An Engineering Design of an Improved Synchrotron Light Monitor Mirror Mechanism for the Daresbury SRS

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Abstract

The synchrotron light monitor mirror is the first optical element on a beam line used exclusively for accelerator diagnostics' purposes. Its function is to deliver radiation to a monitoring station that is used for both accelerator physics experiments and to support normal SRS operations. Beam studies are undertaken with varying electron orbit positions and to accommodate these changes a remotely operated precision mechanism is required. This paper covers the design of the mechanism, including a study of the heat load on the mirror and the physical stresses produced in the structure.

1. INTRODUCTION

The Synchrotron Light Monitor (SLM) mirror mechanism forms part of an Ultra High Vacuum (UHV) experimental beam line operating at a pressure of approximately 2×10^{-9} Torr. Its function is to deliver visible synchrotron radiation through an angle of 120° to the Light Monitor station. The light is then used for diagnostic purposes by the accelerator physics group, during this time the origin of the radiation can be varied. The station monitoring equipment is fixed, so it is necessary to vary the angle of the mirror face to redirect the beam. The SLM mirror mechanism is situated within the Storage Ring tunnel, so the mechanism must be operated remotely. The mirror is also the first optical element on the beam line and therefore requires cooling.

This design is based on existing design principles developed at the Laboratory, however changes have been made to satisfy the relatively large movement required of this particular mechanism.

2. MIRROR MECHANISM DESIGN

A mechanism is required to produce small angular rotation with fine resolution in two planes about the mirror face.

Horizontal Rotation	± 17.5mRad
Vertical Rotation	± 10.0mRad
Resolution	± 0.1mRad

A rotational drive was not capable of producing the small angular movement with sufficiently fine resolution, therefore a method of converting linear drive motion to small angular movement was developed. This mechanism involved the use of tapers to convert relatively large linear movements into much smaller movements acting at 90° to the input motion. These small linear movements can then be converted to angular motion by using pivot mechanisms.

As the mechanism is to operate within the confines of a vacuum vessel an intricate design had to be developed to accommodate both the cooling of the mirror and the rotation mechanisms.

By using Computervisions CADDS5 Computer Aided Design, the designer was able to create a solid model of the mechanism and check the interaction between components. The solid model can then be simply applied to Finite Element Analysis and Computer Aided Manufacturing technology. This closed loop approach to design, analysis and manufacture reduces design and manufacture time, therefore leading to a reduction in the overall project cost.

