UNIVERSAL MOUNTABLE HIGH PRECISION ROTARY HEAD FOR MICRO DEGREE METROLOGY*

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Abstract: *Micro Angular measurement tools having the resolution in the range of 10^{-2} arc-second or better is required to calibrate gratings and mirrors at grazing angles (<1°). Such types of mirrors/ gratings are used for laser and synchrotron beam related experiments. With the evolvement of micro machining technique angular positioning tools in the range of 10^{-2} arc-second are also required. The basic tool required to measure such a high accuracy is a rotary table over which other metrological elements can be mounted i.e. laser source or target. Achieving such a high order of resolution is a challenging task. An ultra high precision universally mounted rotary mechanism, with a resolution of 0.02 arc second has been indigenously designed and developed. The total range of movement is ±13°. In this design required resolution has been achieved by indirect drive. This rotary table has two stages of drive. The second stage table is rotated with respect to the rough table. The course stage is directly driven by stepper motor and gives the resolution of 26 arc-second. The fine stage is indirectly driven by a set of lower and higher pair combinations. Both the stages are motorized with feedback arrangement and controlled with a common P.C. based control console. Apart from rotary mechanism, mounting arrangements for laser source or target are also very important and should be of the same order of accuracy. Special type of mounts based on flexural design has also been developed which has four D.O.F. movements. Range of angular adjustment is ±2° with a resolution of 10 arc sec. Laser source or target can be mounted on such a mount for its precise alignment with respect to the axis of rotation of rotary table. All the D.O.F. movements are manually operated.*

Keywords: *Rotary Mechanism, Ultra High precision, Target/Laser Mount, Wavelength Scanning, Backlash Free Control.*

1. INTRODUCTION

A standard rotary table available is driven by a worm and worm gear and the absolute accuracy of the angle is about 0.1 arc-second. However in micro angular measurements rotary stages are required with a resolution of one hundredth of a second or better. To achieve such a high resolution, rotary stage is to be built with an accuracy of two order of magnitude higher i.e. one thousandth of a second. Such a high-resolution rotary motion cannot be achieved by direct mounting the motor and encoder to the rotary table because at present highest value of micro-stepping drive available is 5,00,000. This micro-stepping stepper motor will give the resolution of 0.26 arc sec, which is much higher than the required resolution for micro measurements. Similarly for feedback also very high PPR (pulses per revolution) rotary encoder will be required i.e. $1x10^8$ PPR to meet the required resolution whereas available rotary encoders are of maximum 100,000 PPR. To use 100,000 PPR rotary encoder gear ratio of 1:1000 is to be used in between the table and the stepper motor. Such a high gear ratio will make the rotary table bulky and backlash will also be very high. enough and with slight vibration desired positional accuracy gets disturbed. Here all mounting arrangements should

