stage, while calibrating the actuators.

For the components alignment, it is necessary to transfer the reference, representing the beam axis, to the outside surface of the RF structures. This means that the supporting system shall include also the feature for the reference transfer.

Girders

Since the girder stiffness is of high importance the detailed study of different materials, currently available on the market, was accomplished.

The potentially suitable materials for the girder production are summarized in Table 1. A number of simulations were done by considering several materials and different girder shapes (Table 2) before choosing the best solution fulfilling the CLIC requirements.

Table 1. Girder material comparison

Material	Static Deformation loaded with RF components (μm)
Aluminium -6061- AHC	43.39
Austenitic Stainless Steel	36.49
Silicon Carbide (SiC)	3.38
Structural Steel	36.29
Stainless Steel 440˚C	35.32
Titanium	46.86
Carbon Fibers	66.68
Epument 140/5	15.08
Aramid Fiber	69.96

Due to limited space, the girder should be as compact as possible (Figure 3). Therefore, the rectangular girder external envelope (320 mm × 150 mm × 2000 mm) is defined as the result of an extensive optimization.

The girder must have low static deformation and be reliable as fundamental part for the CLIC supporting system. Simulations based on the structural behavior were made comparing

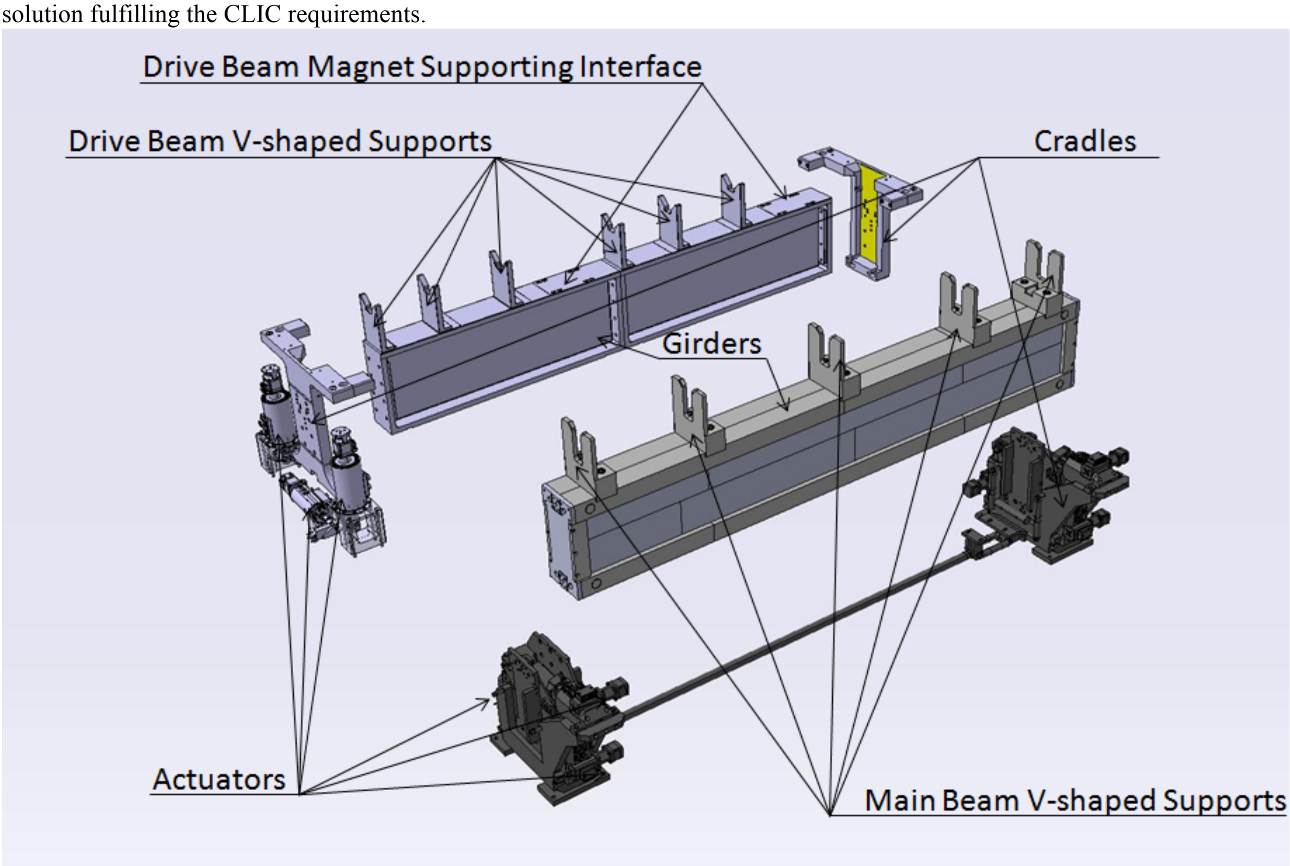


Fig. 3. CLIC two-beam module type 0 supporting system the mechanical properties of the different mentioned materials. The best stiffness to damping ratio was valid for silicon carbide (SiC), and it is chosen.

