Vulcan Target Area West upgrade grating mounts design

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Introduction

Some of the past Target Area West (TAW) experiments that required two CPA beams had to rely on the scheme in which two short pulse beams were produced by spatially splitting a single short pulse beam, thus reducing energy of each beam by a factor of 0.5[1]. The recent upgrade of the TAW has improved its short pulse capability by enabling a second short pulse beam in addition to the one already existing. This has made two short pulse beams, along with the existing six long pulse beams, readily available to the users[2].

The upgrade required a considerable engineering effort that has been put in to the design and construction of new compressor chamber, new optical mounts, vacuum supply system, beam delivery lines with support tables and enclosures. An extension to the target chamber to bring one of the short pulse beams to the target and to increase working volume of the target chamber has also been designed and built.

Prior to the upgrade, there was only one main CPA beam line available that relied on the use of gold gratings. It was decided to use a pair of new dielectric gratings for the second short pulse beam, while keeping gold gratings for the existing beam[2]. The dielectric gratings required new mounts that were designed, built and installed by the CLF engineering group. This report gives some details on the design of these gratings mounts.

Grating mounts design

New mounts were required for accurate positioning and stable support of dielectric gratings inside the compressor chamber. Mounted in an aluminium alloy bezel, each grating is a glass ceramic slab approx 430×470×100 mm in size which alone weighs over 55 kg. One of the grating mounts was specified to have five Degree of Freedom (DOF), while the other to have four DOF only. To allow remote control over gratings position, all motion axes are motorized driven by stepper motors coupled with high-ratio planetary gearhead reducers. Axes positions are measured directly at the output with optical incremental encoders and the information from the encoders is then fed back to the control system.

The main features of the grating mounts are very compact and rigid design, extremely fine axes resolution, rolling bearings that provide smooth motion along the axes, high load capacity, breaking of the axes when powered off. Compact design was required due to space restrictions inside the compressor chamber. General specifications for the grating mounts are listed below (also see Figure 1).

1. Travel range:

Rotation about X, °	±5
Rotation about Y, °	±180
Rotation about Z, °	±4
Translation along X, mm	±25
Linear stage *, mm	±150

2. Drive system
   Stepper motors with gearhead reducers
3. Encoder type
   Optical incremental with magnetic reference marks

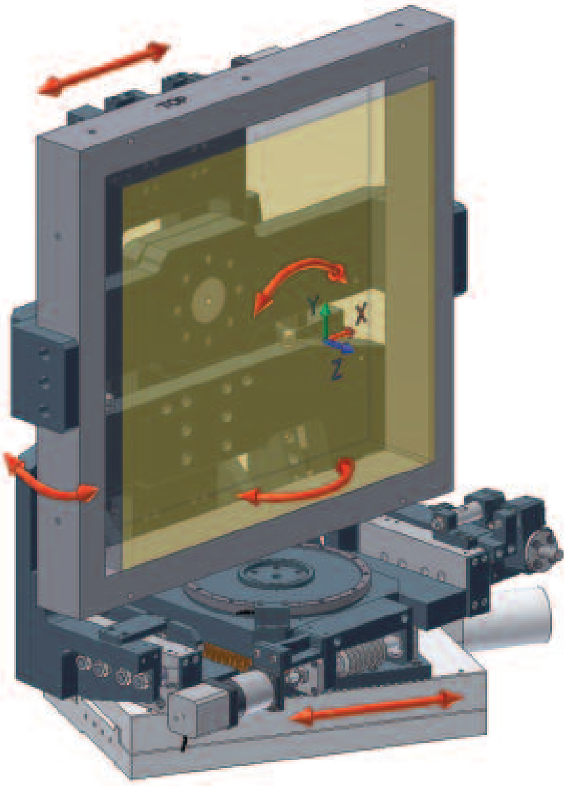

Figure 1. 3D model of 5 DOF version of grating mount.

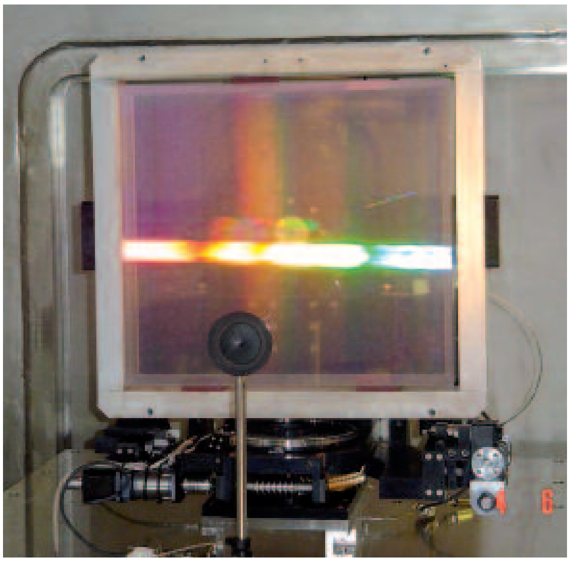

Figure 2. 4 DOF grating mount inside compression chamber.

