Spectral effects in a reflective fiber Fabry-Perot for magnetic field sensing subjected to reciprocal perturbations

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ABSTRACT

The influence of the intrinsic linear birefringence and/or the external reciprocal perturbations on the free spectral range of a reflective fiber Fabry-Perot, for magnetic field sensing, with a conventional or a Faraday rotator mirror, are analysed and discussed. By means of the calculation of the eigenvectors (two mutually orthogonal eigenpolarisations) and their eigenvalues, the optical frequencies of such sensor, are evaluated. Results show an improvement in the finesse of the resonator respect the transmissive configuration.

Keywords: Fiber optic sensor, Fabry-Perot interferometer, free spectral range, Jones calculus, anisotropic cavity, optical fiber interferometer, Faraday rotator mirror, polarisation.

1. INTRODUCTION

Several authors have analysed the use of active and passive Fabry-Perot cavities in transmission in order to measure the Faraday rotation, so as a fibre Fabry-Perot resonator enhances the Faraday rotation of linearly polarised light [1-6]. However, apart from the previous work presented for fiber laser sensor by Kim and coworkers, the application to the fiber Fabry-Perot resonators in reflective configuration hasn't been totally analised in detail [7-9]. This communication, presents a study of the effects of the intrinsic or extrinsic anisotropies made over the free spectral range of these devices in reflective configuration with a conventional or a Faraday Rotator Mirror (FRM). By using the eigenvectors (two mutually orthogonal eigenpolarisations) and their eigenvalues, of this fiber optic sensor, its optical frequencies are evaluated.

2. THEORETICAL MODEL

Using Jones calculus the Jones matrix of the Fabry-Perot sensor proposed can be obtained for a roundtrip in its cavity. The transmision and reflexion of the wave through the cavity can be studied considering an infinite number of beams as a result of the reflexions in the two surfaces which limitate the cavity, as shown in Fig. 1. The output must satisfy the resonance condition such that the optical wave has to come back to the same phase and state of polarisation (SOP) after a round trip inside the cavity. This requeriments leads to an eigenvalue equation whose solutions provide two mutually orthogonal eigenpolarisations (eigenvectors), in general elliptical eigenpolarisation modes, with their optical frequencies (eigenvalues). After a straightforward calculation we can directly obtain the parameters of interest, the eigenpolarisation modes, and their resonance frequencies.

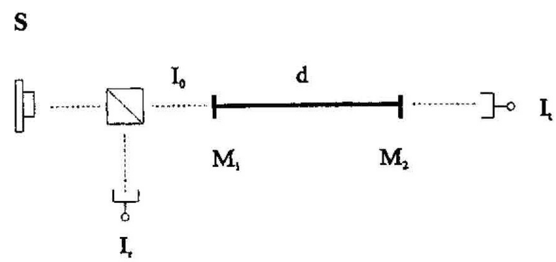

Fig. 1: Diagrame of a Fabry-Perot interferometer. F: ligth source ; M_1, M_2 : mirrors; d: fiber length; I_0 ,I_r,I_t : Input, reflected and transmited irradiances

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3. RESULTS AND DISCUSSION

Several configurations of fiber Fabry-Perot cavities analysed. The first one is an isotropic cavity, where the reflective index is the same in all directions. This results in a trasmited intensity in relation with the incident given by:

$$\frac{It}{Ii}=\frac{1}{1+\left(\frac{2F_t}{\pi}\right)^2 Sin^2\left(\frac{\delta}{2}\right)} \quad (1)$$

where F_t is the finesse, $F_t=\frac{\pi\sqrt{R}}{1-R}$, $R=r_1^2=r_2^2$, and δ is the phase delay in a roundtrip in the cavity.

If the reflectivity of the second mirror r2=1, is only possible the inrterrogation in reflection of the isotropic cavity, and in this case the reflected intensityversus the incident intensity is given by:

$$\frac{Ir}{Ii}=\frac{r_1}{1+\left(\frac{\pi}{2F_r}\right)Sin^{-2}\phi} \quad (2)$$

where F_r is the finesse in reflection, $F_r=\frac{\pi\sqrt{r_1}}{1-r_1}$

Fig.2 shows that the finesse in a reflective configuration is improved by a two factor in relation to the finesse in transmision.

