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LVF-based FBG interrogation simulation calculation

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LVF-based FBG interrogation simulation calculation

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Abstract— We propose a miniature FBG(Fiber Bragg Grating) interrogation based on the LVF(Linear Variable Fliter), which is very suitable for measurements in aircraft because of its small size, light weight and vibration insensitivity compared to conventional interrogation. We analyzed the relationship between the performance of the interrogation and the optical properties of the LVF by simulating the light passing through the LVF demodulator by means of theoretical simulations before the actual construction of the instrument, and we also find that the inhomogeneous illumination of the incident light can impair the performance of the interrogation.

1. Introduction

FBG sensors themselves have obvious advantages over electrical sensors, such as high sensitivity, resistance to electromagnetic interference, the ability to sense over long distances and in a distributed manner, and the ability to be used in harsh environments. Despite all these advantages, the proportion of the sensor market share is small. However, with the development of science and technology, FBG has been used in more and more fields with its good characteristics, structural inspection [1], border security [2], aerospace monitoring [3], and other fields.

However, the development of demodulators limits the application of FBG. The traditional demodulators are used to obtain the spectral information of reflected light from FBG by dispersion of the light reflected from FBG through prisms or gratings [4]. However, these demodulators suffer from poor robustness, large size, and high price. Emadi [5] proposed a spectrometer based on linearly graduated filters that can achieve sub-nanometer spectral resolution. The device does not require focusing distance and also does not need to strictly restrict the position relationship between the components, so it has the characteristics of small size and vibration insensitivity. The linear gradient filter can convert the spectral distribution of the input light into the spatial distribution of the light intensity, that is, the spectral transmission characteristics of the linear gradient filter change with the lateral position, then I can measure the spatial position distribution of the light and thus derive the spectral distribution of the input light. From this idea, we propose a linear gradient filter-based FBG demodulator and want to apply it to the distributed temperature measurement of aircraft. We propose a structure as shown in Figure 1, where the reflected light from the FBG is collimated and expanded, and then incident positively onto the linear gradient filter, and the spatial distribution of the transmitted light is collected by a CCD. We simulate the light entering the linear gradient filter by theoretical calculations and analyze the optical properties of the linear gradient filter and the effect of the non-uniformity of the incident light on the fiber demodulation.

2. Description of the prototype

As shown in Figure 2, when optics containing two wavelengths pass through the LVF, light of different wavelengths appears at different transverse positions and the rest of the light is reflected back. the LVF can be viewed as consisting of an infinite number of FP cavities with cavity thicknesses into continuous variations, and it is known from the optical properties of the FP cavities that