2.1. Horizontal Rotation Mechanism

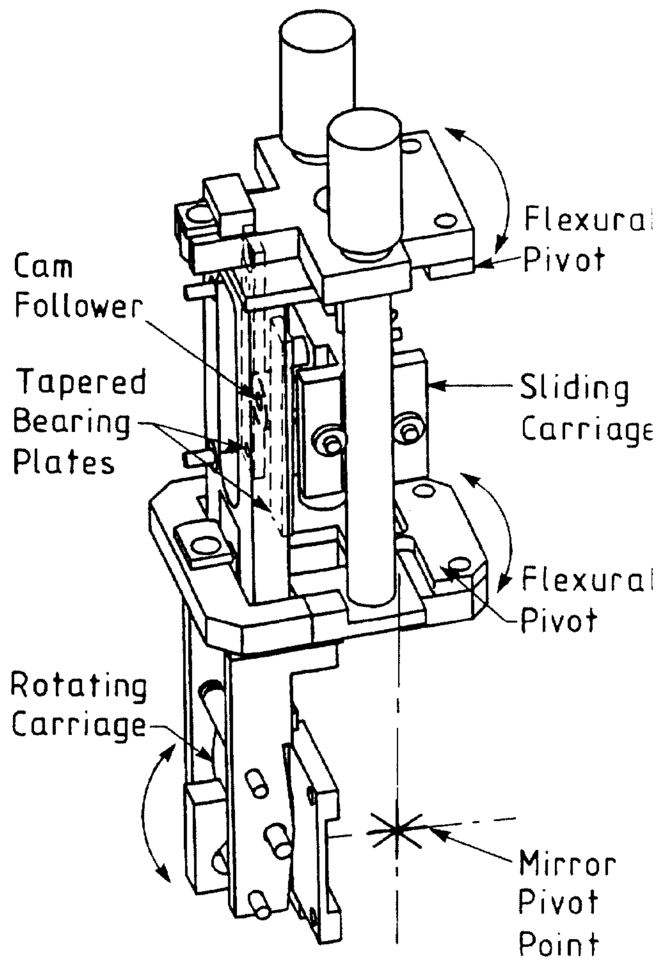


Figure 1. Rotation Mechanisms

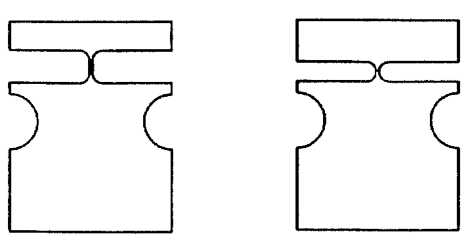
The diagram above (Figure 1) can be used to explain how rotation in the horizontal plane is obtained. A cam follower moves vertically against a taper bearing plate which in turn provides horizontal movement to the flexural pivots producing rotation in the horizontal plane. The cam follower is constrained to move vertically with a sliding carriage assembly and guide bars. The linear motion is provided by a motorised linear vacuum drive. The bearing plate is kept in contact with the cam follower by a stainless steel extension spring. The tapered bearing plate is set at 3:60 slope which over the stroke of 25mm produces small angular movement with fine resolution. Due to the sliding motion between the pivot plates and the flexural pivots they are made out of different materials. The top pivot plate, bottom flexural pivot, and the bearing plates are manufactured from phosphor bronze whilst the remaining components are stainless steel.

2.2. Vertical Rotation Mechanism

The linear drive full stroke of 25mm horizontally is converted by a taper to a vertical linear motion of 0.75mm. This movement pushes a plunger which rests against a rotating carriage fixed to the back of the mirror (refer to Figure 1). The carriage has an arc slideway which moves through 2 sets of 3 bearings producing the angular motion. When the plunger is withdrawn an extension spring keeps the carriage in contact with the plunger, thereby returning the mirror. The spring must be sufficient to overcome the resistance in the cooling pipes.

2.3. Flexural Pivots

Due to the relatively high horizontal rotation required for this particular mechanism, the flexural pivots were analysed carefully for risk of possible failure. By using FEA techniques and designing a test rig to move the pivot through the angle required until failure, it was discovered the existing design principles could not work in this range. The software package used was Rasna Mechanica both Applied Thermal and Applied Structure modules were required for the project. Using Applied Structure an optimum shape for the new flexural pivots was found. By closed loop design of the new pivot using FEA and CADDS5 it was possible to try various solutions before manufacturing the test flexural pivot. This reduced the development time of the new pivot. The test pivot was cyclic tested on the same rig as the existing design and run constantly for 7 days without failure. The new flexural pivot was then incorporated into the design, Figure 2 below illustrates the difference between the two pivots.



New Original

Figure 2. Flexural Pivots

2.4 Motors, Controls And Linear Drives

Motors were sized based on the calculated vacuum loading of 8.31kg, the friction and inertia within the motor was also accounted for. Both DC Servo motors and Stepper motors were considered to drive the mechanism. Subsequent calculations indicated either a McLennan 23HS108E Stepper motor or a McLennan GM2410 DC Servo motor could be used. Although both motors have advantages and disadvantages it was decided to opt for the stepper motor for several reasons. An electronic control system has been developed at the Laboratory for use with stepper motors to overcome the problem of losing the position of the linear drive, which may happen using a conventional shaft encoder. It is wired in to a closed feedback loop and driven to a point, as a DC Servo normally would be controlled, this would act as a basis for the control system. The stepper motor could also be assembled directly to the Vacuum Generators ZLDS225M linear drive, the DC Servo would require an adapter.

3. THE MIRROR

3.1. General Description

The mirror is manufactured from Silicon Carbide, and the optical surface of the mirror is to be parallel to ±0,01mm. The overall dimensions of the mirror are 90mm long x 80mm high x 20mm thick and the optical surface of the mirror is 90mm long x 60mm high.

3.2. Mirror Mount

The mirror is mounted onto a copper cooling plate using four kinematic mounts, these are spring loaded clamps that enable the mirror to expand freely thereby minimising the stress within the mirror. It is impossible for the surface of the copper plate to be in complete contact with the rear of mirror due to surface finish, parallelism, etc., therefore wetted gallium is used as an interface between the cooling plate and the mirror. The gallium fills the free space between the two components and significantly improves the heat transfer process. Research has shown however that gallium can attack copper over a period of time at high temperatures [1]. The copper must be coated with a suitable resistant material. In this case a Nickel coating was used to prevent embrittlement.

3.3 Cooling Mechanism

The Copper Plate is cooled by the SRS Water Ring Main, which is at approximately 20°C. Copper pipes transporting the water are vacuum brazed into a recess on the rear of the copper plate. To avoid complicating the subsequent thermal analysis an equivalent heat transfer coefficient is derived for the heat transfer between the cooling water carried by the copper pipes and the cooling plate. This value was calculated using the Reynolds, Prandtl and Nusselt Number for the usual operating conditions of 20°C and flow rate of 380 l/hr. On the basis of these figures the equivalent heat transfer was found to be $0.017 W/mm^2/K$.

