PHASE TRAJECTORIES OF AEROELSTIC OSCILLATIONS OF SURFACE PIPELINE

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Summary
This article is devoted to research dynamic behaviour of surface pipeline in a horizontal uniform wind flow. The investigations have been carried out on the basis of the conventional equations for the interactions between a bluff body of a circular cylinder and a uniform wind flow. The analysis was performed by a hybrid computer complex on the base of analog devices and digital computer treatment. Time processes, spectral characteristics of distributing of energy of oscillations on their frequencies and phase trajectories, are received at transient and stationary behaviours of vertical vibrations in a wide frequency range. The hysteresis effects in a resonance frequency ranges and zones where itaraction of free and forced oscillations appear.

Keyword : aeroelastic oscillations ,surface pipeline, phase trajectories.

1. INTRODUCTION

Research into aeroelastic oscillations in structures and buildings subjected to an air flow is of interest owing to the progressively longer bridge span frameworks and overpasses and taller mast- and tower-type structures. No matter to which type such lengthy structures under consideration belong, the aerodynamic loads, which affect the structures and cause their steady oscillations, represent the non-linear conservative functions of the displacements and the velocities of the structural components.A distinguishing feature of the oscillations of the elastic structures in a wind flow is the complex interactions between the aerodynamic loads and the parameters of oscillations of bodies in a wind flow.

2. THE MODEL OF AEROELSTIC OSCILLATIONS OF SURFACE PIPELINE

In some models of the aeroelastic oscillations of structures, the values the aerodynamic force are determined not only by the aerodynamic resistance but also by the periodic load resulting from the alternate shedding of the Karman vortices from the lateral surfaces of the bluff bodies.

The load of this type arises from the stalled flow-around of the structures and represents an external periodic force with its frequency depending on both the cross-sectional shape in a structural component and on the wind flow velocity.

This article describes the results of the research into peculiarities of the dynamic interactions between a surface pipeline and a horizontal uniform wind flow.

The investigations have been carried out on the basis of the conventional equations [1-3] for the interactions between a bluff body of a circular cylinder (i.e. a surface pipeline) and a uniform wind flow. To adapt these conventional nonlinear differential equations to the objective of this research, the following definitions were entered:

$$\begin{gathered} m\ddot{y} + \frac{1}{\pi}\delta\,\omega_0\,\dot{y} + f(\dot{y}) + R(y) = F(t) \\ Ry = \alpha y + \gamma y^2 + \beta y^3 + F_0 \end{gathered} \tag{1}$$

where δ, ω_0 are the logarithmic decrement and the natural frequency of a pipeline, respectively; $f(\dot{y})$ is the non-stationary aerodynamic force [1-3]; $R(y)$ is the elastic restoring force; and $F(t)$ is the aeroelastic Karman force.

$$f(\dot{y}) = \frac{1}{2}\rho V^2 d \sqrt{1+\left(\frac{\dot{y}}{V}\right)^2} \left(C_X \frac{\dot{y}}{V} - C_Y^{\alpha} arctg\left(\frac{\dot{y}}{V}\right)\right) \qquad (2)$$

where ρ is a air density; V is a wind flow velocity; d is a pipeline diameter; C_X is the aerodynamic drag ratio; C_Y^{α} is the ratio, taking into account the aeroelastic nature of a circular cylindrical body.

$$f(\dot{y}) = \frac{1}{2}\rho V^2 d \sqrt{1+\left(\frac{\dot{y}}{V}\right)^2} \left(C_X \frac{\dot{y}}{V} - C_Y^{\alpha} arctg\left(\frac{\dot{y}}{V}\right)\right) \qquad (3)$$

where C_K is the ratio of the Karman force; ω is the frequency of stalling the Karman vortices; and S_h is the Strouhal number.

The form of equation (2) suggests that the described system should be the one with self-induced periodic oscillations in its right-hand side. In this instance, the self-induced oscillating properties are conditioned by the nonlinear aerodynamic resistance.

3. THE METHOD OF INVESTIGATION AND RESULTS

The hybrid modelling was chosen as the basic method of investigation. At modelling on hybrid computer complexes (HCC) the real system is replaced by physical (electric) model, and the computer becomes the working model. HCC incorporate analogue and PC. HCC possess the speed of analogue computers, accuracy and the wide memory size of the PC. Unlike PC, HCC enables the user to observe visually computing process by means of oscillographs, recorders etc.; and also allows to change parameters of investigated model during computing process. Thus, HCC gives the opportunities [5] for studying influence of parameter changes on behaviour of investigated systems, and also allows to follow the modes which are not sold on PC.

In the hybrid modeling, the analysis of the oscillations was performed for a steel pipeline having the length of $l = 35m$, the diameter of $d = 0,426\ m$, and the wall thickness of $\Delta = 0,004\ m$.

The wind flow velocity values varied within the range of $V = 0 \div 30 ms^{-1}$. Let us assume that the value of the initial static deflection of a pipeline is equal to $W_C = 0,05077\ m$. Then, the parameters in equation (1) take on the following values: $\alpha = 199 s^{-1}$; $\gamma = 84 m^{-1} s^{-2}$; $\beta = 551 m^{-2} s^{-2}$; $F_0 = 9,97 \quad ms^{-2}$. The point with $y_{\dot{r}} = -\ 0,0508m$ corresponds to the equilibrium state of the system.

Fig.1 shows the analytical skeleton curve and the amplitude-frequency curve, which was obtained in the hybrid simulations. It is evident that these curves correlate with each other fairly well. The system under consideration is a rigid one. Within the range of the wind flow velocities from $V < 4,4 ms^{-1}$ to $V > 6 ms^{-1}$, the oscillations can be interpreted as the forced ones with small amplitudes.

