A Fast Switching Mirror Unit at FLASH

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Abstract. At the Free Electron Laser Hamburg the laser beam is diverted towards 5 different test sites by massive silicon mirrors, which are mounted into vacuum vessels. One of these vessels is operated in permanent switching mode. The pursued switching frequency is 5 Hz. The initial motion concept is characterized by the motion of the entire vessel perpendicular to the laser beam by a linear drive. The initial vessel with a steel body allowed a switching at 2.5 Hz at the demanded precision. By substituting the steel body with one made of titanium, the frequency could be increased to 3.125 Hz. Further increase should be possible with a new motion concept, leaving the vessel stationary, which is not yet implemented. Another concept which is currently examined is the exclusive motion of the mirror inside the vacuum with piezo motors. Although the motors meet the requirements concerning the accuracy and driving speed, a steady motion under ultra-high vacuum conditions is not yet possible since the cooling of the motors is still insufficient.

1. Introduction

The Free Electron Laser Hamburg (FLASH) is a linear accelerator producing brilliant laser light from 4 to 60 nm wavelengths, providing unique experimental opportunities to investigate the atomic structure and the properties of materials, nanoparticles, viruses and cells. In the experimental hall, the laser beam can be directed towards five different sites in the experiment hall by massive silicon mirrors which are mounted into vacuum vessels. The movement of the vessels is carried out perpendicular to the beam by linear drives; the mirror itself is mounted into the vessel with an angle of three degrees to the incoming beam. With the vessel moved 30 mm out of the beam the laser goes through it into the beam line straight ahead without being deflected, with the vessel moved into the beam it is deflected into the diverging beam line.

One of these vessels is operated in permanent switching mode, allowing a simultaneous use of the laser beam at two different experiment stations. Since the laser beam at FLASH is pulsed with a frequency of 10 Hz, the motion has to be synchronized to the beam pulses (trains). The ideal switching frequency would be 5 Hz, with respectively one train passing through and one being deflected. The motion is processed according to a reference curve similar to the Bestehorn sinusoid (see figure 1), a curve which reduces jerk and guarantees minimal stress for the mirror. Nonetheless, when the state of rest begins the mirror always shows a certain horizontal angle distortion and a position misalignment. The limit of the angle distortion is 1 arc second, while the position misalignment must not exceed few micrometres. In practice the switching frequency is then limited owing to the repeated maintenance of minimal positional error, the finite drive torque available, the large mass, and the high clearance distance required.
2. Initial design of the Fast Switching Mirror Unit

2.1 Mounting concept

As can be seen in figure 2, the steel vacuum vessel consists of a round tube with a diameter of approximately 250 mm, with flanges welded to each side. The mirror is installed in the middle of the vessel. It is mounted into a fastening plate, which is attached to the chamber flanges. In case of heat input into the mirror by the FEL beam, a cooling plate, arranged on top of the mirror, is supposed to ensure a fast heat transport from the mirror towards the cooling pipe and out of the vessel. The vertical fastening of the cooling plate and the mirror is assured by screws. Additionally, on the reverse side of the reflecting surface, there are two taper keys which push the mirror towards elevations in the fastening plate. The overall mass of the assembly is more than 60 kg, which limits the maximum switching frequency to 2.5 Hz. Measurements revealed that the horizontal angle distortion as well as the position misalignment met the requirements.
2.2 Implemented and Proposed Improvements

In order to increase the possible switching frequency, the translatory inertia had to be reduced significantly. This goal could be achieved by substituting the construction material of the vacuum vessel. A suitable material was found in titanium, a metal which is applicable for the use under vacuum conditions, whose mass is only half that of steel and which offers a sufficient stiffness. Nonetheless, first tests with a vessel made of pure titanium (titanium grade 2) were not successful. At FLASH, flanges must be designed in a way that they allow at least a 10-fold reutilization. However, after being mounted 3 times, the sealing edge of the flanges became unsuitable, showing deep striations and mechanical flattening. As a result, for the second test, the vessel was remade in a titanium alloy (titanium grade 5 or TiAl6V4) which turned out satisfactory. The sealing edge endured a 20-fold reutilization without showing any damage.

By using titanium as vessel material, the mass of the assembly could be reduced to about 48 kg. This lead to an improvement of the maximum switching frequency from 2.5 Hz to 3.125 Hz at the demanded precision. Further significant weight reduction could be achieved by replacing the 250 mm steel flanges with titanium.

3. Stationary vessel

Further significant mass reduction could be realized by a change of the entire motion concept (see figure 6). In this concept, the vacuum vessel stands still; the mirror is moved from outside the vacuum with the help of 5 bellows which compensate the motion. At the edges of the basic plate which is attached to the linear drive, massive angle brackets serve as the mounting for the 4 brackets which carry the mirror’s fastening plate. Through the fifth angle bracket the cooling pipe is lead out of the vacuum. The vessel has a rectangular layout, which reduces the required space concerning the width of the assembly. Furthermore the installation of the mirror and its fastening plate inside the vessel, which has to be carried out from the top, proves to be less difficult. With this concept, the translatory inertia could be reduced to approximately 20 kg, which should allow a maximum switching frequency greater than 3.125 Hz. Anyway, this concept is still a study and not yet implemented.

Figure 6. Motion concept with stationary vessel
4. Mirror motion with piezo motors under ultra-high vacuum (10^{-10} mbar) conditions

The mirror motion executed from outside the vacuum always requires components to compensate the motion, i.e. bellows. These bellows have a limited lifetime; the ones used here guarantee 10 million cycles. Under a constant switching frequency of 5 Hz this would necessitate their replacement approximately every 23 days. With the operation of the entire drive components inside the vacuum vessel the bellows remain stationary. Furthermore the masses can be reduced significantly, the assembly becomes more compact. At the time of conception the availability of motors suitable UHV conditions was in question, so the motion concept shown in figure 7 was developed. In figure 7 the mirror is moved by 4 piezo motors, these motors are attached to a stationary base plate which is mounted into the vessel. Linear bearings assure the motion perpendicular to the laser beam and two encoders continuously measure the position and a possible tilt of the mirror. The mass of the moved parts is approximately 10 kg.

The installed motors HR8 are the most powerful ones of the series of piezo motors from the supplier Nanomotion. This motor has 8 ceramic edges, which are pushed against ceramic driving strips. Through combining 2 oscillations with similar frequencies, the ceramic edges generate elliptical movements, resulting in a translation along the driving strips. Due to the small oscillation amplitudes the precision of the motor is below 100 nm. Each motor is able to move up to 3,2 kg at a maximum speed of 250 mm/s if adequate cooling is ensured. The cooling of the motors poses the most important challenge since 2 Watts have to be transported from each motor. In the current setup full-speed motion under vacuum conditions is possible for about 40 s, followed by a cool-down phase of 400 s. To ensure extended operation, the driving speed must be limited to 50 mm/s [1].

![Figure 7. Mirror motion with piezo motors under uhv conditions](image)

5. Conclusion

By using the present linear drive a motion from outside the vacuum vessel at a switching frequency of 5 Hz cannot be assured at the demanded precision because of the high masses of the moved parts. Further problems occur as the inevitable vacuum bellows have a limited lifetime, which necessitates a frequent replacement. By executing the motion of the mirror exclusively inside the vacuum vessel by piezo motors, masses can be reduced significantly and the frequent replacement of the bellows can be omitted. Nonetheless, a steady motion is not yet possible because the cooling of the piezo motors is still insufficient. This issue is currently being addressed, and possible executions determined.

6. References

[1] Nagler J 2009 Diploma Work, Berlin HTW