3.4. Heat Load On The Mirror Face

The heat load is based on 4W/mRad/100mA. For design the aperture has been taken as 5.08mRad and the beam current as 500mA (max.) giving a total Q of 101.46W. The mirror is located 4.489m from the tangent point and at an angle of 30° to the beam therefore the heat load is applied to a narrow band of ±1.12mm x 46.6mm along the horizontal centre line giving a heat load of 2.225W/mm to be applied to the elements.

3.5. Temperature Gradient Across The SLM Mirror Face

The success of the experimental work carried out depends upon the ability of the mirror to deflect light through the correct angle. It is therefore essential to estimate the amount of thermal distortion of the mirror face with the proposed cooling mechanism and materials before continuing with the design. To accurately predict the shape of the mirror face under thermal loading, it was considered necessary to use Finite Element Analysis (FEA).

The 3-Dimensional model was transferred from CADDS5 in the form of an iges file to Rasna Applied Thermal. 3D solid brick and wedge elements were then created (see Figure 3). The heat load is applied to the surfaces of the elements in the narrow band. The elements in this region are much smaller and therefore increase the accuracy of the results in this area. The equivalent heat transfer calculated in 3.3 is then applied to the elements on the rear of the mirror where the recess would lie (shown by the paler elements). Running the analysis gave the following results :-

Maximum Temperature = 62.8°C
Minimum Temperature = 23.7°C

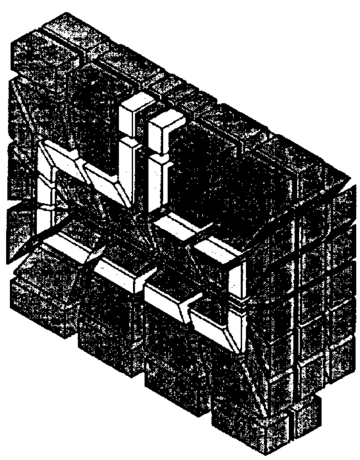


Figure 3. Solid Model Of The SLM Mirror

3.6. Structural Analysis Of The SLM Mirror

The Structural Analysis will determine the distortion of the mirror face and the stresses within the mirror. These occur as a result of the thermal gradient previously obtained. The thermal gradient results are transferred into Rasna Applied Structure as the load for the structural analysis. Structural constraints are now considered, the mirror is prevented from moving freely in all directions by the cooling plate. It is assumed the mirror will slide freely over the gallium and come to rest in one corner of the copper cooling plate one corner of the mirror can be totally constrained in all directions. The spring mounts were sized such that the mirror could expand freely but the corners were kept against the cooling plate at all times, this allowed all the corners to be constrained in at least one direction. Using these loadings and constraints an analysis was run. The maximum stress in the model occurred where the heat load was applied and found to be 18.9N/mm^2. This is an acceptable level for Silicon Carbide.

The distortion of the mirror face along the horizontal axis determines the experiments accuracy, as it causes blurring of the image. The plot below, Figure 4 shows the profile of the mirror face along its horizontal centre-line.

The maximum angular error due to thermal distortion is 9.5 arcsecs in the region of the beam footprint, Figure 5 shows a plot of angular error along the length of the mirror. This results in only a 0.16mm error at the experiment.

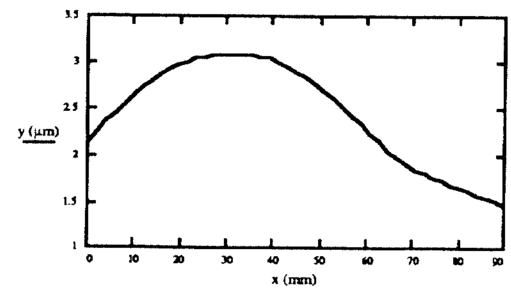


Figure 4. Profile Of Deformed Mirror Face

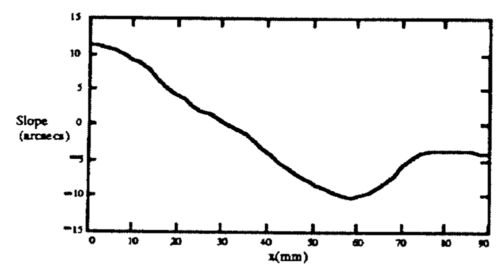


Figure 5. Slope Of Mirror Face

4. CONCLUDING REMARKS

The SLM Mirror Mechanism was manufactured by Vacuum Generators (Telford) and delivered to Daresbury. The movements were confirmed at the Laboratory using a dummy aluminium mirror and a laser. The mirror has now been mounted on to the cooling plate and the mechanism is being prepared for installation in the July 1994 shutdown.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] W.R. Hunter and R.T. Williams, "Grain Boundary Diffusion of Liquid Metal Coolents in Optical Materials for use with High Power Synchrotron Radiation.", Nuclear Instruments and Methods in Physics Research 222, pp. 359-363, 1984.