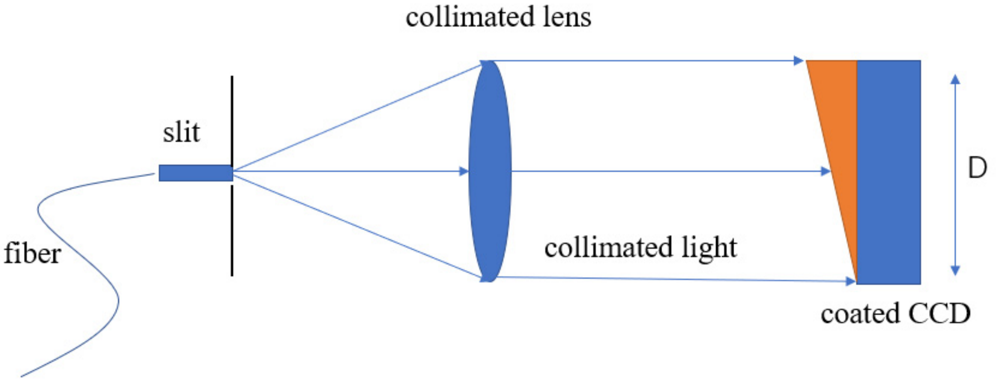

Fig.1 Schematic diagram of FBG interrogation

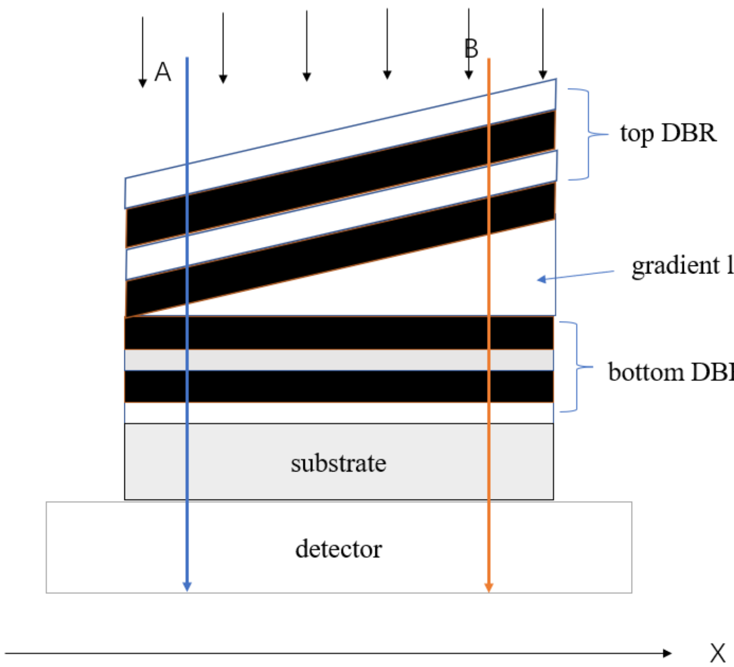

Fig.2 Schematic diagram of LVF optical properties

$$N\lambda_x = 2n_c c(x) \qquad (1)$$

where N is an integer indicating the resonance level, $c(x)$ the thickness of the cavity at the position, n_c the refractive index of the cavity (ignoring the dispersion effect of the medium), is a constant, and λ_x the wavelength transmitted at the position x . From the above equation, it is obvious that the wavelength varies continuously with the thickness.

3. Simulation

We will simulate, through matlab, how the light reflected from the FBG will produce a light spot with a light intensity distribution after passing through the LVF. I make some assumptions that the light reflected from the FBG $I_{sig}(\lambda_c)$ is a single wave with a wavelength of λ_c, and a FWHM of δ_0. The light collimated by the collimating lens has a Gaussian distribution in space with a FWHM of $3mm$. Then the light irradiated to the LVF can be expressed by the following equation:

$$I_{in}(x,\lambda_c) = I_{in}(x)\int I_{sig}(\lambda_c)d\lambda \quad (2)$$

where λ denotes the wavelength in the spectral bandwidth of the reflected light from the FBG, and x denotes the lateral position on the LVF space.

As we said before for LVF it has a special optical property, the wavelength of light that can be transmitted at different lateral positions is not the same, I can use a matrix to represent this wavelength selection of LVF, $T(x,\lambda)$. The final light signal received at the CCD $I_{out}(x)$ can be expressed by the following equation.

