Pulse compression using segmented grating in Gekko MII system, ILE

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Abstract. A segmented (tiled) grating array is now investigated as a new compressor system for the reason of manufacturing cost of large aperture single grating. However, the considerable freedom of motion of segment arises new difficulties on pulse compression and focusing. We constructed a real compressor system using a segmented grating for 15cm aperture laser beam at Gekko MII 100TW laser system, ILE, for investigating several alignment techniques. In order to produce clean pulse shape and focused pattern generated by misalignments or line density mismatching between segment gratings, we applied the image rotation technique as a compressor arrangement. In addition to reduce uncertainness of motion of all optics, we introduced several sensor/detector such as laser level meter or position sensor. It is also shown that a capacitance detector can keep the perfect flatness of segmented grating surface. Using these techniques we demonstrated pulse compression close to Fourier transform limit.

1. Introduction
As a new generation CPA PW laser system, a segmented (tiled) grating array is being investigated in a compressor system to reduce the manufacturing cost of large aperture single grating. However, the segmented grating has a considerable freedom of motion, which gives new difficulties on pulse compression and laser focusing. For example, a slight piston error among gratings could make interference in pulse shape as well as near field and focused pattern. In addition, a humble mismatch of line densities leads to separation of focal pattern in many spots \cite{1} as well as the separation due to tilt or piston error among gratings.

In order to avoid such misalignment, several techniques have been proposed to adjust segmentation using interference measurement \cite{2,3}. The image rotation \cite{1,4} is a powerful method to naturally compensate the line density mismatching and piston/translation error when only two gratings are used as segmented grating. Under these fundamental techniques, we built an actual compressor system in Gekko MII (GMII) 100TW laser system at Institute of Laser Engineering (ILE), Osaka University.
The pulse width after the pulse compression is stably achieved about 1.4 times of transform limit as in section 3. Also several alignment techniques we used are fully discussed in the next section.

2. Compressor alignment
The GMII system is a high energy CPA glass laser system, which consists pulse stretcher, phase adjuster (mini-compressor), OPCPA pre-amplifier, main glass amplifier, and large compressor. The system is designed to provide laser energy up to 100J with 500fs pulse duration, corresponding to peak power of 100TW on target.

Four dielectric gratings (HORIBA Jobin-Yvon), each size of 20cm in height and 41cm in width, are newly installed. The groove density is 1740/mm. The measured diffraction efficiency and surface deformation at Littrow angle is almost 95% and 0.1λ for 1µm light. We set a segment as a second and third grating on double-pass compressor arrangement. In order to apply image rotation technique for the segmented grating, we choose “V-shape” geometry as shown in Fig 1. In this section, we explain the detail of compressor geometry and several alignment methods including initial and iterative procedure.

2.1. Compressor Geometry
Figure 1 shows the overview of the compressor chamber. The first grating pair consists grating 1 (G1) and segmented grating (G2 and G3). The incoming pulse is incident on G1 with 72.5° and distance between this pair is 1.35m. The pulse diffracted from the segments is inverted in horizontal image via reflection at M2 and M3, and then goes into second grating pair (G3-G2 and G4) with same incident angle and distance.

![Figure 1 Schematic view of compression chamber. The laser pulse travels in turn of mirror 1 (M1), grating 1 (G1), G2G3 segment, M2, M3, G3G2, G4, M4, M5, and M6.](image)

After pulse compression the laser pulse is delivered to interaction chamber via M4, M5 and M6. A slight transmitted light at M4 is detected to monitor the pulse shape with auto-correlator, prepulse level with pin-photo diode, far-field pattern with CCD, and so on.

2.2. Alignment methods
Considering a diffraction limit of focused pattern, the horizontal tilt error between two gratings of segment should be less than 10µrad to keep a single spot. On the other hand, requirements for piston and vertical tilt error are not so severe due to the automatic compensation by image rotation technique, where the light diffracted at one grating surely goes on another grating after image rotation. The alignment accuracy for the pulse compression is about ten times looser than that from focusing. From these points of view, we only need to take grateful care to keep horizontal parallelization among all gratings in this compressor geometry. We used two techniques for initial setup and other two for main alignment methods.
2.2.1. Initial setup

It is quite difficult for a single laser beam to adjust vertical tilting for all optical components in compressor because of the difficulty of identification of parallelization among every incident and reflected/diffracted beams. For simplicity of vertical alignment, we introduced a laser level meter (TAJIMA TOOL, BL10T-KJC), which can emit line focused laser light for 360 degree in horizontal direction and 280 degree in two orthogonal vertical directions at the same time. The level accuracy is about 0.1mrad for each direction and orthogonal accuracy is about 90°±0.012°. We aligned the vertical tilt by wrapping over the reflected line from some optical component to the line from the level meter quite easily.

