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DESIGN OF A CCD-BASED LASER ALIGNMENT DETECTION SYSTEM*

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Abstract

Accelerator online alignment technology is an important means for accelerator stability detecting. A CCD-based laser alignment detection system is designed for the linear accelerator, and the detection distance of the system could reach 100m. The reference comparison method is used to detect the laser imaging position acquired by the reference detector at different times, and to obtain the relative positional deviation of the measurement reference or the tested objects. Through the measurement error analysis, the precision of the system is expected to reach ±10μm.

INTRODUCTION

Accelerator online alignment technology is an important means for accelerator stability detecting. The long distance laser alignment technology has been used in several accelerators to monitor the displacement of units in linac. Fresnel zone plate is first used in the laser alignment system, in which the annular zone plate focusing the laser on one point, and the laser offset can be measured according to the principle of light wave interference when the measured object position changed. SLAC, America, first used the laser alignment technology in its 2 miles linear accelerator, and the alignment precision can measure up to ±100μm. The Poisson spot laser alignment system, is used in the European X-ray Free Electron Laser, and its alignment precision measures up between ±100μm and ±200μm, and that in SKEKB 500m-long laser-based alignment system achieved ±40μm[1,2]. Due to the long transmission distance and good linearity of the laser beam, it can be used as a reference for particle accelerator mounting alignment [3]. But in long distance detection, the laser spot will spread out which will effect on the detection precision. This paper shares a new design of the laser alignment system based on the CCD detector, which detection distance is expected to reach 100m, and the measurement precision is expected to ±10μm.

THE LASER ALIGNMENT DETECTION SYSTEM (LADS) BASED ON CCD DETECTOR

The laser alignment detection system (LADS) mainly consists of a laser generator and laser beam control system, an optical path transmission passageway, two reference CCD detectors, three measuring CCD detectors, a data processing system, as shown in Figure 1.

The laser generator generates the laser, which is required a high power stability and mode stability, light intensity fluctuation is less than 5% and the mode change is also less than 5%. The optical controller is used to control the position of the light path, exit position and exit angle of the laser beam and expand the laser beam at the same time. The optical path transmission passageway is maintained in a vacuum environment to reduce the laser power attenuation and light intensity distribution changed[4], and the passageway should be covered with black paint of acrylic resin to avoid the reflected light obstructing the measurement. Two reference CCD detectors are installed at the beginning and end of the system, used to detect the laser reference position. Three measuring CCD detectors are installed on the tested objects, and each detector consists with one laser compressing system, one CCD imager, moving component with position feedback system. The number of the detectors can vary depending on the number of the tested objects. The laser needs to be compressed by the laser compressing system after a long distance propagation, which is relatively fixed with the CCD imager. The moving component drives the laser compressing system and CCD imager to the working position when the measurement is needed, otherwise the component drives them in the position which do not block the laser path. The position is feed back by the position feedback system with the 2μm precision. The data processing system and light intensity distribution data processing system are used to collect all the data and calculate the CCD imaging position.

The LADS working process can be described as follow. Two positioning benchmark must be selected in the two sides of the section that will be measured, 40 meters away, and install the two reference CCD detectors on them. The laser beam is generated by a He-Ne laser generator, which is emitted through the beam expander system and the control beam path. Correct and keep the laser beam stable imaging in the two reference CCD detectors and it can be used as a baseline to detect changes in the position of the tested objects. The three measuring CCD detectors are evenly distributed on the optical path on the measured reference or tested objects, with interval of 10m. The measuring CCD detectors need to be calibrated one by one. The one when finished calibration is driven away from the laser beam, including the first reference detector. All the first calibrated positions are used as the reference position for future measurements. The correlation image algorithm can be used to calculate the positional deviation of the laser on the measuring detector, and then the position deviations between the

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measured reference and the laser beam reference are determined [3].

