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FBG based Real Time Derailment Assessment in Railways

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Abstract: - This paper proposes the use of FBG sensor to measure the lateral and vertical forces at the rail-wheel contact point. The ratio of lateral and vertical force at the flange contact contact point is called Nadal limit for a certain critical value for which derailment is likely to occur. Simulation has been done for the measurement of lateral and vertical forces with the increasing velocity and taking the range of radius of curve from 600m to 1000m.

Keywords: Fiber Bragg Grating, Nadal's limit, flange climb derailment, curve negotiation

1. INTRODUCTION

Derailment is an accident in railways, where a carraige, or part or the entire train, leaves the tracks on which it is travelling. Every year this problem leads to loss of lives and property. Hence it has become important to propose a monitoring method for the derailment assessment. Many authors have reported the use of conventional sensors in this regard. C. Hung has reported the use of MEMS acceleration sensor and MEMS angular velocity sensor for the detection of early sign of derailment [2]. Hiroaki Ishida et.al has reported the use of load cells and actuator for the measurement of lateral, vertical displacement and creep forces [7]. Akira Matsumoto.et.al. has reported the use of magnetostrictive displacement sensors for the measurement of vertical contact forces [9]. But these conventional sensors can't be used in hazardous environment unlike FBG sensors. Although many fiber sensors are commercially available but they have certain disadvantages like low spatial resolution and complexity in interrogation of output signal. So in order to overcome these problems sensor based on Fiber Bragg gratin (FBGs) has been used in this paper. This paper proposes the use of FBG sensor to measure lateral and vertical forces. The ratio of lateral to vertical force (Derailment coefficient) for a certain critical at which derailment is likely to occur is called Nadal limit. Thus by finding the derailment coefficient a monitoring method for the derailment assessment has been introduced.

2. DERAILMENT ASSESSMENT USING FBG SENSOR

Derailment can be considered as a function of wheel load, lateral force, normal force and attack angle of the wheel contact with the rail [4]. Derailment can occur on curve track or straight track. To find the safety against flange climb derailment, Nadal proposed a theoretical estimation method based on the ratio of lateral to vertical force [4]. Railway derailment may occur due to Wheel flange climb, Gauge widening, Rail rollover, Track panel shift [10].

Derailment due to flange climb only has been discussed in this paper. Wheel flange climb derailment occurs when wheel Climb on the top of the railhead and then run over the rail. Wheel climb derailment generally occurs where the wheel experiences high lateral force in combination with circumstances where there is reduced vertical force on flanging wheel. The high lateral force is induced due to large angle of attack whereas vertical force is reduced when there is rough track or large track twist. So flange climb derailments mainly occur on curves. This lateral to vertical force ratio (Q/Y) depends on Curve radius, Wheel rail profiles, Bogie suspension characteristics, Train speed

Fig (1) shows the lateral and vertical forces at the rail-wheel contact point (flange contact point).

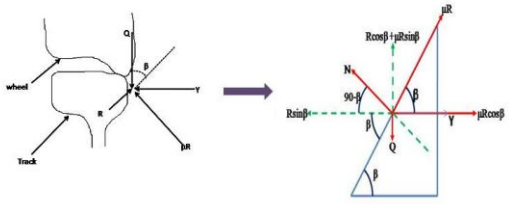

Fig.1. Free body diagram for the estimation of Nadal ratio

Where Y is lateral force, Q is vertical force and β is flange angle at the contact point.

As shown in fig (1) the forces are resolved in X and Y axes giving the following equation

$$Y = R\sin\beta - \mu R\cos\beta \quad (1)$$

$$Q = R\cos\beta + \mu R\sin\beta . \quad (2)$$

Taking the ratio of both the equations and dividing the numerator and denominator of RHS part by Rcosβ derailment coefficient is achieved

$$\frac{Y}{Q} = \frac{\tan\beta - \mu}{1 + \mu\tan\beta} . \quad (3)$$

Where

μ =coefficient of friction between wheels and rail contact.

R= normal reaction force

μR= tangential friction force due to creep

Both R and μR varies as a function of Y. Climb does not occur with increasing Y till μR is saturated and flange contact slide down the rail. However for a certain critical value of Y/Q tangential friction is about to drop below its saturated value and flange climb occurs due to rolling instead of sliding. This critical value of Y/Q for which derailment is just about to occur is called Nadal limit.