Figure 3. 5 DOF grating mount inside compression chamber.

3. Drive resolution (200 steps/rev on motor)

Rotation about X, µrad	$<7.5*10^{-4}$
Rotation about Y, µrad	$<4*10^{-3}$
Rotation about Z, µrad	$<1*10^{-3}$
Translation along X, µm	0.2
Linear stage *, µm	5

4. Encoder resolution

Rotation about X, µrad	$6.6*10^{-5}$
Rotation about Y, µrad	$2*10^{-4}$
Rotation about Z, µrad	$3.5*10^{-4}$
Translation along X, µm	0.02
Linear stage *, µm	0.1

* - Linear stage is a standalone unit that can be mounted at the bottom of the grating mount, see Figure 1 for illustration.

Figure 1 shows 3D model of a 5 DOF version of the grating mount. All angular movements are performed about the centre point located on the front face of the grating.

General view of the 4 DOF version of the mount placed inside the compressor chamber is shown in Figure 2.

General view of the 5 DOF version of the mount placed inside the compressor chamber is shown in Figure 3.

Each of the mount axes is motorized driven by a stepper motor coupled with a planetary gearhead reducer used to increase drive resolution and improve output torque. For the translation along the X axis, output shaft of the gearhead is connected through a flexible coupling to a lead screw. When the motor is de-energized, braking happens naturally due to the weight of the moving parts. Smooth and precise linear motion along the axis is provided by a matched pair of linear recirculating ball bearings.

Drive mechanisms of the rotary axes for the rotations about the X and Y also include lead screw assembly and are attached to the stationary and moving parts through rotary ball bearings. This creates a pair of pivot points on the stationary and moving parts. Linear motion of the lead screw nuts is thus converted into rotations about the X and Y axes. Breaking for the rotation about the X axis is done by the non-reversible lead screw mechanism. Because the centre of the gravity of the grating is not on the axis, the produced moment load results in the force applied to the nut which is always unidirectional. Hence the torque imposed on the axis drive is always unidirectional. This helps to minimize backlash in the drive chain. Braking of the Z axis happens naturally when the drive is powered off due to the high moving mass as in the case of translation along the X axis.

Smooth rotation about the X axis is provided by eight track rollers, four on each side of the mount, riding on curved guides. The guides were designed and made specifically for this purpose from 17-4PH hardened stainless steel. On each side, two of the four rollers have eccentric shafts. This allows to adjust preloading and to reduce clearance between the rollers and the guides. For the rotation about the Z axis, a single high-capacity rotary cross-roller bearing is used. Situated behind the grating, this bearing is preloaded and takes radial, axial as well as moment loads. The use of a single bearing helped to minimize mount foot print. Preloading of the bearing eliminates backlash and assists in braking of the axis.

Continuous rotation about the Y axis was made possible by the use of a worm gear mechanism situated at the bottom of the mount. It should be noted that it was specified for the Y axis to have a range of motion within ±180°, which in the current design is only limited by the length of the drive and encoder cables. Due to the height restriction, the worm wheel was made stationary and the worm screw is moving in its housing about the wheel. The worm screw is linked to the drive motor with gearhead through a flexible coupling. A single high-capacity cross roller bearing supports and provides smooth motion for the heavy load comprising the weight of the grating in its bezel and the drive mechanisms and elements of three axes. As well as the bearing of the Z axis, this bearing is preloaded to eliminate backlash and takes axial, moment and radial loads. Breaking of the Y axis is done by a combined effort of the bearing preload and the weight of the moving parts.

Cross roller bearings for the rotations about Z and Y axes were chosen over ball bearings not only because of the higher load carrying capacity, higher stiffness and ability to take combined loads. Most of the time, load on the bearings is static. Therefore, larger contact area between the rollers and bearing racing tracks, as compared to the ball bearings, helps to prevent indentation of racing tracks by the rolling elements.

Most of the parts of the grating mounts are made from high-strength 7075 aluminium alloy. Noncritical parts are made from 5083 aluminium alloy. Shafts and optical encoder rings are made from stainless steel. Bronze alloy was used for the worm wheel. Stainless steel fasteners are used throughout. All of the machined parts and bearing units were made vacuum compatible.