Table 2. Comparison of girder shapes and the baseline configuration

Configuration	Deformation (μm)
SiC	3.38
SiC (Girder Baseline Configuration)	1.14
SiC	3.52
SiC	1.95

The CERN technical specification was used as a basis for the girders procurement. The length (up to 1946 mm) remains the main challenging criteria for SiC girder manufacturers. The sintering procedure needed for the SiC to be manufactured, is restrained by the industry feasible solutions (e.g. furnace dimensions, material homogeneity etc). Hence several manufacturing techniques (such as brazing, epoxy gluing) have been studied. Before the girder baseline design optimization, the wall thickness was considered to be 10 mm. After structural simulations it was increased to 50 mm. Such a value remains fully compatible with the space constrains and the limitations of the SiC fabrication methods.

Alternative girder studies and further design have been progressed to acquire additional simulation comparative data. The basic criteria of the investigation, in comparison with SiC baseline girders, were:

Less fabrication steps;

Smaller production time scale;

Higher component fixation flexibility;

Lower cost.

The mineral cast materials were discovered. One of them, "Epument 145B" (Figure 7) used recently for the girders of XFEL accelerator in PSI [6], looked particularly interesting for the CLIC two-beam module. Such a material has proven to have similar deformation values to the SiC.

For all girder types, static deformation simulation was accomplished. The weight estimate of each of the components supported on the girder was done individually, based on preliminary design having additionally a 20 % safety margin (Figure 4). The drawback noticed with Epument 145B material is a low modulus of elasticity comparing to typical SiC.

EEpument = 40 – 45 GPa:

Static Deformation of 53.5 μm (for loaded 1946 mm MB girder);

ESiC = 170 – 210 GPa:

Static Deformation of 6.81 μm (for loaded 1946 mm MB girder).

However, several micrometers of precision, which are necessary for the compensation of deformation due to future components loading, can be obtained by pre-stressed precision grinding after the cast out of the mould. The weight and radiation hardness criteria are met by the Epument material. For the modal analysis of type 0 two-beam module, each girder was individually investigated applying the working principle of the actuators, which set the girder edge boundary conditions. The analysis was based on the girder design of three different European companies producing CLIC two-beam module girders.

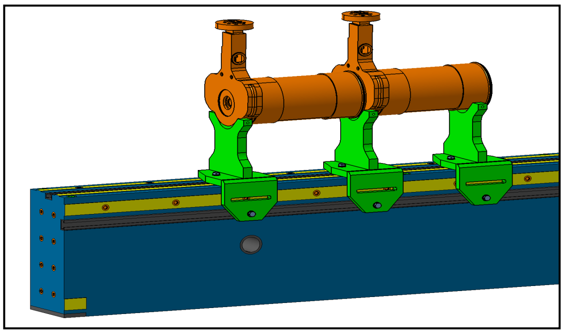
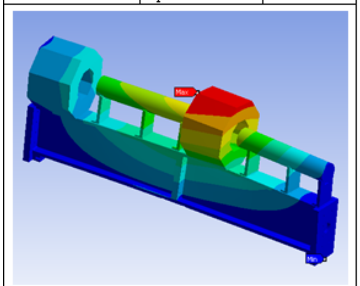


Fig. 4. Epument girder with mounted steel V-shaped supports

Three independent analyses were made on different configuration girders (Table 3). Each configuration was optimized according to both, material feasibility and industrial fabrication process.

Table 3. Girder Modal Analysis

Firm	Material	Frequency [Hz]
Firm A	SiC	49.85
Firm B	SiC	25.05
Firm C	Epument 145B	34.08



For SiC two separate fabrication techniques were used:

Two SiC halves, 1 m long each, brazed together (Firm A);

Standard rectangular SiC mechanical beams of a smaller size were glued together forming the required girder (Firm B).