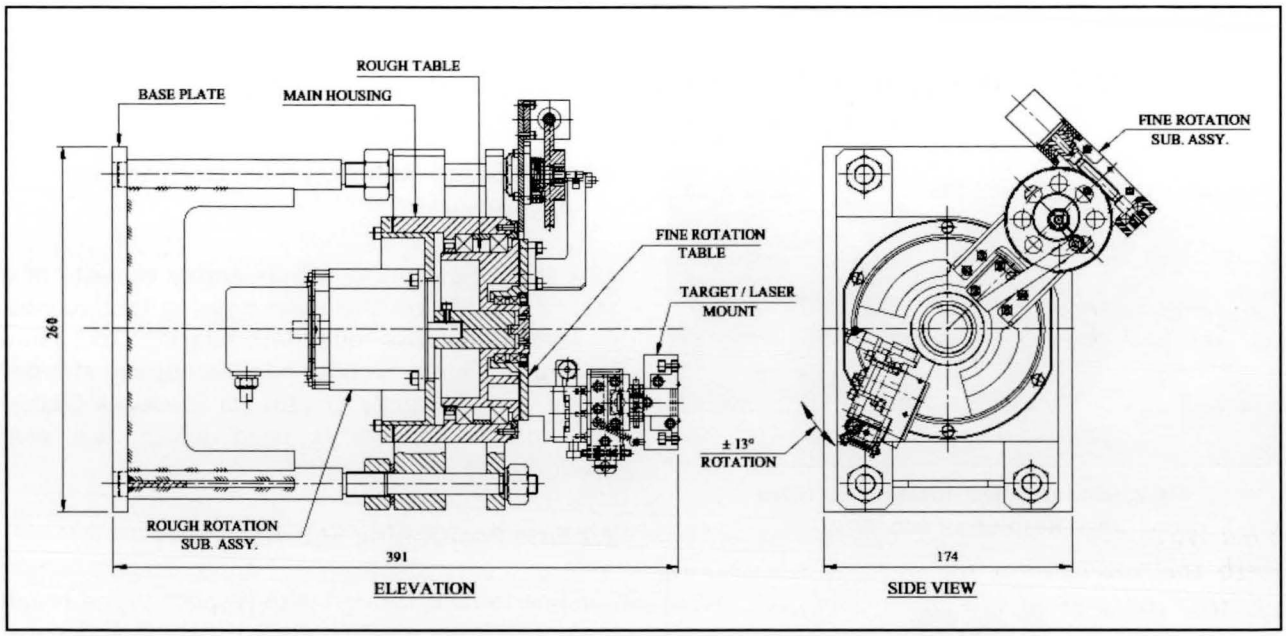
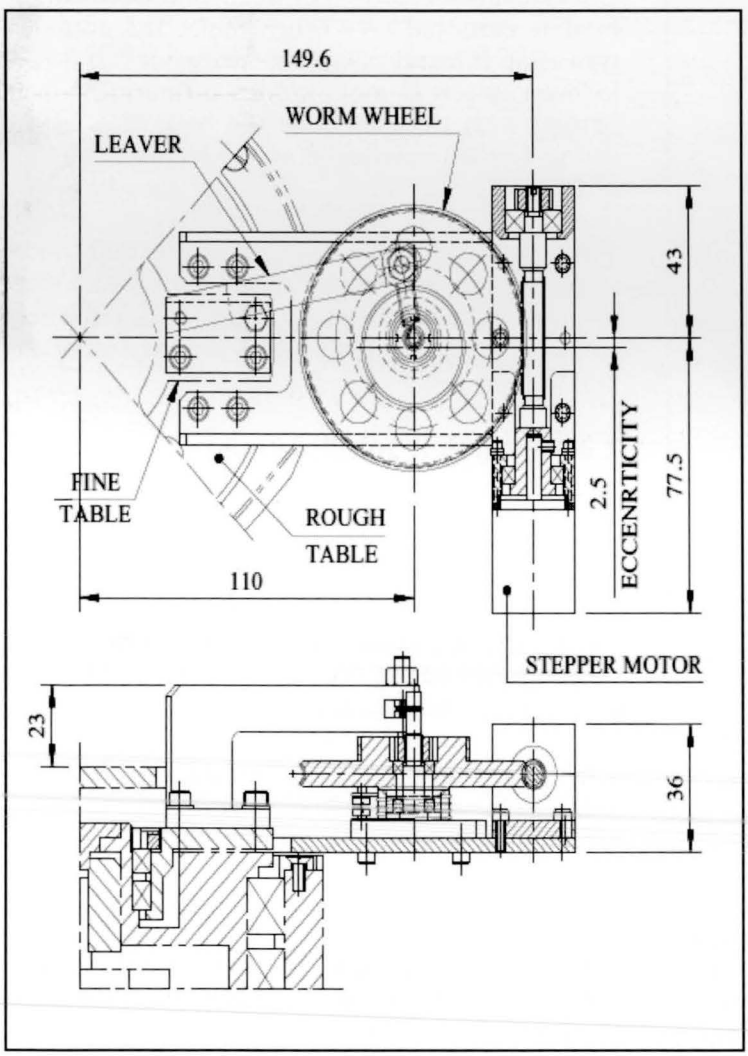


Fig 1. Universal Mountable High Precision Rotary Head



be rigid with fine adjustment facility (manually).

