ANALYSIS OF MECHANISM OF GALLOPING OF ICED CONDUCTOR
Fan Shexin*, Mo Yiwei, Zhu Jianxin
Guangxi University, Nanning, China
fsx@gxu.edu.cn

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 derivative 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 DISCUSSION
Supposing $L_1 > 0$, $M_1 + \rho_i r g \sin \theta_0 > 0$, if $L_1 < 0$ and $|L_1|$ is sufficient large, $\Rightarrow \text{tr}A > 0$, which is happening of galloping of iced conductor. This is similar to Den Hartog judgment in negative damping.

Supposing $M_1 > 0$, $M_1 + m_i r g \sin \theta_0 > 0$, if $D_1 < 0$ and $|D_1|$ is sufficient large, $\Rightarrow \text{tr}A > 0$, 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, $c_j$, $c_2$, and $c_\alpha$ can be neglected. Supposing $L_1 > 0$, $M_1 > 0$ and $|M_1|$ is sufficient large, $\Rightarrow \text{tr}A > 0$, 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, $\rho_i$ is the unite length ice mass on conductor, $r$ is radius of conductor, $\theta_0$ is initial torsional angle, $\text{tr}A$ 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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Keywords: galloping, negative damping, negative rigidity, trace judgment.

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[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.

2.1 HYPOTHESIS

(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:

\begin{equation}
MX'' + CX' + KX = 0 \quad (2-1)
\end{equation}

where \( X = \begin{pmatrix} y \\ z \\ \theta \end{pmatrix} \),

\[
M = \begin{pmatrix}
\rho + \rho_l & 0 & \rho r \cos \theta_0 \\
0 & \rho + \rho_l & \rho r \sin \theta_0 \\
\rho r \cos \theta_0 & \rho r \sin \theta_0 & J
\end{pmatrix},
\]

\[
C = \begin{pmatrix}
c_y + \frac{L + D}{V_w} & \frac{2L}{V_w} & 0 \\
\frac{D - L}{V_w} & c_x + \frac{C_z}{V_w} & 0 \\
\frac{M_1}{V_w} & \frac{2M}{V_w} & c_g
\end{pmatrix},
\]

\[
K = \begin{pmatrix}
T_e \left( \frac{n\pi}{L} \right)^2 & 0 & L_1 \\
0 & T_e \left( \frac{n\pi}{L} \right)^2 & D_1 \\
0 & 0 & S \left( \frac{n\pi}{L} \right)^2 - (M_1 + \rho g r \sin \theta_0)
\end{pmatrix}
\]
\[ n = 1, 2, \cdots \], \( \rho \) is the unite length mass of conductor, \( \rho_i \) is the unite length ice mass on conductor, \( r \) is radius of conductor, \( \theta_0 \) 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 \( c_\theta \) 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 \( s \left( \frac{n\pi}{L} \right)^2 \left( M_1 + \rho g r \sin \theta_0 \right) \neq 0 \)

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

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

\[ \Rightarrow K^{-1} M X^\tau + K^{-1} C X^\tau + X = 0 \]  

(2-2)

Let

\[
q = \begin{pmatrix} y' & z' & \theta' \end{pmatrix}^T
\]

\[ q = \begin{pmatrix} \frac{dy}{dt} & \frac{dz}{dt} & \frac{d\theta}{dt} \end{pmatrix}^T \]

\[ q = \begin{pmatrix} \frac{d^2y}{dt^2} & \frac{d^2z}{dt^2} & \frac{d^2\theta}{dt^2} \end{pmatrix}^T \]

\[ \Rightarrow Aq^\tau = q \]

(2-3)

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 \( q = q_0 e^{\lambda t} \),

where

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

\[ U_0 = \begin{pmatrix} y |_{t=0} & z |_{t=0} & \theta |_{t=0} \end{pmatrix} \]

\[ \frac{dU}{dt} \bigg|_{t=0} = \begin{pmatrix} \frac{dy}{dt} \bigg|_{t=0} & \frac{dz}{dt} \bigg|_{t=0} & \frac{d\theta}{dt} \bigg|_{t=0} \end{pmatrix} \]

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

\[
\left( A - \frac{1}{\lambda} I_6 \right) q = 0 \]

(2-4)

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

Trace judgment is that galloping of iced conductor happens, if \( tr A > 0 \).

3
Proof: \( trA = \sum \frac{1}{\lambda} > 0 \Rightarrow \) at least existing a 

\[ \text{Re}\left(\frac{1}{\lambda}\right) > 0 \] that is galloping of iced conductor happening.

The expression of \( trA \) is as following:

\[
trA = \frac{1}{T} \left( \frac{L}{n\pi} \right)^2 \left(-c_y - c_z - \frac{L_1 + 3D_0}{V_w} + f \right)
\]

Where

\[
f = \frac{L_1M_1 + 2M_0D_1 - V_cT \left( \frac{n\pi}{l} \right)^2 \left(c_o + M_1 \right)}{V_o \left( \frac{n\pi}{l} \right)^2 \left(M_1 + \rho r g \sin \theta_0 \right)}
\]

3. ANALYSIS OF MECHANISM OF GALLOPING OF ICED CONDUCTOR

Supposing \( L_1 > 0, \quad M_1 + \rho r g \sin \theta_0 > 0 \), 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 \( M_1 > 0, \quad M_1 + m r g \sin \theta_0 > 0 \), 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, \( c_y, c_z, c_o \) 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 \( L_q, \quad D_q \) and aerodynamic moment derivative \( M_q \) are all the factors of resulting of galloping of iced conductor. Sufficient large negative damping and negative rigidity produced by Aerodynamic force derivative \( L_q, \quad D_q \) and aerodynamic moment derivative \( M_q \) are sufficient condition resulting of galloping of iced conductor.

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REFERENCE