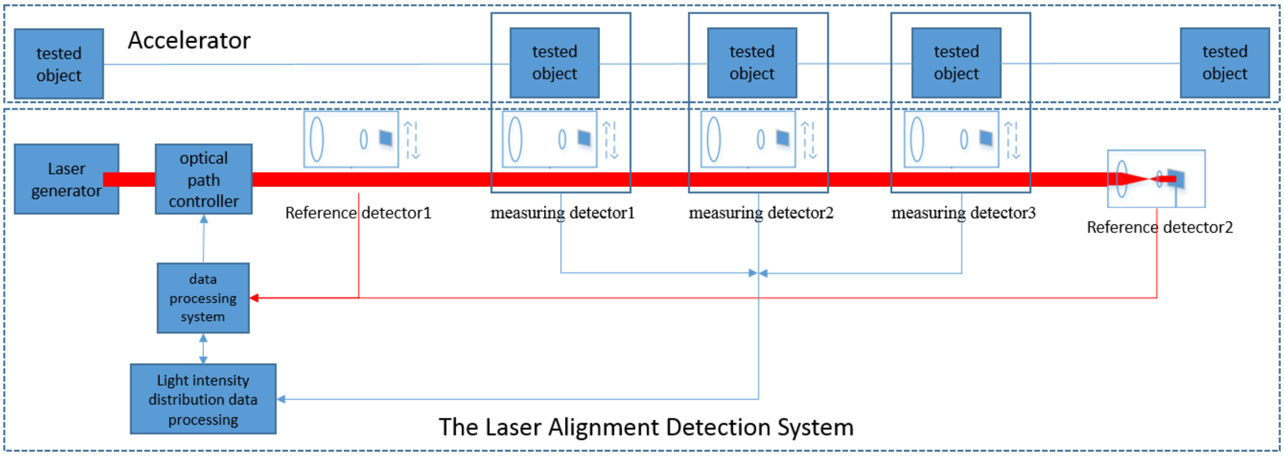

Figure 1: The Laser Alignment Detection System (LADS).

LASER BEAM CONTROL SYSTEM

The laser intensity distribution and positional change at different moments are used to calculate the positional deviations and it is necessary to ensure the stability of the laser emission power and the stability of the mode. He-Ne laser generator is considered to be used in the LADS, which has a 2% power stability error and the laser mode will reach 98% after filtering.

Diffraction after long distance transmission affects the laser light beam diameter, and the relationship between diffraction spot size and ejected beam diameter can be expressed as follow:

$$d = 2.44\frac{L\lambda}{D}$$

In the formula, d is the spot diameter in the position L from exit lens, and D is the ejected beam diameter. When L=40m, λ=632.8nm, D can be calculated as:

$$D = \sqrt{2.44L\lambda}=7.9\text{mm}$$

And when L=100m, D=15.44mm.

A beam expander system[5] is needed to expand the laser beam out from the generator (showed in Figure 2), the diameter of the laser beam is 0.68mm, and the gain of the expander is 12.

The CCD detector's pixel size is 8.3μmX8.3μm, and CCD surface size is 6.5mmX4.8mm, when the laser compressing system's ratio chooses 3:1, so the beam diameter D should be compress to 2.633mm. At the injection of the compressing system, the injection surface size is 19.5mmX14.4mm, so the measurable displacement range is 11.6mm in horizontal direction and 6.5mm in vertical direction.

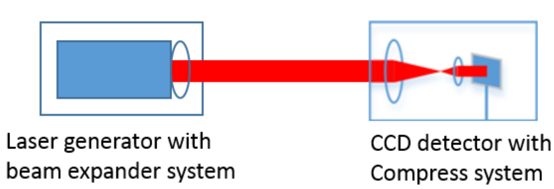

Figure 2: Laser beam control system.

MEASUREMENT ERROR ANALYSIS

The error sources of the system mainly include the positioning error of the detector, the principle error of the detection algorithm, the error caused by the laser beam jitter, and the detection noise. Each error analysis is as follows.

Positioning Error

The longitudinal displacement of the detector is measured by a grating scale with the precision 2μm in each direction δx and δy, and the positioning error can be calculated as:

$$\delta_{\text{PE}} = \pm\sqrt{\delta x^2 + \delta y^2} = \pm 2.83\mu m$$

Principle Error of the Detection Algorithm

The CCD single pixel size is Sp=8.3μmX8.3μm, the compressing system is Ra=3:1 compression ratio, and the displacement calculation precision of the correlation algorithm is i=1/5 pixels, and the principle error of the detection algorithm can be calculated as:

$$\delta_{\text{PEDA}} = \pm Sp * Ra * i = \pm 4.98\mu m$$

Laser Beam Jitter Error

The laser is He-Ne laser, and its power stability error is 2%, of which TEM00 base film accounts for more than 95%, and the stability of the filter laser can reach 98%. Laser power stability has less impact on the detection of related algorithms. The measurement error introduced by laser beam jitter is about 2μm.

$$\delta_{\text{LBJE}} = \pm 2\mu m$$

Detection Noise

Although the algorithm is de-threshold pre-processed, the effect of noise can be reduced, but the detection noise is an inevitable part of the error source. Also considering other factors such as temperature, vacuum tube pressure and other factors, the measurement error caused by such errors is approximately 3μm.

$$\delta_{\text{DN}} = \pm 3\mu m$$

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In summary, the theoretical detection error of the relative lateral displacement between system and references is:

$$\delta = \pm\sqrt{\delta_{\mathrm{PE}}^2 + \delta_{\mathrm{PEDA}}^2 + \delta_{\mathrm{LBJE}}^2 + \delta_{\mathrm{DN}}^2} = \pm 6.77\mu m$$

CONCLUSION

The system is under development and is expected to be tested in October this year. The error of the system will reach the precision of 10μm at 100m according to the analysis result, but it is necessary to control the stability of the temperature, humidity and effective vibration isolation, to minimize external interference. Subsequent experimental research will continue to be shared in the form of papers, and the system will be applied in Hefei light source linear accelerator.

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