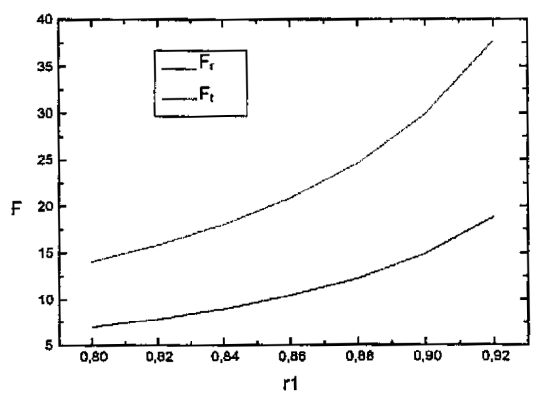

Fig.2: Finesse in transmision and reflection versus the reflexion coefficient

In an isotropic cavity, the free spectral range, the distance between two maximums is:

$$\Delta\upsilon=\upsilon_{m+1}-\upsilon_m=\frac{c}{2nlCos\theta} \quad (3)$$

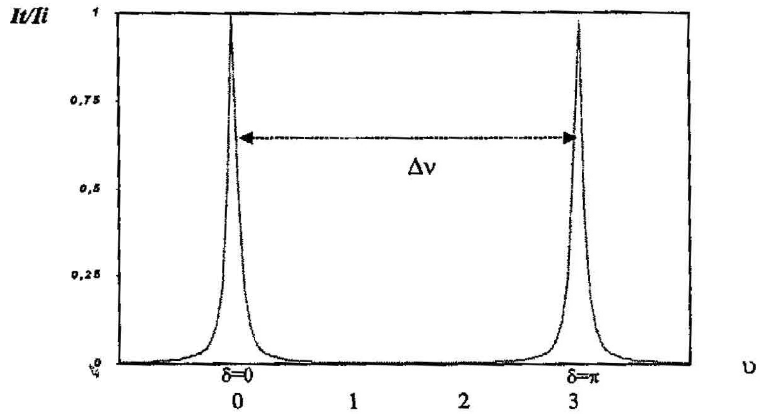

Fig. 3: Free spectral range in transmision of an isotropic cavity

When an isotropic fiber optic Fabry-Perot cavity is under the effect of Faraday effect, the relationships between the optical power, transmited and reflected, with the incident are:

$$\frac{I_t}{I_i}=\frac{1}{2}\frac{1}{1+\left(\frac{2F_t}{\pi}\right)^2 Sin^2\left(\frac{\delta}{2}+\theta_f\right)}+\frac{1}{2}\frac{1}{1+\left(\frac{2F_t}{\pi}\right)^2 Sin^2\left(\frac{\delta}{2}-\theta_f\right)} \tag{4}$$

$$\frac{I_r}{I_i}=\frac{1}{2}\frac{r_1}{1+\left(\frac{\pi}{2F_r}\right)^2 Sin^{-2}\left(\frac{\delta}{2}+\theta_f\right)}+\frac{1}{2}\frac{r_1}{1+\left(\frac{\pi}{2F_r}\right)^2 Sin^{-2}\left(\frac{\delta}{2}-\theta_f\right)} \tag{5}$$

where θ_f is the Faraday rotation, $\theta_f = VNI$, being V the Verdet constant of the fiber, I the electric intensity and N the number of turns of the solenoid.

In this situation, the free spectral range is divided into two subranges that are generally defined for anisotropic cavities as:

$$\Delta\nu_1 = c/(2nd\pi)\ \eta/2 \qquad \Delta\nu_2 = \Delta\nu - \Delta\nu_1 \tag{6}$$