Mineral cast girder (Firm C) was manufactured of epoxy resins reinforced with rocks of various diameters. A mould was used to cast in the girders. All girder reference surfaces were grinded after fabrication with a precision lower than 2 μm. Such accuracy is required, as all RF components will be assembled with respect to these surfaces. All interfaces to the RF components and actuators (Table 4) were also grinded with a precision better than 20 μm. In addition, to achieve necessary precision, once the supporting system assembled, the actuators must be calibrated in order to take into account and minimize the girder manufacturing inaccuracy (Figure 5).

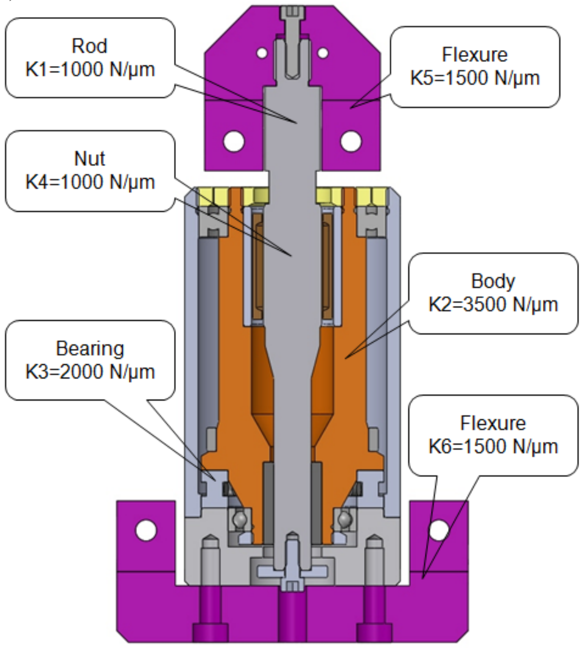


Fig. 5. Micro-Controle ® actuator for CLIC prototype two-beam module

V-shaped supports

The components between the RF components and the girder are the so-called V-shaped supports (Figure 6). The design of such a component has raised issues on stiffness and space availability. The space reservation for the V-shaped supports is very limited.

Another issue is the firm fixation of the V-shaped supports on the SiC girder. The SiC girder has very high rigidity but it is brittle. The mechanical fixation methods are not compatible with such a condition. Therefore it has been decided to either glue or braze the V-shaped supports for having them fully integrated to the girder (Figure 6). Then a clamp with soft material intermediate part will be used, to fix the RF components.

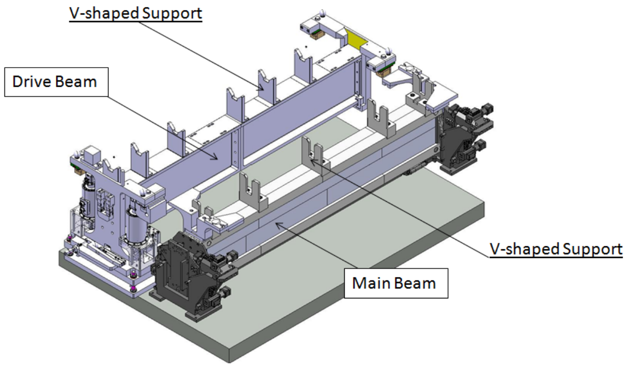


Fig. 6. CLIC two- beam module type 0 supporting system

3. Conclusions

Advanced supporting systems are needed for stabilization and alignment systems of particle accelerators. For the CLIC two-beam module a study of the overall supporting system took place. The aim of this study was the definition of the baseline supporting system material and configuration. A technical specification was issued for the CLIC two-beam module supporting system, taking into account the beam physics requirements. Possible fabrication of prototype CLIC two-beam module supporting system was investigated according to available technologies. Different materials and shapes were examined before defining the CLIC two-beam module supporting system baseline configuration. FEM simulations and analytical calculations were carried out to identify possible problems and to size the supporting system. According to the current program, the first prototype girders are expected to be delivered at CERN in November 2010 for extensive testing.

This study is very challenging and the test results will be of prime importance towards the realization of a post–LHC (Large Hadron Collider) [14] era collider.

