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Wavefront Measurement in the "Shenguang-II" Facility

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The "Shenguang-II" Facility laser uses a 8-beam multi-pass architecture capable of delivering several KJ of infrared or ultraviolet energy in a temporal pulse format of an approximately 1ns quasi-square. Ideally each beam wavefront output from the main spatial filter should be a plane wave. But a real output wavefront of the beam with a 200mm section diameter in our facility always has a curvature radius. To meet the requirements of enhancing the conversion efficiency of KDP, each beam wavefront output from the main spatial filter should resemble a plane wave as possibly as it can. In another word, the curvature radius of each beam wavefront should be as large as possible. We have measured the curvature radiuses of 8 beam wavefronts using Hartmann method and have acquired much better frequency conversion efficiencies by correcting each wavefront according to the measurement results.

A flat board with a 15X15 aperture array and a piece of laser-sensitive paper, with a 20m distance between them, are used as a Hartmann sensor to measure the output wavefront in each beam. The aperture array in the flat board is devised with high precision: the distance between two neighboring 5mm-diameter aperture centers is 15mm with an error less than 20 microns. The diameter of the laser beam in the measurement position is 200mm. After a laser shot, an spot array image is obtained on the laser-sensitive paper. A reading microscope or a profile meter is used to measure the distance between two neighboring spot centers in the image. The center distance offset from apertures to image spots is used to calculate the output wavefront's curvature radius, which the wavefront control system uses to correct the output wavefront. Each step in the whole measurement, from designing to manufacturing and to field measurement, has been done with stringent accuracy and high precision in order to procure better results. Consequently, we have achieved improved output wavefronts with curvature radius more than 3000m under present conditions.

In the future, we plan to install an Adaptive Optics wavefront control system in the 9th beam of the upgraded "Shenguang-II" Facility to control the output wavefront dynamically in a close loop. In this system, a Hartmann sensor with a lenslet array will measure output wavefront aberrations. The data from Hartmann sensor are used to control a deformable mirror to correct these wavefront aberrations. We predict that with the wavefront control system the upgraded "Shenguang-II" will meet its required nearfield and farfield beam characteristics.

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ABSTRACT

The "Shenguang-II" Facility laser uses an 8-beam double-pass architecture capable of delivering several KJ of infrared or ultraviolet energy in a temporal pulse format of an approximately 1ns quasi-square. Ideally the output wavefront of each beam from the main spatial filter should be a plane wave. But a real output wavefront of the laser light beam with a 200 mm section diameter in our facility is always a complex superimposed one. On its cross section, it has a distribution of curvature radius, which is called "local curvature radius" here. But the quality level of the output wavefront is mainly marked by its "global curvature radius", which is an assessing result based on the local ones. To meet the requirements of enhancing the conversion efficiency of the KDP crystal, each beam of wavefront out of the main spatial filter should resemble a plane wave as possibly as it can. Because only in this way can we achieve an optimal match between the injection direction of the laser beam and the functioning angle of the KDP crystal. In another word, the global curvature radius of each beam wavefront should be as large as possible. We have assessed the global curvature radiuses of eight beams of wavefronts by measuring their local curvature radiuses using Hartmann method. Finally, we have acquired better frequency conversion efficiencies by correcting each output wavefront to a better level according to the measurement results.

Keywords: wavefront, measurement, Hartmann method, curvature radius

1. INTRODUCTION

It is well known that theoretically rays of light which come from the focal point of a converging lens and which pass through the lens are converted into parallel rays, as shown in Figure 1. Parallel rays mean a beam of light that has a plane wavefront. In actuality, unfortunately, we can never obtain a real plane wavefront. There are several reasons. Firstly, we are unable to ensure that rays of light that pass through the lens are all exactly emitted from the lens' focal point. Because a real light source, which always has a size, can never be a perfect point. Secondly, the lens inevitably has some blemishes or defects and is not perfect either. So even if we could get a real point light source at the focal point of the converging lens, the output wavefront from an imperfect lens would still not be a plane wavefront. Thirdly, the medium in which the light transmits is not perfect vacuum. There are air currents, turbulence, floating dust in the medium. In a word, we will be unable to obtain a true plane wavefront unless all the three conditions above are all met, which include a real point light source at the focal point, a perfect converging lens, and perfect transmission medium.