$$I_{out}(x) = I_{in}(x)\int I_{sig}(\lambda_c)T(x,\lambda)d\lambda \quad (3)$$

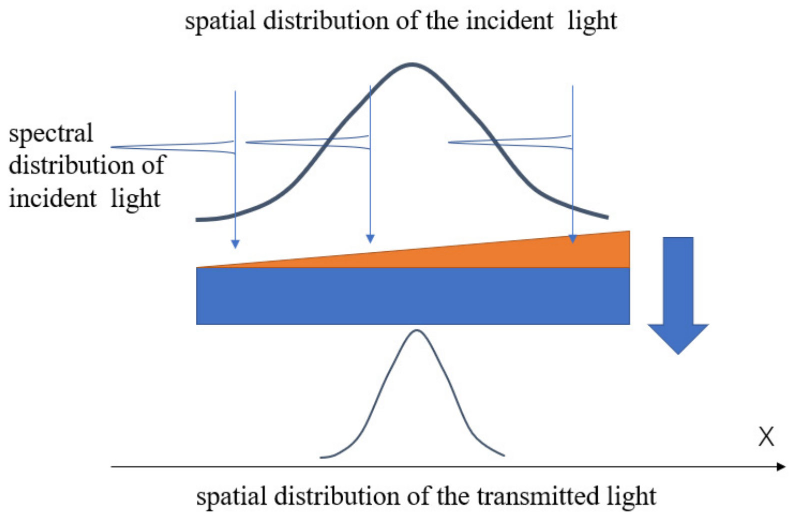

Fig.3 Diagram of incident light transmission through LVF

Figure 3 represents the idea of our whole simulation process. First, we construct the spectrum of the input light, the spatial intensity distribution of the input light, calculate the transmittance of the light in the band at each lateral position through the selective transmittance of the LVF, and then calculate the intensity of the light at each spatial position, and then simulate the spatial intensity distribution detected by the CCD.

Figure 4c shows the shape of the transmission peaks of the LVF used in our simulation, we ignore the dispersion of the medium, and assume that the transmission peaks at each point of the LVF are the same, and the FWMH selected for the simulation is $8nm$.