Fig.2 shows the flow chart for derailment assessment. In this flow chart two cases one for straight track and another for curve track has been discussed.

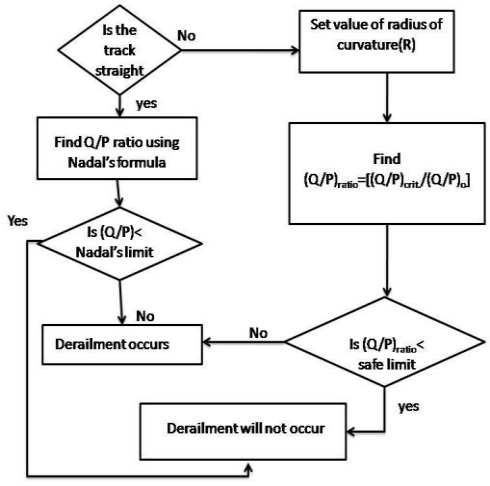

Fig.2 shows the flow chart of Derailment assessment algorithm

For the straight track the radius of curve is infinite and so simply the vertical load and lateral forces have to be measured through shift in Bragg wavelength. For the curve track Wheel load varies due to Centrifugal force, Track twist, Torsion of secondary suspension spring whereas the Lateral force varies due to due to the reaction of inside friction force, centrifugal force and torsion of air suspension, track irregularities. So different analytical equation has been used for both the cases

But at last for both the cases the Q/P ratio has to be measured to get the safety against derailment ratio. The flow chart shown below shows the methodology to find vertical and lateral forces.

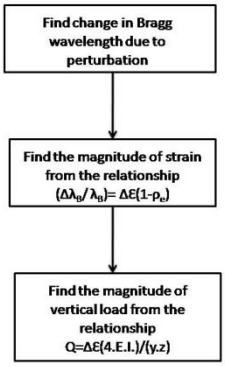

Fig.3 Flow chart to measure vertical load of the wheel

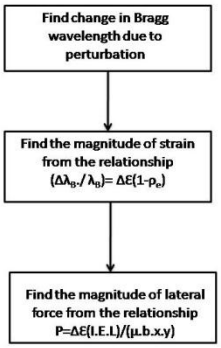

Fig.4 The flow chart for the measurement of lateral force

3. FBG SENSING PRINCIPLE

The working principle of FBG is based on the Fresnel's reflection of light centered at Bragg wavelength λ_B given by

$$\lambda_B = 2n\Lambda \quad (4)$$

Where n is the effective refractive index of the fiber core and Λ is the period of index modulation [3]. The wavelength shift $\Delta\lambda_B$ with respect to change in strain $\Delta\varepsilon$ is given by the following relation

$$\frac{\Delta\lambda_B}{\lambda_B} = (1-\rho)\Delta\varepsilon \quad (5)$$

Where, ρ is the photo elastic coefficient of the fiber.

The reflected wavelength depends on the period of modulation as well as effective refractive index of the fiber. So when perturbation acts on fiber there is either compression or elongation of the FBG thereby changing the period of modulation and hence there is shift in Bragg wavelength. This shift in Bragg wavelength is used to find the magnitude of strain applied on FBG. The wavelength of the reflected light is measured and then transmitted to signal processing unit.

4. set up for the measurement of vertical and lateral forces

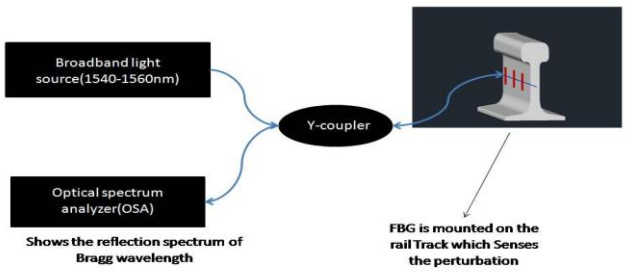

Fig .5Proposed setup

The proposed setup for the measurement of vertical and lateral forces as shown in Fig.5 consists of a Broadband source which launches light into an array of FBGs, via a Y-coupler. The returned signal in the form of shift in Bragg wavelength from the FBGs is recorded on O.S.A

5. Results and Discussion

Fig (6) shows the spectrum without load (red) and with load (black). The shift in Bragg wavelength is used to estimate the magnitude of applied lateral force. In the same manner when, the vertical load is applied, then there is a shift in the Bragg wavelength (Fig.8) thereby giving an estimate of the magnitude of vertical load.