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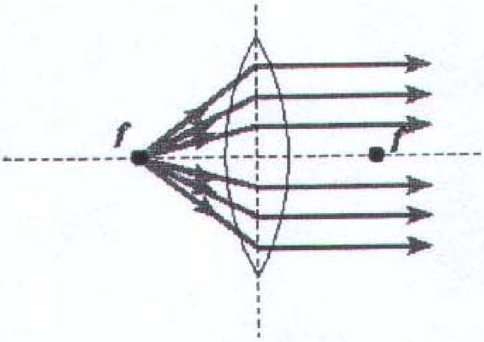

Figure 1: Rays of light emitted from the focal point of a converging lens are converted into parallel rays

Furthermore, to get an output plane wavefront from a simple light source by using a converging lens is a matter, but to obtain an output plane wavefront from a large laser facility is another matter. The laser light in a large laser facility has its own special characteristics. First, a laser light pulse is generated from a comparably small front laser, whose wavefront normally has a regular shape. Then it is amplified through several separated amplifiers and the main amplifier. During the whole process it needs to transmit through a series of optics, such as splitters, wave-shaping units, spatial filters,etc. Therefore, thc final output wavefront is neither a simple plane wavefront nor a simple spherical wavefront, but a complex superimposed wavefront. Observing it through a nearfield analyzer, we can perceive that the output wavefront is basically a quasi plane wavefront superimposed by a series of aberrations. Here, the curvature radius of the quasi plane is called its "global curvature radius". Due to the distribution of the aberrations on the cross section, there is also a distribution of curvature radius there, which is called "local curvature radius" here, especially for a laser light beam with a large section diameter. The larger the wavefront's global curvature radius is, the more similar to a plane wavefront the wavefront is.

The "Shenguang-II" Facility laser uses an 8-beam double-pass architecture capable of delivering several KJ of infrared or ultraviolet energy in a temporal pulse format of an approximately 1ns quasi-square[1~3]. In the optical chain of the facility (Figure 2) there are several spatial filters, each of which is a compound architecture mainly composed of double converging lenses. Among these spatial filters, the main spatial filter, which locates behind the main amplifier, influences the output wavefront most. As we have mentioned above, Ideally the output wavefront of each beam from the main spatial filter should be a plane wave. But a real output wavefront of the laser light beam with a 200mm section diameter in our facility is basically a quasi plane wavefront superimposed by a series of aberrations. On its cross section, it has a distribution of "local curvature radius". But the quality level of the output wavefront is mainly marked by its "global curvature radius", which is the curvature radius of the quasi plane. For simplicity, we will choose the median value of all the local curvature radiuses at a certain beam as its global curvature radius. To meet the requirements of enhancing the conversion efficiency of the KDP crystal, each beam of wavefront out of the main spatial filter should resemble a plane wave as possibly as it can. Because only in this way will we achieve an optimal match between the injection direction of the laser beam and the functioning angle of the KDP crystal. In another word, the global curvature radius of each beam wavefront should be as large as possible. We have assessed the global curvature radiuses of eight beams of wavefronts by measuring their local curvature radiuses using Hartmann method. In the end, we have acquired better frequency conversion efficiencies by improving each output wavefront to a better level according to the measurement results.

