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Analysis of excitation source of vibration stability about precision tiled grating device

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Abstract

Precision array grating is the key device of chirped pulse amplification system, and the stability of the grating tiling device under ambient excitation is very important. Starting from the mechanical stability of the arrayed grating, this paper analyzes the influencing factors of the overall stability of the splicing device, divides the environmental excitation, and discusses the mapping relationship and action form of the main influencing factors, so as to provide the reference basis of environmental excitation for the stability design of the arrayed grating splicing device.

Keywords

Array grating, splicing device, stability, environmental excitation.

1. Introduction

As one of the most prominent and urgent problems of human society in the 21st century, energy crisis has become a key research object in politics, economy, science and technology and other fields[1-3]. In order to achieve energy security, nuclear fusion has always been an important research field[4]. Among them, inertial confinement fusion has become a research focus[5, 6]: by using high-energy laser to compress the nuclear fuel at high temperature, the fusion reaction is initiated, and the temperature of the target is about tens of millions of degrees, and the pressure is about one billion atmospheres. In this regard, the United States has taken the lead: the design target is 192 beams, 500 TW, 1.8 MJ of NIF (National Ignition Facility, USA), which has output laser energy greater than 1 MJ[7]. At present, such a high laser energy depends on high-power Chirped Pulse Amplification (CPA) [8], in which the pulse compressor compresses the broadened and amplified pulse laser by using the dispersion function of diffraction grating. The pulse compression grating needs to carry the amplified very high power (1015 W) pulse laser. The larger the aperture of the grating, the lower the energy per unit area. Under the same damage threshold conditions, more effective laser energy output can be provided[9].

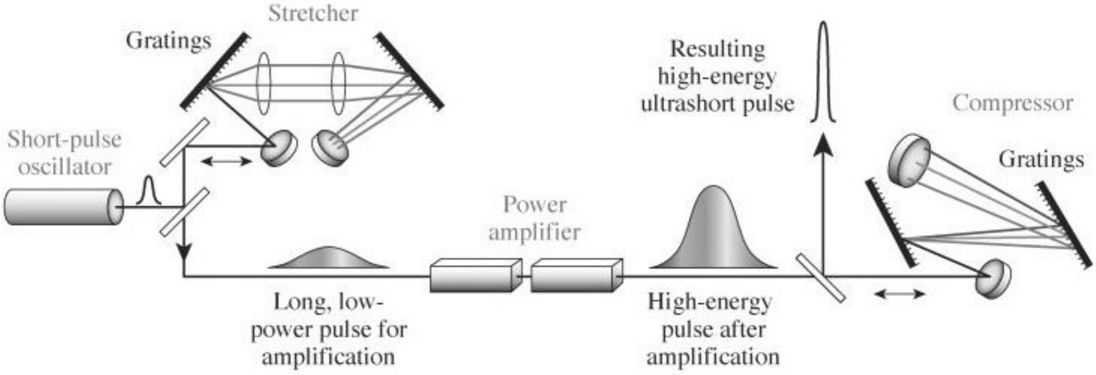

Figure 错误!文档中没有指定样式的文字。 The fundamental principle of CPA[10]

Therefore, how to improve the damage threshold and size of grating has become the research goal of researchers all over the world. At present, there are two ways to obtain large aperture grating: one is to manufacture large aperture grating etching device, but it is very difficult to manufacture exposure lens with aperture of 1 meter or more in both technical and economic aspects (large area exposure, large area etching and large area uniform coating are difficult), which brings great cost pressure for the research work; the other is to use splicing technology Methods several small gratings were assembled into a large grating to produce a large aperture splicing wavefront with small error, so as to achieve the effect of replacing a single larger grating, that is, mechanical splicing[11-13]. Due to the low cost of small aperture diffraction grating and its easy realization and acquisition in technology, the splicing method is widely used in the compressor of high power ultrashort pulse laser device[14]. Therefore, it is almost the only alternative way to develop high-energy short pulse technology in China to obtain large aperture gratings of meter level or above by splicing method[15]. Because the stitching method requires high accuracy (λ / 10), the research on the detection method, control method and stability of the stitching grating system has become an extremely important topic.