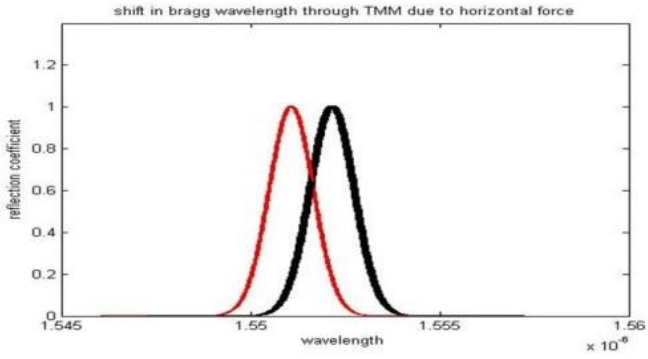

Fig 6: Bragg Wavelength shift due to Lateral force

Fig.7 shows the linear relationship between strain and the load.

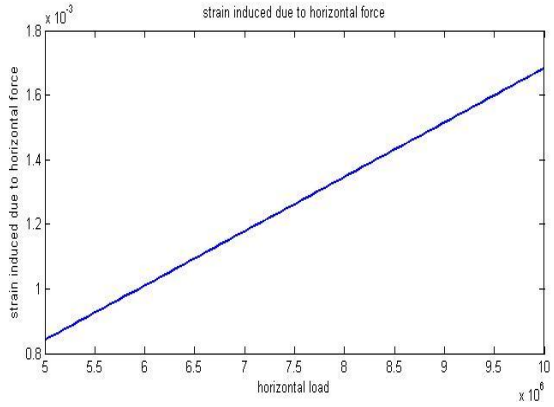

Fig 7: Vertical strain due to horizontal load

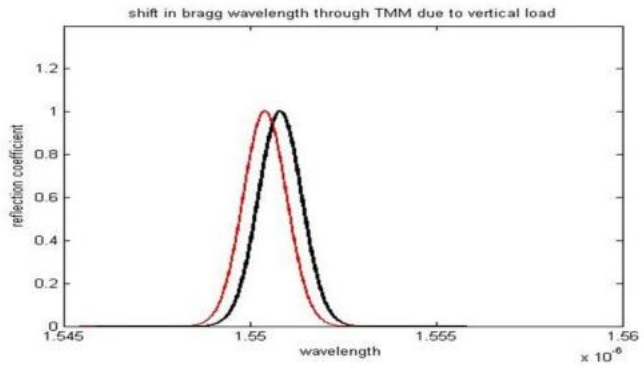

Fig 8: Bragg wavelength shift due to vertical load.

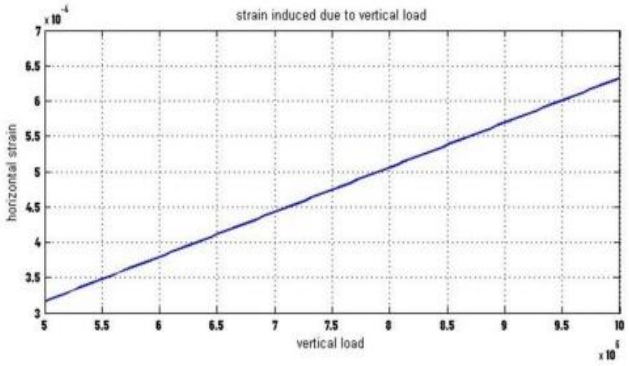

Fig 9: Horizontal strain due to vertical load.

Fig 9 shows the horizontal strain induced due to vertical load. Similarly vertical strain induced due to horizontal strain is shown in fig 7.

Once the magnitude of lateral force and vertical load has been extracted, the Nadal ratio can be calculated by finding their ratio

Simulation result has been derived for the assessment of derailment against curve radius and velocity of the train. This will help in track assessment when train passes through curve track.

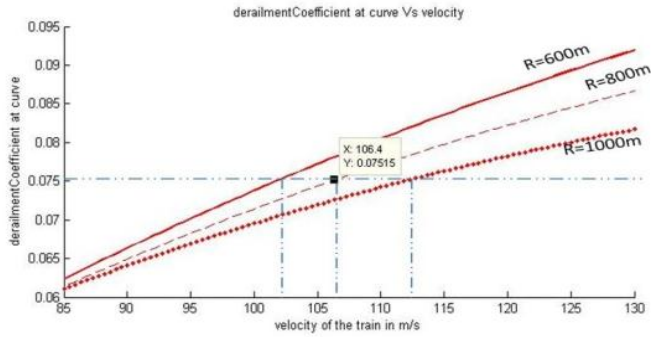

Fig 10: Derailment coefficient for three radii at varying speeds.

