DESIGN, MANUFACTURING AND TESTS OF A MICROMETER PRECISION MOVER FOR CTF3 QUADRUPOLES*

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Abstract

A new remotely controlled moving table has been designed for the quadrupoles of the CTF3 Test Beam Line, as part of the beam based alignment system. This device must provide both vertical and horizontal (transverse to the beam) movements. The specifications request a reproducibility of +/- 5 microns, with a resolution of 1 micron and a stroke of +/- 4 mm. Due to the weight of the magnet, about 50 kg, and the space restrictions, a solution based on small stepping motors with integrated linear spindles has been chosen. The motor responsible of the vertical movement rests on a wedge, with a double purpose: to make the design more compact, and to increase the lifting force for a given motor size. Mechanical switches are used as end-of-movement sensors and home position detectors. The performed tests to check the mover prototype performance are also reported in this paper. Series production of 15 additional units has been already launched.

INTRODUCTION

This paper is focused on the development of high precision movers for the quadrupoles of the TBL experiment of CTF3 [1, 2]. TBL lattice is composed by sixteen identical modules. Each one consists of a 0.8 m long Power Extraction and Transfer Structure (PETS) with coupler, a beam position monitor (BPM) and a quadrupole.

The aim of TBL is to extract as much energy as possible out of the CTF3 beam and to demonstrate the stability of the decelerated beam and the produced RF power. One of the main issues is the transport of a beam with a very high energy spread and no significant beam losses. Other TBL goal is the test of alignment procedures and the study of the mechanical layout of a CLIC drive beam module with some role of industry to build the components, as a long series production would be necessary for CLIC.

TECHNICAL SPECIFICATIONS

The purpose of the movers is to be able to perform beam based alignment in order to control the emittance growth of the beam. Otherwise, the beam cannot be transported until the end of the line. Some simulations have been done to find the required alignment for the quads in TBL. Figure 1 shows the maximum centroid of the beam envelope as a function of quadrupole misalignment. A 20 micron displacement yields a factor of two emittance increase which is just acceptable. In order to avoid emittance growth, 10 microns would be a better value. That request can only be fulfilled using beam based alignment: the position of the beam is measured with the BPMs and then the quadrupoles are moved to the right position. Obviously, both vertical and horizontal displacements are necessary.

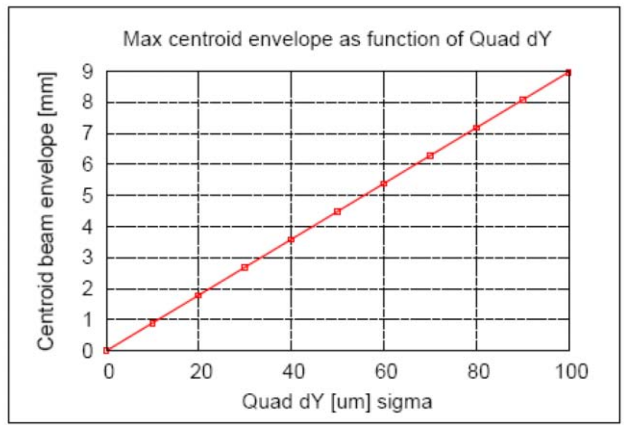

Figure 1: Centroid of beam envelope as a function of quadrupole misalignment.

Table 1 shows the initial technical specifications for the movers, either coming from the beam properties or from the facility layout.

Table 1: TBL quadrupole mover specifications

Parameter	Magnitude	Units
Length	< 200	mm
Stroke	+/- 4	mm
Position resolution	1	μm
Position reproducibility	+/- 5	μm
Movement speed	> 0.5	mm/s
Distance from driver to motor	< 50	m
Mass to move	< 50	kg

MOVER DESIGN

The quadrupole weight is relatively large for the mover overall dimensions. Therefore, the vertical actuator is

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laying on a wedge, instead of a pure vertical position (Fig. 2). The main advantage is that the lifting force is multiplied. In this case, using a 1 to 5 slope, the lifting force is five times the actuator nominal one. This configuration allows a significant reduction of the motor size. Besides, all the parts were made of aluminium, to avoid excessive weight, and also the presence of magnetic volumes near the magnet.