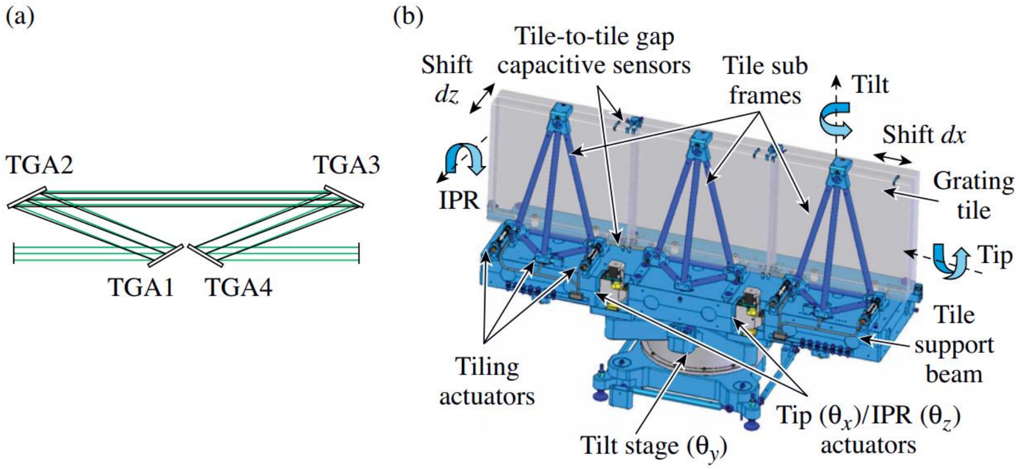

Figure 2 The Omega EP laser compressor and 3×1 tiled-grating[16]

The stability control of precision arrayed grating needs to be optimized comprehensively from the device structure and environmental excitation source. The working environment of grating splicing device is an important basis for the stability research of array grating in compressor. Based on the splicing device, the research on the influence of environmental excitation on the stability of optical path can provide guidance for its performance improvement and technical support for the structural stability design of the device. Therefore, to determine the source of vibration excitation is a prerequisite for the stability of the grating.

2. Influence of grating array on overall stability

The space-time stability of arrayed grating can be expressed by Eq.(1)：

$$S = S[u_{env}(t), u_{str}(t), u_{con}(t)] \quad (1)$$

Where, S is the overall stability of the array grating, which is a function of the environmental excitation factor u_{env}, the structural factor u_{str} and the control factor u_{con}. Among them, environmental factors can also be called excitation factors, and structural factors and control factors can also be called damping factors because the stability of splicing system will be improved in the design process.

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4. Division of environmental load

For the precision optical mechanical system, the environmental load is a necessary consideration in the study of the stability of the optical mechanical system. Environmental factor u_{env} includes vibration u_{vib}, temperature u_{tem} and accidental factor u_{ran}. As

$$u_{env} = \begin{bmatrix} u_{vib} \\ u_{tem} \\ u_{ran} \end{bmatrix} \quad (2)$$

The stability of excitation source refers to the fluctuation of excitation source load, which is characterized by the influence on the stability of optical elements. Due to the excitation of the external environment, the array grating will produce stimulated response, which will lead to position error. The direct result is that the beam pointing deviates from the predetermined position. By improving the structure of the splicing device and optimizing the control scheme, the stability of the splicing device can be improved.

The main environmental factors are the excitation effects of random vibration and temperature load on optical elements. In the stability analysis of optical elements in large solid-state laser device, the excitation factors affecting optical elements were divided[17].