Fig 10 shows derailment coefficient for three radius of curve (600m, 800,1000m) against velocity of the train. This fig shows that derailment coefficient decreases as the radius increases making our assumption stronger that the probability of derailment is low on straight track (infinite radius). This fig also shows that as the velocity (for a particular radius) is increasing, the derailment coefficient is increasing which proofs that at higher velocity the probability of derailment is higher.

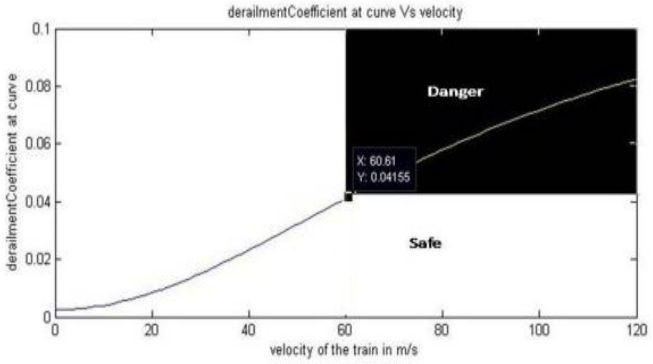

Fig 11: Danger and Safe zones based on Nadal Limit for 700m.

Fig 11 results show the danger and safe zone for a particular radius (700m) of curve and velocity of the train. This fig shows that the derailment coefficient is 0.04155 at velocity of 60.61m/s. It means that if train's speed exceed this speed for a 700m curve track then derailment is likely to occur.

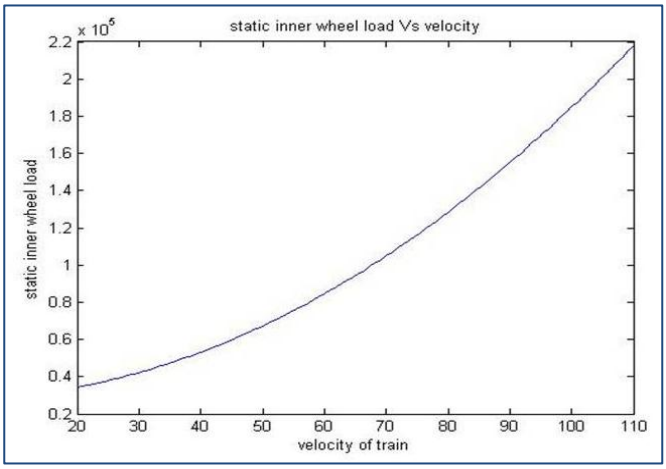

Fig 12: Static inner wheel load of the leading axle.

Fig 12 shows how static inner wheel load of leading axle increases as the train passes through the curve.

Large angle of attack increases the probability of derailment as this increases the lateral force and reduces the vertical force.

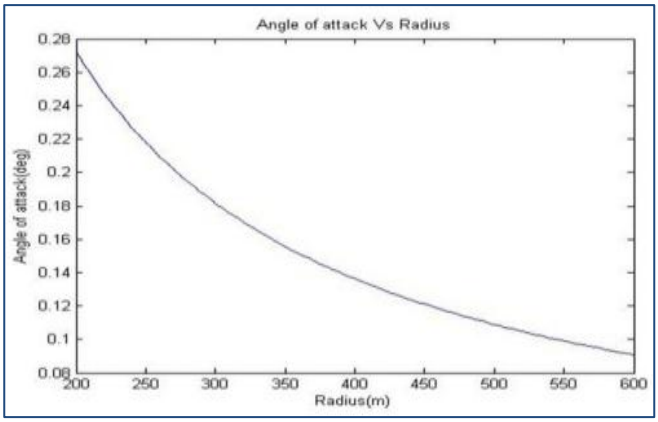

Fig 13: Radii vs. Attack angle

Fig 13 shows that as the radius increases the angle of attack decreases so probability of derailment also decreases

5. Conclusion

The application of forces were measured through FBG sensor and hence derailment coefficient ratio was estimated which gives the safety against wheel flange climb derailment.

6. Acknowledgement

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