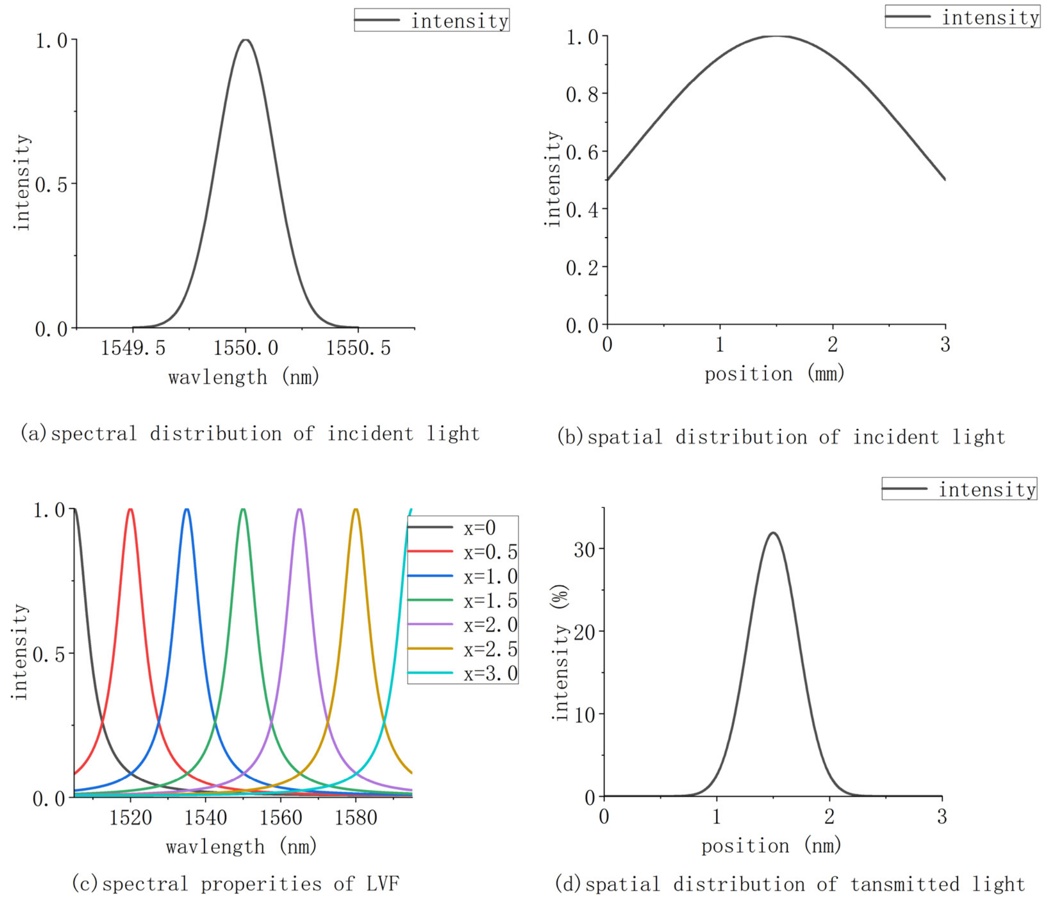

Fig. 4(a) Spatial position light intensity distribution of incident light with FWHM of 3 mm Fig. 4(b) Spectrum of incident light with FWHM of 0.3 nm Fig. 4(c) Transmission peaks at different positions of LVF with 7 points selected at equal spacing in transverse position Fig. 4(d) Spatial spectrum of output light

As shown in Figure 4(d), the lateral size of the light spot finally collected on the CCD is about 1mm (1.0mm-2.0mm) in size, covering about one-third of the entire CCD module. For a 256-pixel CCD, at least 85 pixel points are available, which can theoretically satisfy the fitting of the Gaussian waveform. In terms of spectral energy, the light intensity finally collected on the CCD accounts for roughly one third of the total light intensity.

Figure 5 simulates the transmission of other different wavelengths, and it can be seen from the figure that the wave peak in the middle is obviously higher than that on both sides, which is due to the uneven distribution of spatial light, which is mainly concentrated in the middle, and the energy of non-center wavelength light through LVF is weaker. Figure 5(a) simulates the situation when The profile of the transmission peak at this time is significantly larger than that in Figure 5(b).For the intermediate wavelengths, the energy transmission rate is about , and increasing the FWMH can increase the energy, but at the same time, it will make the wave peak "fat".

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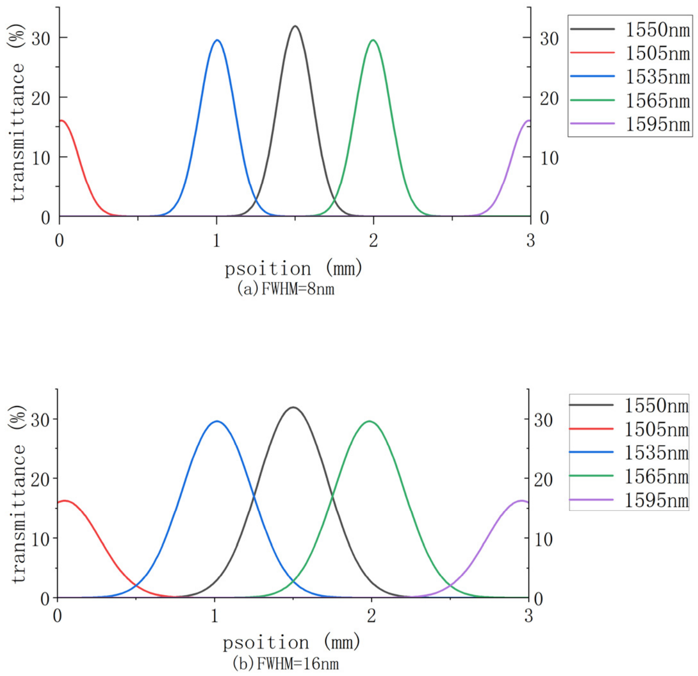

Fig. 5(a) Spatial spectra of some specific wavelengths through LVF, $FWHM: 8nm$ Fig. 5(b) Spatial spectra of some specific wavelengths through LVF $FWHM: 16nm$

