ANALYSIS OF MECHANISM OF GALLOPING OF ICED CONDUCTOR

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Abstract*:* A kind of sufficient judgment of galloping of iced conductor is presented. Analysis of mechanism of galloping of iced conductor is made by use of the judgment . The conclusion is that enough negative damping and negative rigidity are sufficient condition for galloping of iced conductor.

1. Introduction

Galloping of conductor is a kind of aerodynamic non-stability phenomenon. This phenomenon Can happen when wind velocity is moderate and conductor is iced asymmetrically. The damage caused by galloping of conductor is serious for it causes probably the collapse of lines and towers.

The mechanism of galloping of conductor has been researched for long time. In 1932,A judgment of galloping of iced conductor was presented by Den hartog , he thought that iced conductor occurs galloping when lift derivate is negative.It is founded after that iced conductor twisting is the factor causing iced conductor galloping,and some viewpoint on mechanism of galloping of conductor was present.The math model in Den hartog mechanism is over simply. The mechanism present by Nigol and buchan basing on experiment need to be proved ,because the experiment was not content with resemble condition in geometry.In this paper ,A new kind of judgment of galloping of iced conductor is presented ,it contains aerodynamic factors and span structure factors.

2. RESULTS AND QISCUSSION

Supposing $L_1 > 0$, $M_1 + \rho_i rg \sin\theta_0 > 0$, if $L_1 < 0$ and $|L_1|$ is sufficient large, $\Rightarrow trA > 0$, which is happening of galloping of iced conductor. This is similar to Den Hartog judgment in negative damping.

Supposing $M_1 > 0$, $M_1 + m_i rg \sin\theta_0 > 0$, if $D_1 < 0$ and $|D_1|$ is sufficient large, $\Rightarrow trA > 0$, which is happening of galloping of iced conductor. This is not similar to Den Hartog judgment, because $D_1 < 0$ corresponding to negative rigidity .

For Reynolds number being very great , c_y, c_z and c_θ can be neglected. Supposing $L_1 > 0$, $M_1 > 0$ and $|M_1|$ is sufficient large, $\Rightarrow trA > 0$,which is, happening of galloping of iced conductor. This is corresponding to negative rigidity and negative damping synchronously.

where L_1 is initial aerodynamic lift per unite length of conductor and their initial derivative, M_1 is aerodynamic moment per unite length of conductor and their initial derivative, ρ_i is the unite length ice mass on conductor, r is radius of conductor, θ_0 is initial torsional angle, trA is the trace of the matrix of iced conductor dynamical equation group, M_1 is aerodynamic moment per unite length of conductor and their initial derivative, D_1 is initial aerodynamic drag per unite length of conductor and their initial derivative.

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Abstract: **A kind of sufficient judgment of galloping of iced conductor is presented. Analysis of mechanism of galloping of iced conductor is made by use of the judgment . The conclusion is that enough negative damping and negative rigidity are sufficient condition for galloping of iced conductor .**

Keywords *galloping, negative damping, negative rigidity, trace judgment.*

1. INTRDUCTION

Galloping of conductor is a kind of aerodynamic non-stability phenomenon. This phenomenon Can happen when wind velocity is moderate and conductor is iced asymmetrically. The damage caused by galloping of conductor is serious for it causes probably the collapse of lines and towers[1].

The mechanism of galloping of conductor has been researched for long time. In 1932,A judgment of galloping of iced conductor was presented by Den hartog , he thought that iced conductor occurs galloping when lift derivate is negative [2] .It is founded after that iced conductor twisting is the factor causing iced conductor galloping,and some viewpoint on mechanism of galloping of conductor was present[3-12] .The math model in Den hartog mechanism is over simply. The mechanism present by Nigol and buchan basing on experiment need to be proved ,because the experiment was not content with resemble condition in geometry [9].In this paper ,A new kind of judgment of galloping of iced conductor is presented ,it contains aerodynamic factors and span structure factors.

2. TRACE JUDGMENT FOR GALLOPING CONDUCTOR

Coordinate system is taken as right hand system, in which y axis vertical and x transversal. The direction of Wind velocity is in z axis.

2.1HYPOTHESIS

(a) In geometry, subconductor is level and smooth curve.

(b) The high difference of the two ends of span is zero.

2.2 THE DYNAMIC EQUATION GROUP OF ICED CONDUCTOR

From the reference [12], The dynamic equation of iced conductor as following:

$$MX'' + +CX' + KX = 0 \qquad (2\text{-}1)$$

where $X = \begin{pmatrix} y & z & \theta \end{pmatrix}^T$,

$$M = \begin{pmatrix} \rho+\rho_i & 0 & \rho_i r\cos\theta_0 \\ 0 & \rho+\rho_i & \rho_i r\sin\theta_0 \\ \rho_i r\cos\theta_0 & \rho_i r\sin\theta_0 & J \end{pmatrix},$$

$$C = \begin{pmatrix} c_y + \dfrac{L_1+D_0}{V_w} & \dfrac{2L_0}{V_w} & 0 \\ \dfrac{D_1-L_0}{V_w} & c_x + \dfrac{c_z}{V_w} & 0 \\ \dfrac{M_1}{V_w} & \dfrac{2M_0}{V_w} & c_\theta \end{pmatrix},$$

$$K = \begin{pmatrix} T_c\left(\dfrac{n\pi}{l}\right)^2 & 0 & L_1 \\ 0 & T_c\left(\dfrac{n\pi}{l}\right)^2 & D_1 \\ 0 & 0 & S\left(\dfrac{n\pi}{l}\right)^2 - \left(M_1+\rho_i g r\sin\theta_0\right) \end{pmatrix}$$

, $(n=1,2,\cdots)$, ρ is the unite length mass of conductor, ρ_i is the unite length ice mass on conductor, r is radius of conductor, θ_0 is initial torsional angle, J is polar mass moment of inertia per unite length of conductor, c_y is damping in direction of axis y, c_x and c_θ is similar to c_y, L_0 and L_1 are initial aerodynamic lift per unite length of conductor and their initial derivative, D_0 and D_1 are initial aerodynamic drag per unite length of conductor and their initial derivative, M_0 and M_1 are aerodynamic moment per unite length of conductor and their initial derivative, V_w is velocity, T_c is iced conductor tension, l is length of conductor span and S is torsional rigidity.