2. METHODOLOGY

Figure 2 shows the laser's optical layout[1~3] that this measurement involves, from the main amplifier to the KDP crystal. In fact, there is an additional splitter at the focus. The laser light beam, whose direction is perpendicular to the paper plane, first arrive at the splitter and is reflected by the splitter. A part of the light beam rotates its transmission direction 90 degrees and passes through the lens L1 and the main amplifier. After it is reflected by the mirror, it returns and repasses the main amplifier, the lens L1, and the splitter. That is why the facility is called a double-pass architecture.Then the light beam passes the lens L2, and passes the Hartmann board, and finally gets to the image paper. Each of these optics and other optics unshown here, as long as which is prior to the image paper, will contribute wavefront errors. Additionally, since the section diameter of the output beam from the main spatial filter is 200 mm, such a large one, there will be a distribution of wavefront errors on the cross section. Accordingly, we will measure the wavefront's local curvature radiuses at four different locations on the cross section: the top, the bottom, the left, and the right.

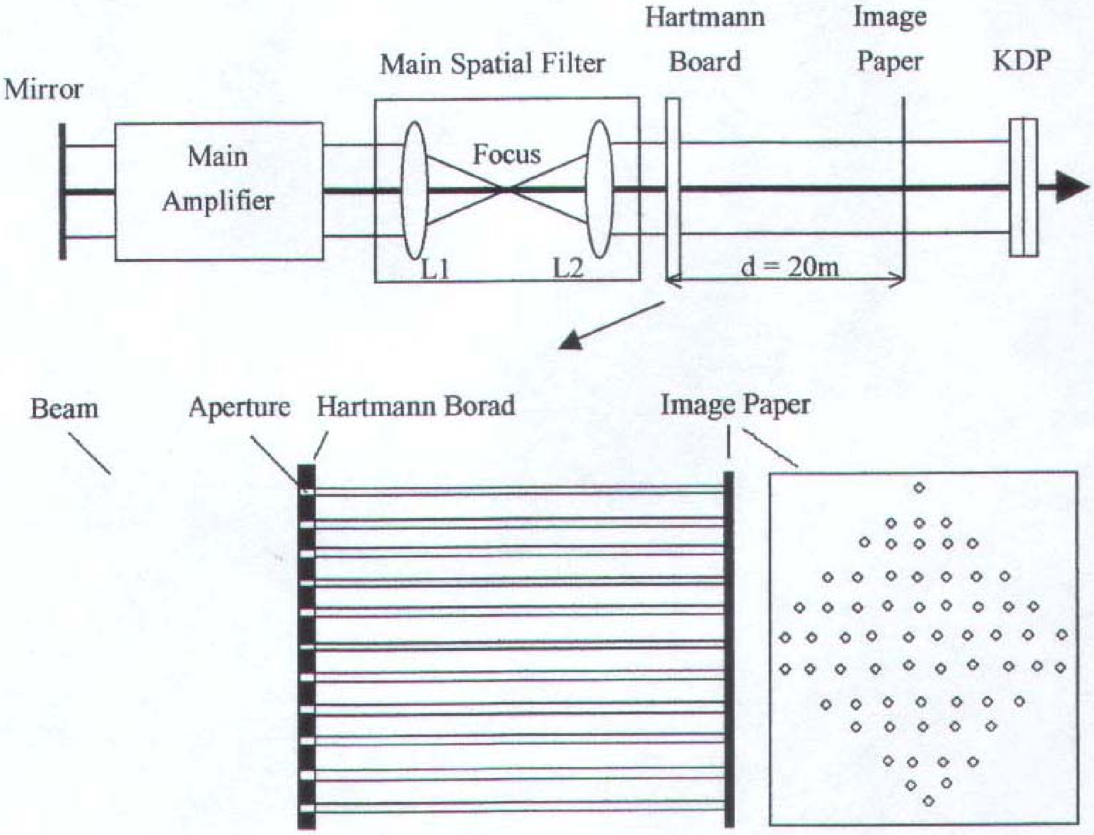

Figure 2: The "Shenguang-II" Facility laser's optical chain layout from the main amplifier to the KDP crystal, showing Hartmann board location and image paper location