Mounting arrangements are based on flexural design with micro adjustment facility. Range of angular adjustment is $\pm 2^0$ with a resolution of 10 arc sec. Each mount has two such types of unit

In this design required resolution has been achieved by indirect drive. This rotary table has two stage of drive. In first stage 50,000 micro-step stepper motor is directly mounted, which gives 26 arc-sec resolutions. Second stage drive is indirect drive. In indirect drive rotary motion is transferred to the rotary table through an eccentric disc and backlash free worm and worm wheel. Eccentric disc is mounted just above the worm and worm wheel and the eccentricity of the disc pushes the lever of rotary table (Fig. 1).

This design is more precise and compact also, hence this has been adopted for design of ultra high precision rotary mechanism. These high-resolution rotary mechanisms are used to rotate the target or the laser mount, etc.

Mounting arrangement of target / laser is also of very high importance. Standard kinematic mounts available in the market are not of this high order of accuracy

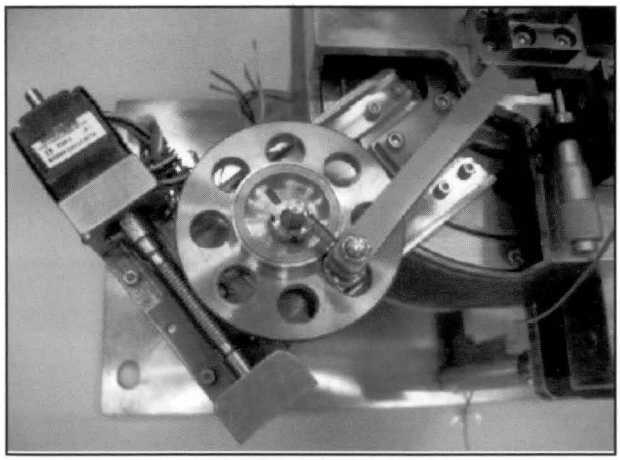


Fig 2. Second Stage Rotation for Ultra High Resolution Sub- Assy

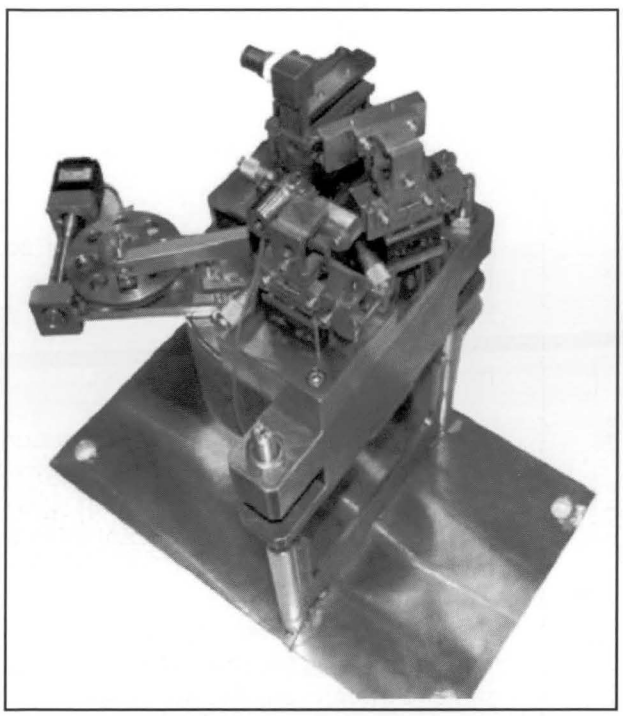


Fig. 3 Assembly with Optical Mounts

which matches with that of rotary stage. Such mounts are also not rigid mounted in perpendicular direction for adjustment in two directions.