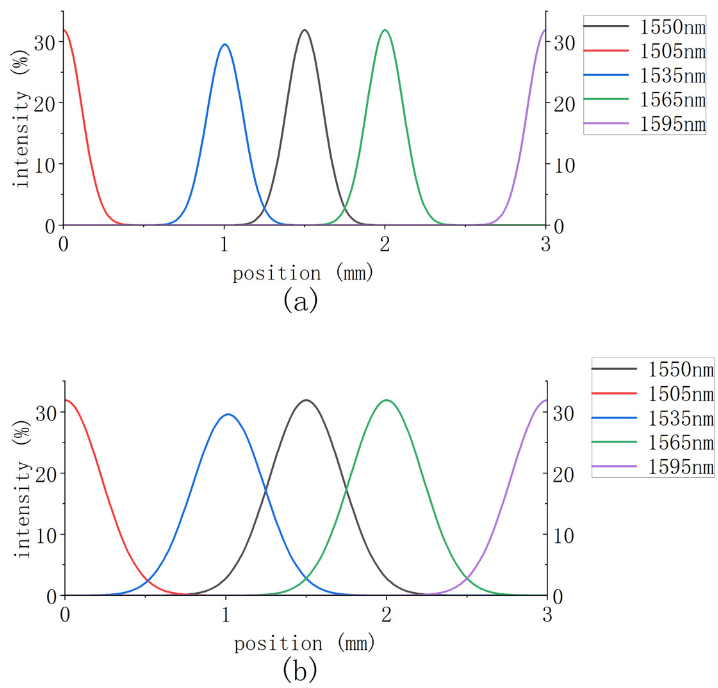

Figure 6a in homogeneous illumination $FWHM: 8nm$ Figure 6b in homogeneous illumination $FWHM: 16nm$

From Fig. 5(a), we can find its central wave as $1505.3nm, 1535nm, 1550nm, 1565nm, 1594.7nm$, and Fig. 5(b), the demodulation is $1506.5nm, 1535.6nm, 1550nm, 1564.4nm, 1593.5nm$ correct for all the wavelengths in the middle, but as the FWHM of LVF increases, the difference between the wavelengths on both sides and the true wavelengths is also larger, in other words, the larger the FWHM of LVF the larger the error is, and it seems that the FWHM of LVF can affect the demodulation accuracy. From Fig. 6a and Fig. 6b, it is found that FWHM does not affect the accuracy, and both plots can accurately demodulate the incident wavelength, thus it can be found that the non-uniform irradiation affects the demodulation accuracy rather than FWHM, which can mitigate this effect.

4. Conclusion

We simulated the reflected light of the FBG after passing through the LVF. The wave crest of the image received by the CCD will move with the change of the wavelength of the incident light, and the change of this spatial position can be inverse to the change of the wavelength corresponding to the incident light, and then the temperature or pressure of the FBG can be measured (the wavelength of the reflected light of the FBG will change with the large change of the pressure). The FWHM of the LVF has no effect on the resolution of the demodulation, as obtained by simulation. (2) Non-uniform irradiation may cause the collected boundary signal to be too small. (3) Non-uniform irradiation will produce errors in the interrogation of the edge wavelength. Based on the above analysis, we will consider the effect of non-uniform irradiation when designing this demodulator in the future, and improve the collimation optics to try to mitigate the effect of non-uniform irradiation.

References

[1] CHAN T,YU L, TAM H Y, et al. Fiber Bragg grating sensors for structural health monitoring of Tsing Ma bridge: background and experimental observation[J]. Engineering Structures,2006,28(5): 648-659.
[2] Chen Y,An Wanyue,Liu Huanlin,et al. Improved empirical mode decomposition algorithm for fiber Bragg grating perimeter intrusion behavior classification[J]. China Laser,2019,46(3):175-184..
[3] Tong Xinglin,He Wei,Zhang Cui,et al. Progress of research and application of fiber grating and fiber Farper sensors in aerospace field[J]. Laser Journal,2018(7):1-7..
[4] A.Othonos，Review of Scientific Instruments 68, 4309 (1997).
[5] A.Emadi, et al., "Design and implementation of a sub-nm resolution microspectrometer based on a linear-variable optical filter," Opt.Express 20(1)，489-507 (2012).