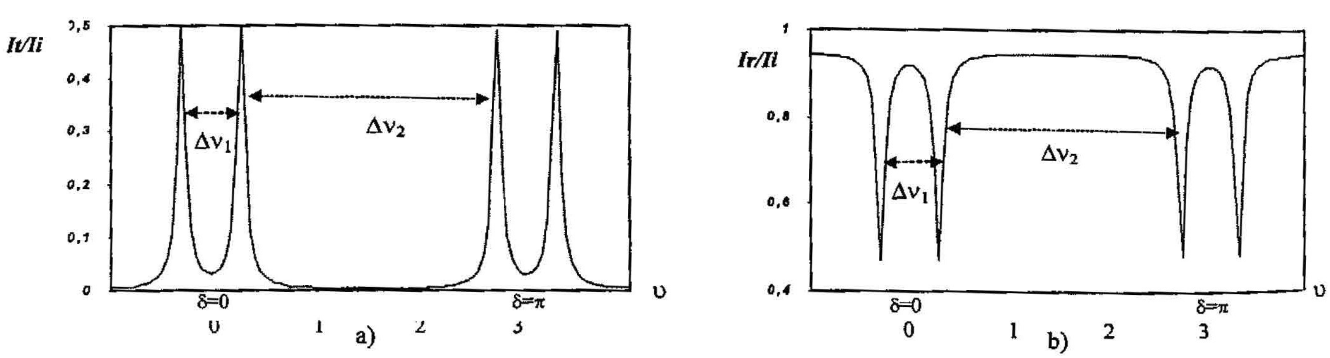

Fig.4: Free spectral range of an isotropic cavity under the effects of a magnetic field a) in transmision b) in reflexion

4. ANISOTROPIC FIBER FABRY-PEROT CAVITIES

Two different configurations of fibre Fabry-Perot configuration are analysed. The first includes a conventional mirror (R_2=1), Fig. 5a), and the second a FRM, Fig.5b). In both cases the optical fiber in the cavity has an intrinsic linear birefringence b=4.4 rad/m and a reciprocal circular birefringence G=30.1 rad/m. By means of the variation of the electrical current the free spectral range of this resonator can be controlled.

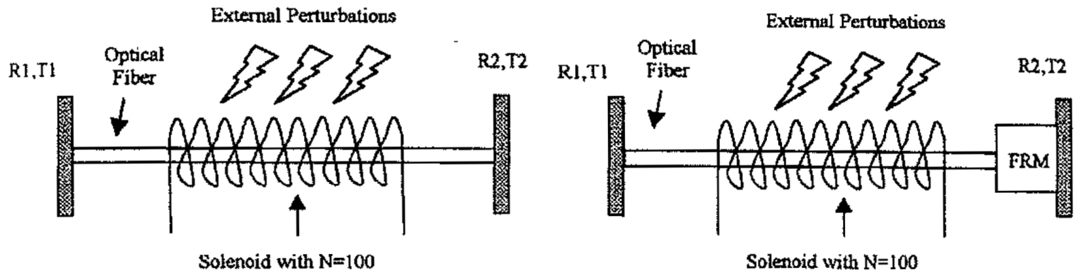

Fig. 5: The two F.P. configurations analised. a) with conventional mirrors b) with a conventional mirror and a Faraday Rotator Mirror.

4.1. Anisotropic fiber Fabry-Perot with conventional mirror

The interrogation in reflection of this structure (R_2=1) improve the sensitivity and finesse of these Fabry-Perot sensors respect the interrogation in transmission with R_2<1, and it only needs access at the input side of the transducer.

The electrical current influence on the frequency separation between polarisation modes has been analysed. The minimum values of the instrument function split into two as a consequence of the exposition of the cavity to magnetic fields. The difference between both resultant frequencies can be defined in terms of the cavity eigenvalues.

The frequency gap is represented in Fig. 6 as a function of the magnetic field applied for different values of fibre linear birefringence. For higher values of linear birefringence, linearity and sloppiness of the curves are getting distortion. For a 3.5kG magnetic field, and absence of birefringence in the fibre, the frequency split is about 600 kHz, getting smaller when the fiber birefringence increases to B=7.39 10^{-6} ($\Delta\nu_1$ = 400 kHz) and even smaller for B=1.25 10^{-5} ($\Delta\nu_1$ = 300 kHz) where $B = \lambda.b / 2\pi$ and λ = 1553 nm.