2. DESCRIPTION

PC based universally mountable high precision and backlash free rotary head with feedback has been successfully developed to carry out micro degree metrology. The total range of the instrument is $\pm 13^0$. This table consists of following sub-assemblies :

1. First stage (Coarse) rotational mechanism sub-assembly.
2. Fine rotational mechanism sub-assembly.
3. Base mount sub-assembly.
4. Target/Laserl mount sub-assembly

2.1 First Stage Rotational Mechanism Sub-Assembly

First stage positioning sub-assembly consists of a table mounted on the main housing by two nos. of preloaded cross roller THK bearing. This table is coupled with 50,000 micro-stepping stepper motor and is directly driven. For feedback 50,000 PPR rotary encoder is used which will give resolution of 26 arc-second.

2.2 Fine Positioning Sub-Assembly

The fine table is rotated with respect to the rough table. This is done with the help of worm and worm wheel and a cam follower mechanism (Fig. 2).

The mechanism consists of worm and worm wheel module mounted on a rough table. The eccentric cam is an integral part of worm wheel. The cam follower which is mounted on a fine table is in contact with the cam with the help of a tensile spring. The worm wheel is preloaded with the help of a spiral spring and thus eliminating any backlash.

The worm shaft is driven by a 50,000 micro stepping stepper motor. The combined effect of arm length, eccentricity, gear ratio and micro stepping results in nanometer movement of the fine table.

2.3 Base mount Sub-Assembly

The complete assembly is mounted on three numbers of studs mounted on the base plate (Fig. 3). The assembly is self balanced by proper distribution of self weight of different components around the axis of rotation and thus reducing the torque required by the stepper motor of rough positioning sub-assembly.

2.4 Target/Laser Mounts Sub-Assembly

Target/laser is mounted on fine positioning table and will rotate about the central axis of the assembly.

For plane adjustment of Target/Laser, special type of mount has been designed and developed (Fig. 4).