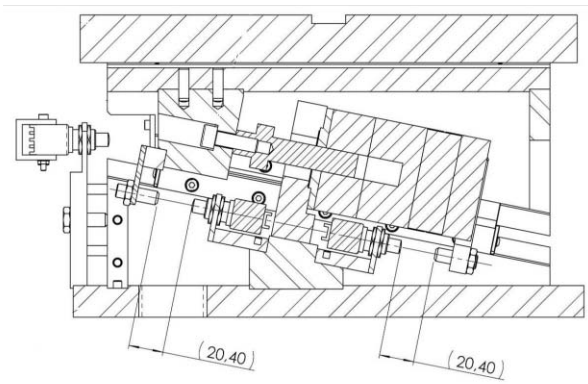

Figure 2: Cross section showing the vertical actuator laying on a wedge and the stroke.

Figure 3 shows the horizontal actuator, which is smaller, as it only needs to deal with inertial forces. The horizontal and vertical movements are independent thanks to a vertical linear guide attached to the horizontal actuator. When the vertical motor is switched on, the horizontal actuator blocks the horizontal component of the movement, and the displacement is purely vertical.

Both actuators are based on five-phase step motors. The requested displacement resolution is achieved, and even shorter ones are available by using the right switching scheme in their drivers. These actuators have an integrated screw shaft. Motors with independent spindles were also considered, but the present choice eases the assembly with reasonable price. An electromagnetic brake is included to hold the position even if the power is cut off. The backlash should be avoided if one wishes to fulfil the required movement reproducibility. The own quadrupole weight helps to reduce the vertical backlash, while a spring is used to eliminate the horizontal one.

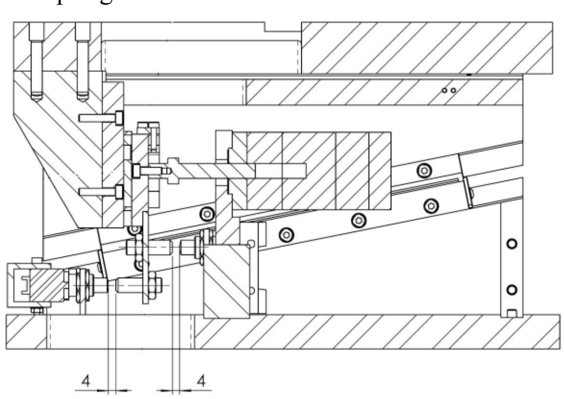

Figure 3: Cross section showing the horizontal actuator, the vertical blocking guide and the stroke.

Figure 4 depicts the general layout of the mover. Some plates are made transparent to ease the location of the inner parts to the reader. V-shape linear guides are used for both movements. Torque on screws must be controlled during assembly.

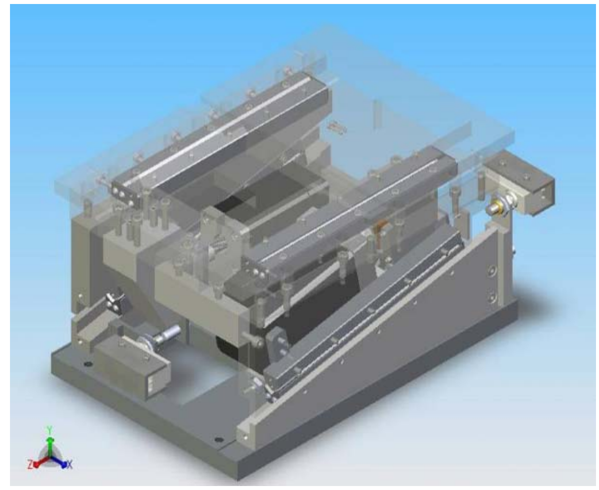

Figure 4: General layout with some transparencies.

Simple mechanical switches are used as end-of-movement sensors (Fig. 2 and 3) and also as home position detectors. They are not very accurate. Surprisingly, an extremely good reproducibility is obtained for the zero position if one passes several times in both directions over the switch and detects the signal.

All the choices have the aim to keep low fabrication costs, as sixteen units are needed. Therefore, direct position measurement systems have not been included, such as high precision linear transducers with a closed loop control. In principle, the simplest solution is preferred. In case of failure, the design will be more sophisticated.

The control system is based on a Siemens PLC. The implementation into the accelerator control system is done by FESA classes.

Fiducials for alignment in the accelerator line are installed on top of the magnet. Mover position can be regulated both in horizontal and vertical directions (Fig. 5).