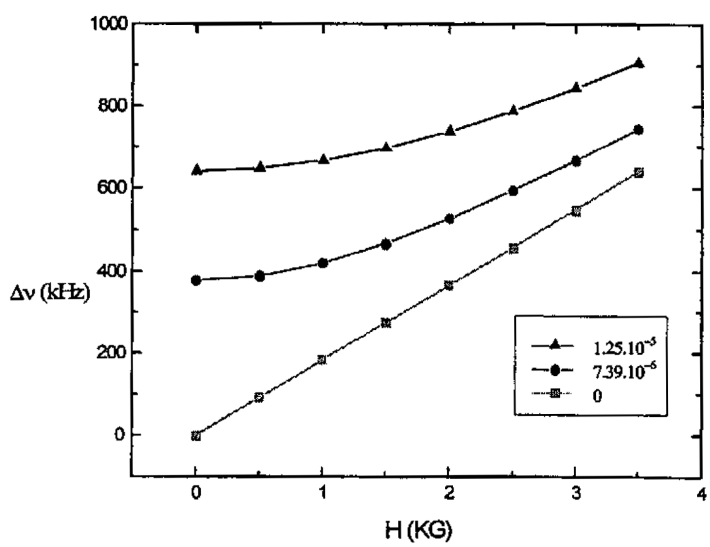

Fig. 6: Frequency gap evolution as a function of magnetic field for three values of fibre optic linear birefringence

Fig. 7 shows the frequency gap between the two eigenpolarisation modes versus the electric current applied. In this case the eigenvalues are

$$\lambda_{1,2} = \exp(\pm j\eta) \qquad \eta = -2\frac{G}{\left(G^2 + (b/2)^2\right)} VIN \tag{7}$$

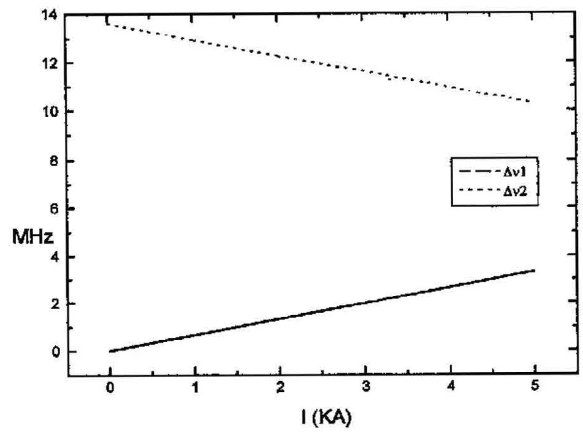

Fig. 7: Frequency gap variation between F.P. cavity resonance polarization eigenmodes using a conventional mirror (R=1) versus electric current for N = 100

The variation of the two frequency gaps Δv_1 and Δv_2 are linear and in the order of 0.48 kHz/A.

4.2. Anisotropic fiber Fabry-Perot with Faraday rotator mirror

In this case one of the ended mirrors of the cavity is a FRM. Following the same method as before the eigenmodes of this structure are given by:

$$\lambda_{1,2} = \exp(\pm j\eta) \qquad \eta = Cos^{-1}(-2VNI) \tag{8}$$

where V is the Verdet constant, I is the electric current and N is the number of turns of the coil. It shows that the phase delay between both eigenpolarisations after a round trip in the cavity resonator is independent of the reciprocal birefringences. Again, as Fig. 8 shows, the spectral separation between the minimums of the reflectivity transfer function can be controlled by means of the Faraday effect. In this case the variation of the two frequency gaps Δv_1 and Δv_2 are linear and in the order of 0.75 kHz/A.

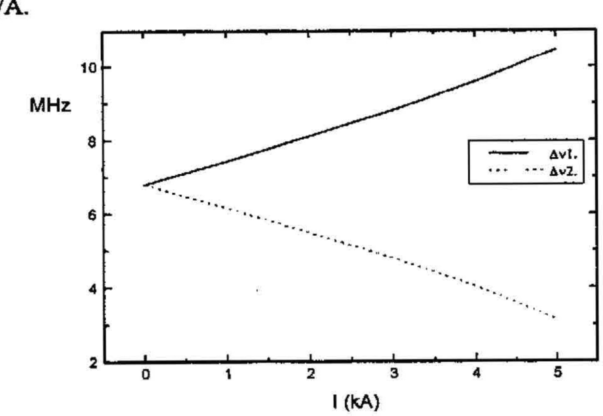

Fig. 8: Frequency gap variation between Fabry-Perot cavity resonance polarization eigenmodes using a Faraday rotator mirror versus electric current for N = 100.