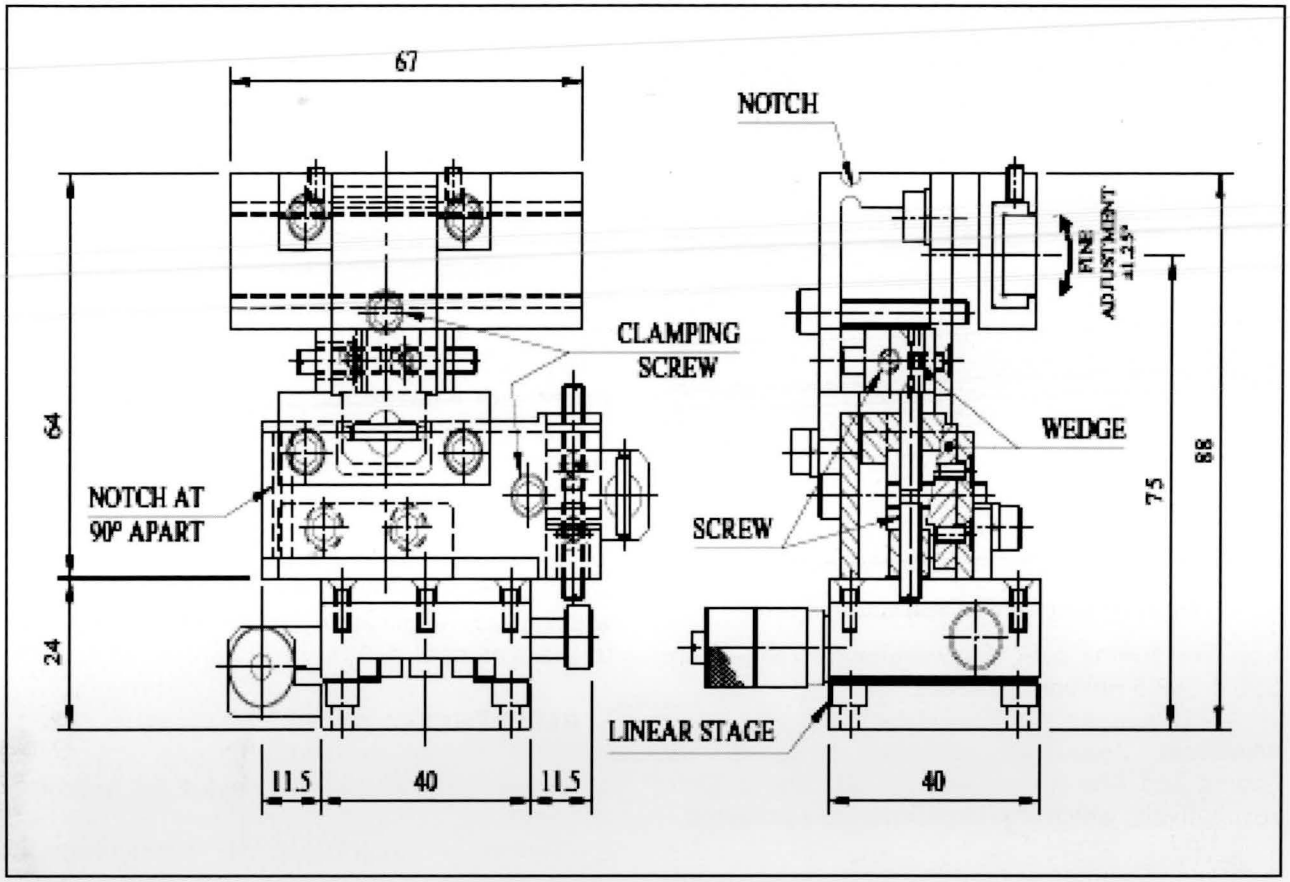


Fig 4. Target/Laser Mount Sub- Assy

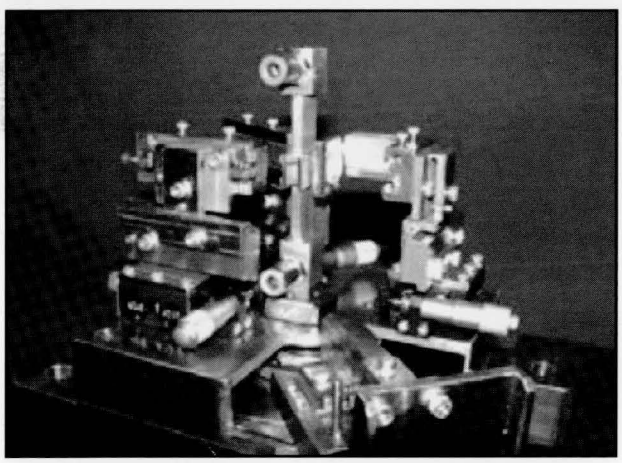


Fig 5. Testing Arrangement with Optical Cavity

Notch is provided in a U-plate. The notch will act as a hinge. One link of the plate is clamped while the other link is rotated with the help of wedge mechanism with respect to the clamped link. One more U-plate with notch will be clamped to the first U-plate in 90^0 position to give motion in other direction. The wedge mechanism helps in precise manual positioning of the Target/Laser. With the help of these two motions plane of Target/Laser source can be aligned w.r.t. the axis of rotation. With this arrangement

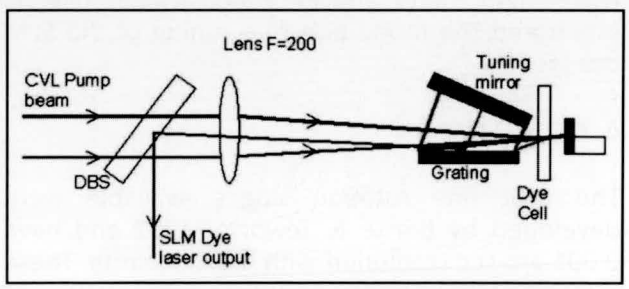


Fig 6. Schematic of SLM GIG Dye Laser Arrangement for Testing Rotary Head

$\pm 2^0$ alignments can be achieved. Once the Target/Laser is positioned, mechanism will be clamped by locking screw and thus making it a rigid member.