Acknowledgement
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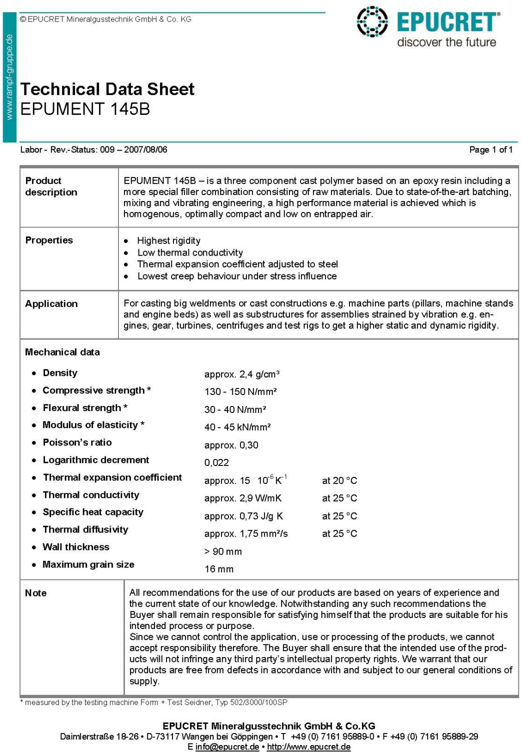
References

1. http://www.linearcollider.org/
2. H. Braun et al., "CLIC 2008 Parameters" CLIC-Note-764, CERN-OPEN-2008-021, Geneva, Switzerland (2008).
3. J.P. Delahaye et al., "Towards CLIC feasibility", IPAC2010, Kyoto, Japan, 23-28 May 2010
4. G. Riddone et al., "Technical Specification for the CLIC two-beam module", EPAC08, Genoa, Italy, 23-27 June 2008
5. H. Mainaud-Durand, "The CLIC Alignment Studies: Past, Present and Future", CERN-TS_note-2005-028, Geneva, CERN, 06 Jan 2010
6. http://www.psi.ch/
7. ANSYS ® Workbench 2.0 Framework, Version 12.1.0, 2009 SAS IP, Inc
8. CATIA ® Version 5.16 © Dassault Systemes 1994-2008.
9. CLIC Parameter List at 3 TeV: http://clic-meeting.web.cern.ch/clic-meeting/clictable2010.html
10. CLIC website: http://clic-study.web.cern.ch/CLIC-Study/
11. http://www.boostec.com
12. Micro-Controle:http://www.newport.com/
13. http://www.epucret.de/en/home/
14. http://lhc.web.cern.ch/lhc/

Appendix

Table 4. Micro-Controle ® actuator specification

Travel	+/- 3 mm	+/- 3 mm
Sensitivity of Displacement	0,5 µm	+/- 0,5 µm
Position Repeatability	≤ 1 µm	≤ 1 µm
Speed	> 0,01 mm/s	> 0,01 mm/s
Maximum charge (per girder)	1000 kg/girder	
Description	Rotating nut, worm gear reduction, roller screw	
Resolution	27 nm	
Load capacity	6000 N	
Stiffness	~240 N/µm	
Motor	Nema 17 stepper motor (42 mm)	



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Technical Data Sheet
EPUMENT 145B

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Product description	EPUMENT 145B – is a three component cast polymer based on an epoxy resin including a more special filler combination consisting of raw materials. Due to state-of-the-art batching, mixing and vibrating engineering, a high performance material is achieved which is homogenous, optimally compact and low on entrapped air.
Properties	• Highest rigidity • Low thermal conductivity • Thermal expansion coefficient adjusted to steel • Lowest creep behaviour under stress influence
Application	For casting big weldments or cast constructions e.g. machine parts (pillars, machine stands and engine beds) as well as substructures for assemblies strained by vibration e.g. engines, gear, turbines, centrifuges and test rigs to get a higher static and dynamic rigidity.

Mechanical data

• **Density**	approx. 2,4 g/cm³	
• **Compressive strength ***	130 - 150 N/mm²	
• **Flexural strength ***	30 - 40 N/mm²	
• **Modulus of elasticity ***	40 - 45 kN/mm²	
• **Poisson's ratio**	approx. 0,30	
• **Logarithmic decrement**	0,022	
• **Thermal expansion coefficient**	approx. 15 · 10^{-6} K^{-1}	at 20 °C
• **Thermal conductivity**	approx. 2,9 W/mK	at 25 °C
• **Specific heat capacity**	approx. 0,73 J/g K	at 25 °C
• **Thermal diffusivity**	approx. 1,75 mm²/s	at 25 °C
• **Wall thickness**	> 90 mm	
• **Maximum grain size**	16 mm	

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Fig. 7. Epument 145B material specification