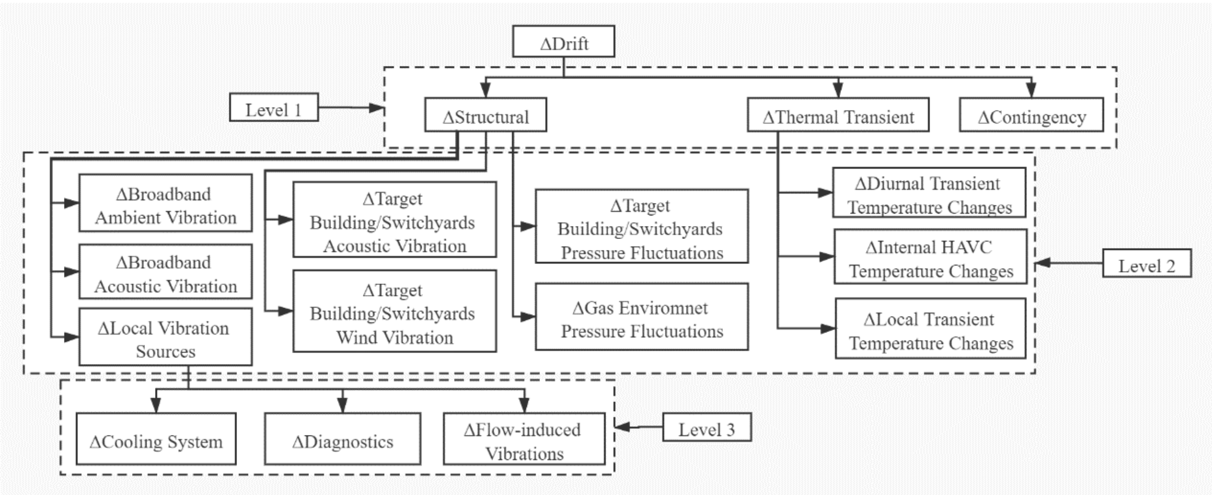

Figure 3 The classification of effect of environmental excitation[17]

5. Mapping relationship of main influencing factors

The influence of vibration and temperature on the splicing device is expressed as the displacement caused by the load, which is expressed as absolute value from the numerical point of view. The improvement of the mechanical structure and control method of the device shows a relative proportion for the stability of the device. Because of these two improvements, the displacement stimulated response of the device can be restrained to a certain extent. Therefore, the mapping relationship between the stability of the grating splicing device and the four factors of vibration, temperature, structure and control can be expressed as Eq.(4),

$$\begin{aligned} S &= S[u_{env}(t), u_{str}(t), u_{con}(t)] \\ &= u_{str}(t) \cdot u_{con}(t) \cdot [u_{vib}(t) + u_{tem}(t)] \end{aligned} \quad (4)$$

Where S is the stability function of the device; $u_{env}(t)$ is the environmental influence factor, which includes the vibration influence factor $u_{vib}(t)$ and the temperature influence factor $u_{tem}(t)$; $u_{str}(t)$ is the mechanical structure influence factor; $u_{con}(t)$ is the control method influence factor.

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The above formula shows that the influence of vibration and temperature on the device is superimposed, and the improvement of its structure and control will affect the vibration and temperature at the same time.

6. The action form of each influencing factor

These factors affect the stability of the device in many ways, and it is very complicated to discuss them comprehensively. However, the function of grating device is to provide stable and high quality beam, and the influence of displacement amplitude is the main content of this paper. Based on the comprehensive displacement of grating in various cases, it can be seen that

The deformation of the device affected by temperature is

$$u_{tem} = l \cdot \alpha \cdot t \tag{5}$$

Among them, u_{tem} is the deformation of the component affected by temperature, l is the component size, α is the thermal expansion rate of the component, and t is the temperature change of the component.

The deformation of the device affected by vibration is determined by the dynamic equation shown in the following equation

$$M \cdot \ddot{u}_{vib} + C \cdot \dot{u}_{vib} + K \cdot u_{vib} = F \tag{6}$$

Where u_{vib} is the deformation of the member affected by vibration, M is the mass of the member, C is the damping of the member, K is the elastic modulus of the member, and F is the excitation of the member.

The structural change of the device is the compound effect of the material and structural characteristics of the mechanism. It works together with the external excitation of the component, and has an effect on the vibration, temperature and other aspects of the device,

$$u_{str} = u_{str}(A, \rho, l, K, P, \lambda, \alpha, \ldots) \tag{7}$$

Where, A is the structural characteristics of the component, ρ is the material density, l is the component size, K is the elastic modulus, P is the Poisson's ratio, λ is the thermal conductivity, and α is the thermal expansion rate. These factors are closely related to the structure design of the device, so it is not easy to carry out algebraic calculation, many factors should be determined by experimental methods.

The influence of the control program on the device is the transfer function of the control method, if

$$U_{con}(s) = L\ (u_{con}(t)) \tag{8}$$

so

$$U_{con}(s) = \frac{L\ [out]}{L\ [in]} \tag{9}$$

Where, L is the symbol of Laplace transform.

7. Conclusion

In summary, the space-time stability of arrayed grating is mainly affected by environmental excitation, structural characteristics and control methods, and the external excitation mainly comes from environmental factors. Furthermore, the specific action form of environmental factors is the device deformation caused by temperature gradient and random vibration. To solve this problem, we need to start from the manufacturing materials, structure and feedback control program of grating splicing device to build a targeted stable system.

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