A typical Hartmann method involves basic devices such as a Hartmann sensor and a CCD. Normally the Hartmann sensor is mainly composed of a lenslet array, which is used to receive the light beam and to transform the light beam into an array of light signals. The CCD is used to receive the array of light signals and to store the position information of each light signal. Owing to the large beam diameter, it is hard to find a suitable Hartmann sensor and a proper CCD to directly measure the output wavefront. Therefore, we have to replace it with a Hartmann board and an image paper. The Hartmann board is a flat iron board with a 15X15 aperture array. The aperture array in the flat board is devised with high precision: the distance between two neighboring 5mm-diameter aperture centers is 15 mm with an error less than 20 micron. The image paper is a piece of paper with a coat of laser-sensitive material on its one surface. As shown in Figure 2, the Hartmann board is placed closely behind the main spatial filter. The image paper is placed 20 m behind the Hartmann board. Both the Hartmann board and the image paper are perpendicular to the light beam and are finely collimated in the optical chain.

After a laser shot, an image of a spot array is obtained on the image paper. A reading microscope or a profile meter is used to read the distance between two neighboring spot centers in the image. The reading microscope we use is a 50 mm JXD-2 one manufactured by Changchun No.3 Optical Instrument Factory. The profile meter we use is a 98-J one manufactured by Shanghai Optical Instrument Factory, whose best precision is 1 micron. The center distance offset from apertures to image spots is used to calculate the output wavefront's curvature radius through the following formula:

$$r = dh'/(h'-h)$$

where d is the distance between the Hartmann board and the image paper, h is the distance between two neighboring aperture centers, h' is the distance between two neighboring spot centers, and r is the curvature radius of the output wavefront. To guarantee the measurement precision, the distance between two aperture centers is measured through a JXD-2 reading microscope, the precision of which is 0.01 mm. The average of the measurement results is 14.980 mm, which is used as the value of h. Figure 3 shows the geometric principle of this calculation. Here it shoud be noted that approximation has been taken in the calculation: because r is far larger than h or h', we take it as a condition that CP_i is approximately perpendicular to P_hP_h' at P_h and to P_iP_i' at P_i.

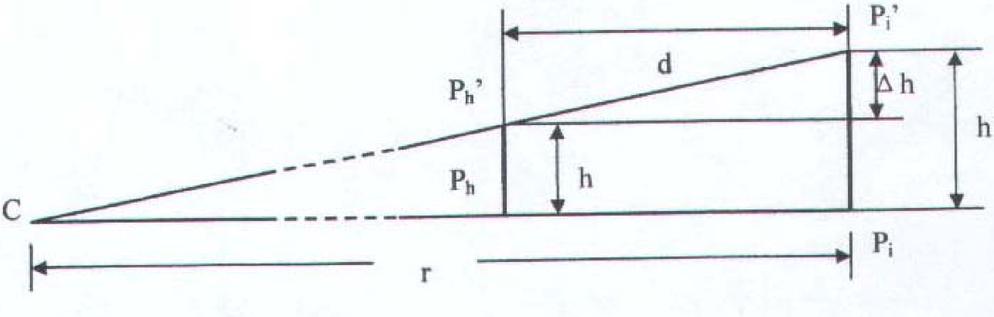

Figure 3 The geometric principle of the calculation of the curvature radius

3. RESULTS

Each step in the whole process of the measurement, from designing to manufacturing and to field measurement, has been done with stringent accuracy and high precision in order to get better results. All eight beams have been measured before correcting. Typical measurement results of eight beams are shown in Table 1. As mentioned above, due to a large beam diameter, there is a distribution of curvature radius on the cross section. Therefore, it is natural that the curvature radius of a certain beam might be positive at one point on the wavefront but negative at another. But a certain sign should dominate among the mutiple measurements of the same wavefront, which is the sign of the global curvature radius.