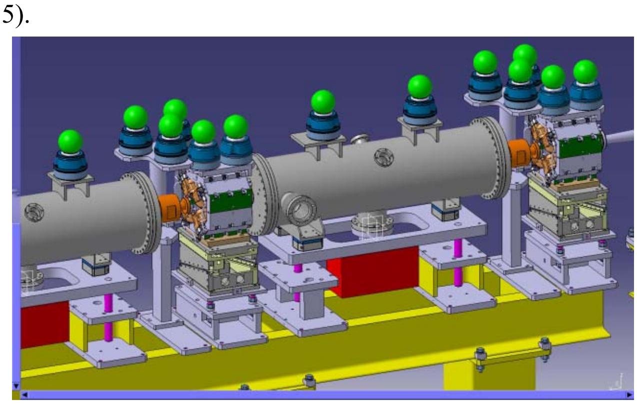

Figure 5: General TBL layout.

PROTOTYPE TESTS

A first prototype has been assembled at CIEMAT (Fig. 6). It was proved that the drivers could be placed up to 50 m away. The quadrupole was replaced by a dummy mass of 50 kg, because the quadrupoles had not been fabricated yet. No major differences are expected compared to an actual magnet, because the vibrations due to the cooling system will not be so large to affect the mover stability. Both horizontal and vertical strokes were correct, and also the movement speed. The horizontal movement reproducibility and resolution was achieved without problems, for short and long displacements: the backlash was about 3 microns (Fig. 7).

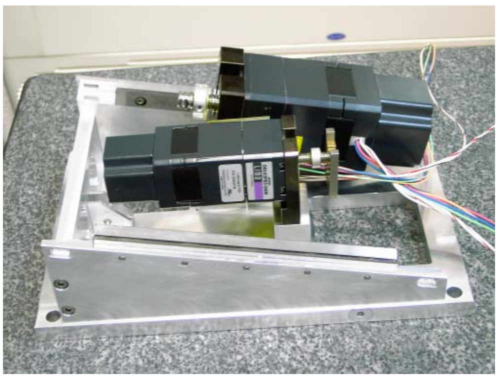

Figure 6: Assembly intermediate step at CIEMAT.

On the other hand, the vertical movement resolution was correct. The backlash was larger, about 7 microns. However, vertical reproducibility was only fulfilled when the dummy mass was not on the mover. After several cycles of measurements, the origin of the problem was discovered: the gravity centre of the dummy mass was about 60 mm off the mover symmetry axis, and both sides of the mover were not moving exactly in parallel, causing discrepancies of some microns in each displacement. This is not the case of the final application, were the magnet centre of mass is close to the mover symmetry axis.

Figure 7: Test of horizontal movement with dummy mass.

In conclusion, the first prototype mover was within specifications. However, some minor changes were made and will be applicable for the rest of the series production:

- Switches based on flexible plates were not robust enough, and they will be replaced by a button-type one (it is already shown in Fig. 2 and 3).
- Besides, as the new model is prepared for over-travel beyond the switching position, the home position switch can be eliminated. The end-of-movement switches can now also be used as reference.
- The first prototype had two connectors, one for the switches, and another for the motors. In the series, there will be only one connector with 28 pins.
- The electromagnetic brakes are not necessary. Due to the spindle properties, the position was hold when the power was cut off, even without them.

All these tests were performed with a simple controller from the same company who produces the actuators, Oriental Motors. In a second stage, the final control system to be used in TBL facility, developed at CERN, was successfully tested (Fig. 8).

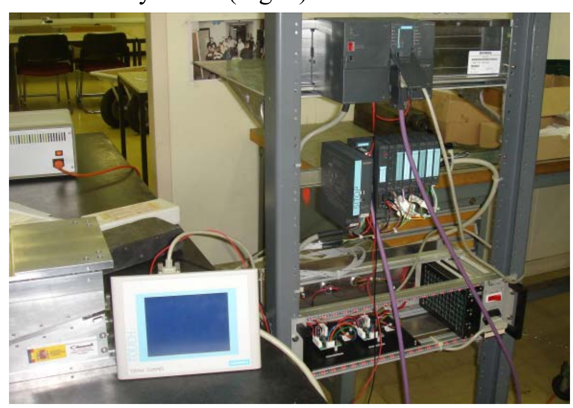

Figure 8: First TBL mover prototype with the control system developed at CERN.

CONCLUSIONS

This paper describes the development of the TBL quadrupole movers. The most demanding specification is the position reproducibility. The first prototype has been designed and assembled at CIEMAT. Tests were performed successfully for both horizontal and vertical movements. The control system has been developed at CERN. Recently, the series fabrication of the rest of modules (15 units) has been launched.

REFERENCES

[1] G. Geschonke and A. Ghigo, “CTF3 Design Report”, CERN/PS 2002-008 and LNF-02/008, 2002.

[2] S. Doebert et al., “Progress on the CTF3 Test Beam Line”, EPAC’06, MOPLS097, http://www.jacow.org