All motion axes are directly encoded with either linear or angular incremental optical encoders. The encoders measure axes positions directly thus eliminating possible errors from the drive mechanisms. As a part of the encoder system, magnetic reference marks are placed in the middle of axes travel and are used as "home position" sensors. In addition to that, there are contact limit switches placed at the ends of travel of all axes except for the rotation about Y axis. In addition, the Z axis has adjustable hard stops. Hard stops for the rotation about X and the translation along X are non-adjustable.

As mentioned earlier, one of the grating mounts has a fifth degree of freedom, which is a translation done by an add-on off the shelf linear stage mounted at the bottom of the grating mount, as shown in Figure 1. The travel range of the linear stage is ±150 mm and it is compatible with the rest of the system in terms of the motor type and encoder system.

Grating mounts setup and installation

In order to test the grating mounts, a dummy grating was made out of aluminium alloy closely representing the shape and weight of the real grating in its bezel. The dummy grating was mounted on and then performance of the drives was checked for the compliance with the original specifications. Drives resolutions were also checked at that stage.

For the installation of the grating mounts, a special support frame was made. It allowed to pick each mount at the back and to maneuver it to the compressor chamber, then to gently place inside. Figure 4 shows one of the grating mounts mounted on the support frame and being positioned inside the compressor chamber. The same support structure was used to maneuver the gratings into the compressor chamber and drop them onto the mounts, as shown in Figure 5.

The grating mounts were initially placed inside the compressor chamber without the optics in them. Because of the cost of the gratings and their delicate nature, a dry run was first done for which the dummy grating was picked up with the above-mentioned support frame, moved to the compressor chamber and dropped on the mount. Practicing with the dummy grating enabled us to establish the installation procedure and then the actual gratings were safely installed.

Lessons learned

It was discovered during the setup of the grating mounts that the interface electronics of the optical encoders sent error codes when the drive motors were energized. It was believed that this was associated with the electromagnetic compatibility (EMC). Subsequent investigation prompted that the stepper motors were interfering with the encoders. The encoder readheads and signal cables were picking up electromagnetic radiation generated by the stepper motors. Creating local earth loops for the encoder readheads did not help the situation. Placing grating mounts inside the compressor chamber did not help either and probably made things even worse. The inner surface of the chamber now worked as a mirror and the unwanted noise was reflected by the chamber walls and bounced back onto the encoders.

It was advised by the encoder supplier that certain measures could potentially be taken to try and cure the problem. Among the other potential measures, it was suggested that the encoder readheads should be isolated from the main structure by placing an insulator layer between the readhead and the support surface, the signal cables of the encoders and the motor cables should be moved apart as far as possible,

Figure 4. Installation of grating mount.

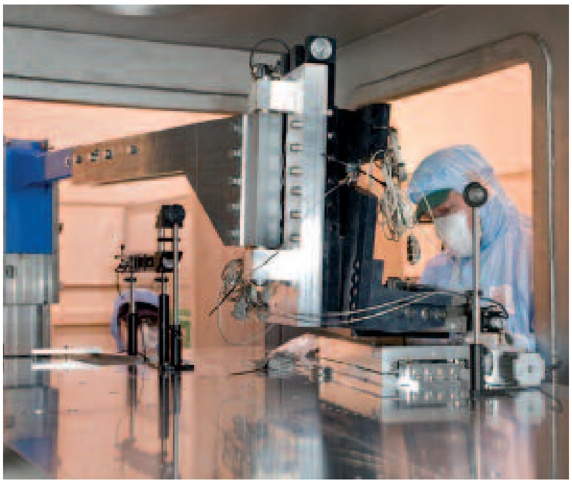

Figure 5. Installation of grating.

signal cables should have triple shielding and the earth points could be moved inside the compressor chamber to find an optimal position. The signal cables of the encoders and the motor cables should also not run along in the same conduit. The encoder supplier also advised on the alignment procedure for the readheads.

Conclusions

To date, as of July 2009, the upgrade has made possible three successful experiments using two short pulse beams together with long pulse beams. Some lessons have been learnt during the setup of optical encoders. With the latter in mind, future installations of optical encoders can potentially be made more reliable and the setup can be made trouble free. A number of new component suppliers have been identified and some useful links have also been established.

References

1. S. Hawkes, CLF Annual Report, 183, (2001-2002).
2. C. Hernandez-Gomez, CLF Annual Report, 260, (2007-2008).