## L.5: Simple technique for estimation of groove density of gratings and inter-grating groove errors

Estimating absolute groove density of grating and inter-grating groove density errors with sub ppm level is desirable both for their characterization and applications such as single or multiple gratings based laser pulse compression, wherein compressed pulse beam fidelity is eventually dictated by the inter- and intra- groove density errors. Since groove density of gratings may deviate from required values due to various reasons, e.g., gratings from two different manufacturers fabricated under different conditions, small deviation in grating groove density may result deviation in expected compressed pulse parameters. Simple indirect techniques have been developed at Advanced Lasers and Optics Division for the estimation of the groove density and inter-grating groove density error. These are easily accessible for larger sizes while being less complicated and low cost compared to direct imaging techniques. Grating groove density (N) is estimated indirectly by measuring angle of diffraction using standard grating equation $N=2\lambda^{-1}\sin\alpha$ at Littrow configuration and inter-grating groove density error ($N_1$-$N_2$) is estimated from measured differential of diffraction angle for grating pair kept side by side for known wavelength of laser source. While estimating inter-grating groove density errors with mentioned accuracies is relatively a simpler task, determining absolute groove densities with sub ppm level remain a challenging task in standard laboratory conditions in absence of a calibrated standard grating.

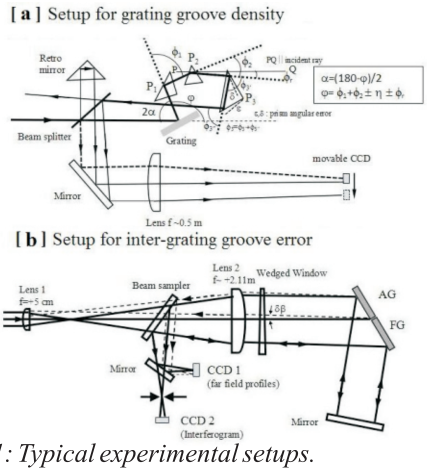


*Fig. L.5.1: Typical experimental setups.*

Simple optical setups with no movable parts, as shown in Figure L.5.1, have been proposed for estimation of absolute groove density and inter-grating groove density errors. Error in measuring larger angles with desired accuracies is minimized by transforming larger angles to smaller ones using set of prisms and intercepting reference and diffracted/ reflected beams on to a single detector to achieve single shot measurement without use of any rotational stage (Figure L.5.1(a)). Angle of diffraction is measured from pre-estimated values of fixed beam rotation and measured value of residual beam angle using equation given in inset of the Figure L.5.1(a).

Differential of diffraction angle ($\Delta\beta=\beta_1$-$\beta_2$) is measured at Littrow configuration under condition that differential angle of incidence ($\Delta\alpha=\alpha_1$-$\alpha_2$) is nearly zero i.e., within few µrad to achieve estimation of groove density errors at ppm level, using setup shown in Figure L.5.1(b). Such an accuracy is achieved by estimating peak locations of the focal spots of the reflected and diffracted beams using slight tip angle between two gratings of tiled grating assembly to avoid piston or tilt like errors in other wise overlapped focal spots and to achieve accuracies below Rayleigh limit dictated by natural beam divergence.

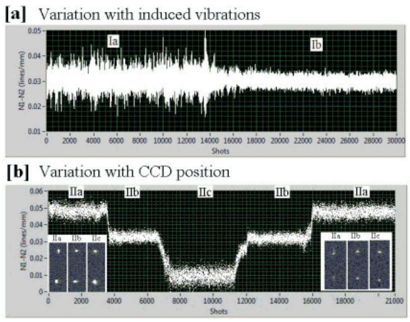


*Fig. L.5.2: Variation in estimation of grating groove error.*

Various gratings from different manufacturers were examined using a standard commercial He-Ne laser operating at wavelength of 632.8 nm. From different measurements carried out independently, groove density of grating #1 is estimated to be 1740 ± 0.23 lines $mm^{-1}$. Inter-grating groove density errors using optical setup shown in Figure L.5.1(b), between gratings #1 and #2, gratings #3 and #4, and grating #2 and #3 is estimated to be around 0.03 lines $mm^{-1}$, 0.41 lines $mm^{-1}$, and 3.58 lines $mm^{-1}$, respectively with typical detector limited accuracy below ±0.005 lines $mm^{-1}$ (~3 ppm at groove density of 1740 lines $mm^{-1}$). Repeatability and reliability study was done for measurement of inter-grating groove density errors under different laboratory environments. It may be noted from Figure L.5.2(a) that inter-grating groove density error is below 0.02 lines $mm^{-1}$ and 0.01 lines $mm^{-1}$ for enhanced and reduced beam pointing owing to induced mechanical vibrations by switching laboratory air conditioners on and off, respectively. CCD detector position may also affect estimation of differential of diffraction angle and hence inter-grating groove density error as depicted in Figure L.5.2(b) (diffraction spots are shown to be separated in inset) with repeatability ensured to be within 0.02 lines $mm^{-1}$.

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