In addition, a 2-dimensional position sensor (Keyence, LJG sensor) is used to define an initial surface flatness of segmented grating in piston direction. This sensor can detect the surface shape over 3cm long in horizontal direction with 1 µm accuracy, so that we applied this sensor crossing the gap between segmented gratings in several vertical points, resulting in achievement of less than 1µm surface flatness by combining an interference adjustment for horizontal tilt same as described below.

2.2.2. Main alignment methods

Once the compressor is set up, the chamber is kept in vacuum for a long time to avoid accidental moving of optics during evacuation and leak. For this purpose, we set a motion sensor in vacuum chamber after an initial alignment of compressor system is completed. The procedure of initial adjustment for horizontal tilting we carried out is mainly interference measurement between each two grating to be a single spot on the far-field pattern, based on a technique described in ref 2 and 3. As a motion sensor, three capacitance detectors are used to measure the distance between the sensor and metal frame of grating holder in order to detect tilt and piston motions. The sensor has a 1 nm resolution with 100 µm of detectable range. In order to check the stability, we performed a test experiment for measuring a temporal displacement of two gratings using one sensor. Fig. 2 shows the output signal corresponding to the distance with time as well as the far field patterns by reflected He-Ne laser over the segment gap (inset).

![Figure 2](image)

Figure 2 Temporal evolution of displacement of one motion sensor. The far field pattern in several timing is also inset.

The measurement was started after the initial surface adjustment by interference technique. About 60 minutes later, the far field pattern breaks into two spots due to thermal motion of the grating holder. At 60 min., we re-adjusted the surface flatness again, and then start to keep the displacement becomes within 50 nm by moving actuators of one grating of segment over 70 minutes. As the results, the output signal ranged between 250 to 200nm as in this graph and the far field patterns were successfully kept a single spot. After that, we stopped to move the grating and then the focused pattern gradually separated into two spots again. From this result, we made a feedback control of grating to keep the displacement within 50 nm for each axis.
3. Pulse compression
We have demonstrated the pulse compression using a low-energy (1mJ) and small-aperture (1cm) beam. The spectral width of this pulse has about 10 nm (FWHM) whereas the width of amplified pulse is expected to be 4 nm due to gain narrowing in glass amplifier. The compressed pulse width is measured with a second order single-shot auto-correlator. Left graph in Figure 3 shows the typical single shot pulse shape detected with the auto-correlator. The pulse width is 290 fs, which is about 1.4 times of transform limit of 10 nm Gaussian pulse. The spectral shape of pulse amplified in our OPCPA system is far from Gaussian, so that this pulse width is reasonable from Fourier transform of the experimental spectral shape.

In order to check the level of pre- or post-pulse in the detectable range of auto-correlator (10ps), we accumulate 25 shots as shown in right graph in Fig. 3. The peak intensity shows saturation after 10 shots accumulation. There are side peaks at about 1 ps before and after the main pulse, both of which contrast ratio are about $10^{-3}$ and the pedestal shelf gradually decreases. These side pulses may be caused by spectral clipping at the segment gap because of comparable small beam size to the gap. The pre-pulse contrast and decrease of shelf agree with the calculation including clipping effect.

4. Summary
We constructed a real compressor system using a segmented grating for 15cm aperture laser beam at Gekko MII 100TW laser system by investigating several alignment techniques. In order to produce clean pulse shape and focused pattern generated by misalignments or line densities mismatching between segments, we applied the image rotation technique as a compressor arrangement. In addition to reduce uncertainty of motion of all optics, we introduced several sensor/detector such as laser level meter or position sensor. It is also shown that a capacitance detector can keep the perfect flatness of segmented grating surface. Using these techniques we demonstrated pulse compression close to Fourier transform limit.

References
[1] M. C. Rushford et al., submitted in Opt. Lett. (2007).
[2] J. Bunkenburg, T. J. Kessler, W. Skulski, H. Huang, Opt. Lett. 31 (2006) 1561.
[3] L. Zeng and L. Li, Opt. Lett. 31 (2006) 152.
   Y. Hu, L. Zeng, and L. Li, Opt. Commun 269 (2007) 285.
[4] M. C. Rushford et al., Opt. Lett. 31 (2006) 155.
[5] G. Xu et al., submitted in Opt. Lett. (2007).