Table 1: The measurement results of eight beams before correcting

BEAM	h' (mm)	r (m)	BEAM	h' (mm)	r (m)
1	15.108	2360	5	15.030	6012
	15.032	5781		15.106	2397
	15.167	1622		15.160	1684
	15.122	2129		15.102	2475
2	15.145	1835	6	15.105	2416
	14.932	-6221		14.922	-5145
	14.868	-2655		14.878	-2917
	14.887	-3201		14.867	-2631
3	14.910	-4260	7	14.905	-3974
	14.907	-4084		14.902	-3821
	14.935	-6637		14.915	-4589
	14.955	-11964		14.945	-8540
4	14.929	-5854	8	14.949	-9644
	14.930	-5972		14.910	-4260
	14.935	-6637		14.907	-4084
	14.927	-5632		14.917	-4735
d = 20m, h = 4.980mm					

Among the results of the eight beams, we can see that half of the beams have a low quality level of wavefront. Their global curvature radiuses are between 2000 m and 3000 m. Other beams have comparably better wavefronts, whose global curvature radiuses are between 4000 m and 6000 m. All these optical chains are corrected. There are several measures we can use to correct the output wavefront, such as improving the input wavefront, adjusting the main spatial filter, or tuning other small spatial filters. The specific method here we have taken to correct the output wavefront's curvature radius is to finely adjust the position of the lenses in the main spatial filter behind the main amplifier. After correcting, the output wavefront's curvature radiuses of eight beams are measured again. Typical results are shown in Table 2.

Contrasting Table 2 with Table 1, we can see that the global curvature radius of every beam, except beam 3, has a notable increase. The effect of the correction is shown in Table 3. In the end, including all 8 beams, we have achieved improved output wavefronts with global curvature radiuses at least more than 5000 m under present conditions. In consequence of the improvements of the output wavefronts, the frequency conversion efficiencies of KDP have been increased remarkably.

Table 2: The measurement results of eight beams after correcting

BEAM	h' (mm)	r (m)	BEAM	h' (mm)	r (m)
1	15.063	3629	5	15.001	14286
	15.012	9382		14.965	-19953
	14.983	99886		14.985	59940
	14.990	29980		14.988	37470
2	14.915	-4589	6	15.012	9382
	14.963	-17603		15.002	13638
	14.948	-9342		15.008	10720
	14.940	-7470		15.007	11116
3	14.913	-4451	7	15.025	6677
	14.932	-6221		14.998	16664
	14.900	-3725		14.982	149820
	14.937	-6947		14.977	-99846
4	14.993	23066	8	14.963	-17603
	15.002	13638		15.007	11116
	15.002	13638		14.998	16664
	15.062	3673		14.993	23066
d = 20m, h =14.980mm					

Table 3: The effect of the correction

BEAM	1	2	3	4	5	6	7	8
Before correction	2245	-2928	-5449	-5913	2436	-2774	-3898	-4498
After correction	19681	-8406	-5336	13638	25878	10918	11671	13890

4. CONCLUSIONS

A good output wavefront of the laser beam is one of the important characteristics that contribute high-quality shot in the “Shenguang-II” Facility laser, especially for the Inertial Confinement Fusion experiments. First, better output wavefront can help realize higher KDP’s frequency conversion efficiencies. Second, a spatially symmetric compression of the target nucleus will not be achieved without good output wavefronts of the beams. Here we have measured the output wavefronts’ curvature radiuses of 8 beams in the “Shenguang-II” Facility in order to correct them to a better level.

Though we have obtained distinct improvements, it is hard to further increase the measurement precision and to achieve better correction effects using this method under present circumstances. In addition, the aberrations of the output wavefront are sufficiently severe that the upgraded "Shenguang-II" Facility must develop finer wavefront correction in order to fulfill its design requirements.

In the future, we plan to install an Adaptive Optics wavefront control system in the 9th beam of the upgraded "Shenguang-II" Facility to control the output wavefront dynamically in a close loop. In this system, a Hartmann sensor with a lenslet array will be used to measure output wavefront aberrations. The data from Hartmann sensor are used to control a deformable mirror to correct these wavefront aberrations[4]. We predict that with the wavefront control system deployed, the upgraded "Shenguang-II" will meet its required nearfield and farfield beam characteristics.

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