2.3 TACE JUDGMENT

Supposing $s\left(\frac{n\pi}{L}\right)^2-\left(M_1+\rho_i gr\sin\theta_0\right)\neq 0$

$\Rightarrow K^{-1}$ as following:

$$K^{-1}=\begin{pmatrix} \frac{1}{T}\left(\frac{l}{n\pi}\right)^2 & 0 & K_{13}^{-1} \\ 0 & \frac{1}{T}\left(\frac{l}{n\pi}\right)^2 & K_{23}^{-1} \\ 0 & 0 & K_{33}^{-1} \end{pmatrix}$$

$$K_{13}^{-1}=\frac{1}{T}\left(\frac{l}{n\pi}\right)^2\frac{L_1}{\left(M_1+\rho_i g\sin\theta_0\right)-s\left(\frac{n\pi}{l}\right)^2}$$

$$K_{23}^{-1}=\frac{1}{T}\left(\frac{l}{n\pi}\right)^2\frac{D_1}{\left(M_1+\rho_i g\sin\theta_0\right)-s\left(\frac{n\pi}{l}\right)^2}$$

$$K_{33}^{-1}=\frac{1}{s\left(\frac{n\pi}{l}\right)^2-\left(M_1+\rho_i g\sin\theta_0\right)}$$

$$\Rightarrow \quad K^{-1}MX''++K^{-1}CX'+X=0 \ . \qquad (2\text{-}2)$$

Let $\begin{cases} q=\left(y \quad z \quad \theta \quad \frac{dy}{dt} \quad \frac{dz}{dt} \quad \frac{d\theta}{dt}\right)^T \\ q'=\left(\frac{dy}{dt} \quad \frac{dz}{dt} \quad \frac{d\theta}{dt} \quad \frac{d^2y}{dt^2} \quad \frac{d^2z}{dt^2} \quad \frac{d^2\theta}{dt^2}\right)^T \end{cases}$

$$\Rightarrow \quad Aq'=q \qquad (2\text{-}3)$$

in (2-3) $A=\begin{pmatrix} 0 & I_3 \\ -K^{-1}M & -K^{-1}C \end{pmatrix}$, where I_3 is the identity matrix order three.

Let $q=q_0e^{\lambda t}$,

where

$$q_0=\left(U_0, \left.\frac{dU}{dt}\right|_{t=0}\right)$$

$$U_0=\left(y|_{t=0} \quad z|_{t=0} \quad \theta|_{t=0}\right),$$

$$\left.\frac{dU}{dt}\right|_{t=0}=\left(\left.\frac{dy}{dt}\right|_{t=0} \quad \left.\frac{dz}{dt}\right|_{t=0} \quad \left.\frac{d\theta}{dt}\right|_{t=0}\right)$$

subsisting the relation into (2-3), we obtain

$$\left(A-\frac{1}{\lambda}I_6\right)q=0 \qquad (2\text{-}4)$$

Obviously, $\frac{1}{\lambda}$ is feature value of A .

Trace judgment is that galloping of iced conductor happens, if $trA>0$.

Proof: $trA = \sum \frac{1}{\lambda} > 0 \Rightarrow$ at least existing a

$\mathrm{Re}\left(\frac{1}{\lambda}\right) > 0$ that is galloping of iced

conductor happening.

The expression of trA is as following:

$$trA = \frac{1}{T}\left(\frac{l}{n\pi}\right)^2\left(-c_y - c_z - \frac{L_1 + 3D_0}{V_w} + f\right) \quad (2\text{-}5)$$

Where

$$f = \frac{L_1 M_1 + 2M_0 D_1 - V_w T\left(\frac{n\pi}{l}\right)^2 (c_\theta + M_1)}{V_w\left(S\left(\frac{n\pi}{l}\right)^2 - (M_1 + \rho_i rg \sin\theta_0)\right)}$$

3. ANALYSIS OF MECHANISM OF GALLOPING OF ICED CONDUCTOR

Supposing $L_1 > 0$, $M_1 + \rho_i rg \sin\theta_0 > 0$, if

$L_1 < 0$ and $|L_1|$ is sufficient large,

$\Rightarrow trA > 0$, which is happening of galloping of iced conductor. This is similar to Den Hartog judgment in negative damping.

Supposing $M_1 > 0$, $M_1 + m_i rg \sin\theta_0 > 0$,

if $D_1 < 0$ and $|D_1|$ is sufficient large,

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$D_1 < 0$ corresponding to negative rigidity .

For Reynolds number being very great , c_y, c_z, c_θ can be neglected.

Supposing $L_1 > 0$, $M_1 > 0$ and $|M_1|$ is sufficient large, $\Rightarrow trA > 0$, which is, happening of galloping of iced conductor. This is corresponding to negative rigidity and negative damping synchronously.

4. CONCLUSION

Aerodynamic force derivative L_1, D_1 and aerodynamic moment derivative M_1 are all the factors of resulting of galloping of iced conductor. Sufficient large negative damping and negative rigidity produced by Aerodynamic force derivative L_1, D_1 and aerodynamic moment derivative M_1 are sufficient condition resulting of galloping of iced conductor.

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