3. RESOLUTION TEST AND VALIDATION

Rotary head has been successfully developed and design / technology is validated by demonstrating it in tunable SLM dye lasers in grazing incidence grating (GIG) configuration in our lab at BARC.

Using this technique of rotational mechanism and arrangement of tuning mirror, grating and end mirror in a GIG configuration (Fig. 5 & Fig. 6), mode

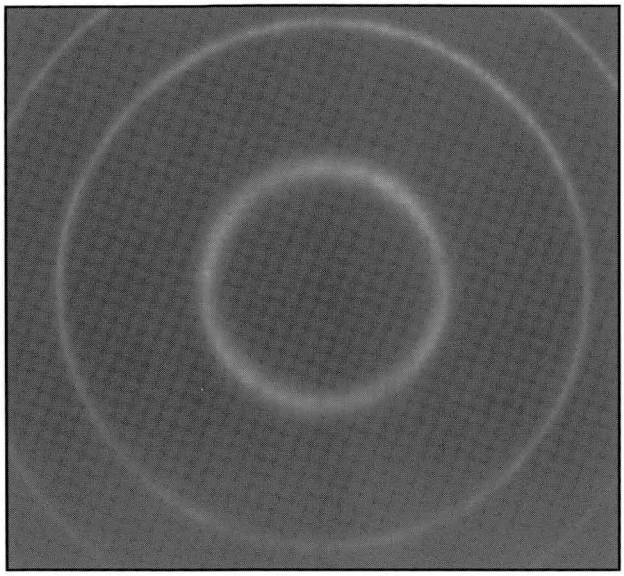


Fig 7. FP Spectrum of SLM GIG Dye Laser

hop free tuning over the wavelength range from 556.4-568.5 nm was achieved.

Minimum frequency change designed for coarse and fine tuning was 39 GHz and 3 MHz, respectively, which was experimentally validated.

Minimum frequency change of 3 MHz corresponds to ~0.02 arc-second in angular terms. Laser wavelength meter and FP etalon fringes (Fig. 7) monitored the mode hop free tuning of the SLM dye laser.

4. CONCLUSION

The best fine rotation stages available were developed by Bonse & Teworte, 1982 and have 0.001 arc-sec resolution with 0.1% linearity. These rotary mechanism were large and heavy and total range of movement is only 2.8^0. Another compact high resolution stage developed by P. Suortti, J. Keyrilainen and M. Fernandez. (J. Applied Crystallography, 2004, 37. 62-66.) has total range of 2 arc-sec with resolution of 0.1 arc-sec and to be used with standard goniometers to increase the range. This unit can not be mounted in vertical or upside down position.

The developed 'Universal Mountable High Precision Rotary Head For Micro Degree Metrology' is successfully tested for its range and resolution in a Single Longitudinal Mode dye laser configuration (Fig. 6) and measuring the minimum wavelength shift by rotating the mechanism by its least count. The shift in wavelength is measured on a wavelength meter. The unit is very compact and can be mounted in any position. The total range of movement is $\pm 13^0$ with a resolution of 0.02 arc second. 12 nos. of such units are successfully installed for generation of single longitudinal mode dye laser at BARC, Mumbai. The mechanism has widespread application from micro-metrology to spectroscopy.

5. REFERENCES

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"If a measurement matters at all, it is because it must have some conceivable effect on decisions and behaviour. If we can't identify a decision that could be affected by a proposed measurement and how it could change those decisions, then the measurement simply has no value"

— Douglas W. Hubbard, How to Measure Anything: Finding the Value of "Intangibles" in Business