As soon as the system reached the boundaries of the range of the fundamental resonance $\omega \approx \omega_0$, a beating mode established (fig. 2). On completion of the transient process, the amplitudes of the natural oscillations gradually decrease and then damp out.

With an increase of the wind flow velocities in the range of the fundamental resonance, the amplitudes of the oscillations drastically increase, too (see fig. 2). The transient time processes clearly display the "swinging" of the system. The oscillation amplitudes attain their peak values at the resonance on the fundamental harmonic at the wind flow velocity of $V_{cr} = 4.78 ms^{-1}$. Under such conditions, the oscillation amplitudes do not exceed $\overline{a_1} = 0,05$. Within this wind flow velocity range, the oscillations in the system under study are self-sustaining and similar to those in the systems with self-induced oscillations. In actual practice, they can hardly be observed in the systems, because the wind flow is ununiform by its nature. The gusts of the wind flow interact with the forced transversal oscillations caused by periodic stalling the vortices.

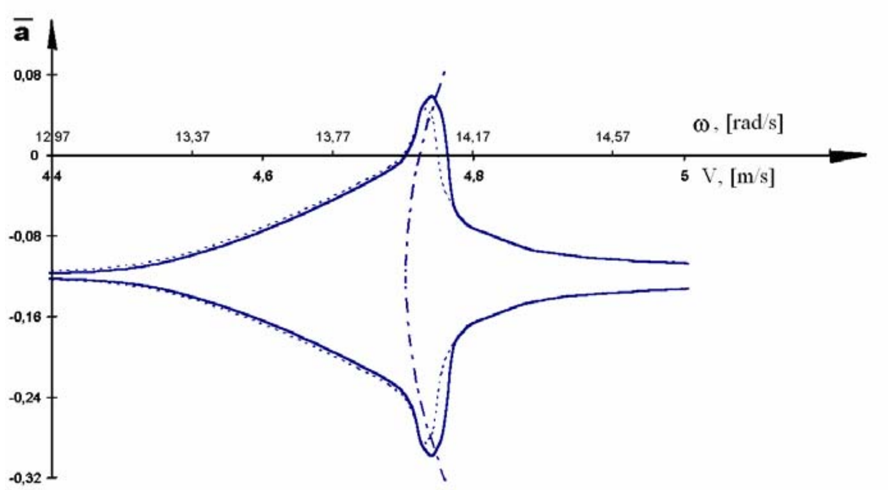

Fig. 1. Amplitude-frequency curves of the vertical oscillations of a surface pipeline in a uniform wind flow

When the wind flow velocities increase still further, the oscillation amplitudes decrease, and the oscillations go onto the unresonance branch of the amplitude-frequency curve. In the transient time processes, "jumps" in the oscillation amplitudes of the system are noted .

The analysis of stability of the aerodynamic oscillations of the fundamental tone carried out on the basis of the constructed resonance curves allows to conclude that the oscillations of this type remain steady as long as the wind flow velocities do not exceed the value of $V = 4,8\ ms^{-1}$. This is explained by the fact that any changes in a wind flow velocity V affect not only the frequencies of the vortical excitement but also the magnitude of the non-stationary aerodynamic force.

With the gradually decreasing wind flow velocity, the amplitudes of the oscillations increased. On the graphs of the time processes in this range, "swinging" of the system is observed. The transition onto the resonance branch of the amplitude-frequency curve took place at the wind flow velocity $V_{st} = 4.75ms^{-1}$, and it was accompanied with the mitigation of the oscillation amplitudes.

Noteworthy also is the fact that the fractional and multiple resonances, which are typical for the non-linear systems, are present at the wind flow velocities corresponding to the critical velocities for the sub- and ultraharmonic oscillations. Thus, a distinctive feature of the system under study is the availability of a regionzone of the subharmonic resonance $\omega \approx 3\omega_0$ (see fig. 3). With the wind flow velocity of $V \cong 14,165ms^{-1}$, the graph of a transient process depicts the modulated oscillations of the fundamental tone commensurable with those at the frequencies of the vortex stalling. On completion of the transient process, the amplitudes of the self-induced oscillations decrease, while those of the forced oscillations increase; hence, by this means the redistribution of oscillation energy is realized.

It should be noted that the range of the subharmonic resonance is narrower than that of the fundamental resonance, and the amplitudes of the subharmonic oscillations are less.

The analysis of the obtained results supports the assertion that both the nature of the variations in the velocities of the wind flow and its duration have a pronounced effect on the characteristics of the surface pipeline oscillations. Particularly, the wind flow velocity of $V \cong 14,165ms^{-1}$ of a short duration can induce significant oscillations at the frequencies of the fundamental tone.

The system under study is defined as that with self-induced oscillations. The phase trajectories obtained on the plane $(y,\ \ddot{y})$ represent the closed curves; and their specific feature is that they are inversely symmetric to the axis $\ddot{y}$.

The "skeleton" curves of the phase trajectories on the plane $(y, \ddot{y})$ numerically estimated for in the "beating" and "swinging" modes (see fig. 2) looked very similar to the sloping straight lines. This is due to the fact that the non-linearity level of elastic force $R(y)$ is not large. The angle of slope of the phase trajectories towards the axis y on the plane $(y,\ \ddot{y})$ is proportional to the natural frequency ω_0 in the system being studied.

Under the action of the non-linear dissipative force, the acceleration of the points of the system mitigates rapidly after this acceleration achieves its maximal value. As a consequence, the ends of the phase trajectories on the plane $(y,\ \ddot{y})$ in the modes of the rapidly decreasing oscillations are sharp (see fig.2).

The phase trajectories obtained for the modulated oscillations on the plane $(y,\ \ddot{y})$ require a more close consideration. They consist of three closed curves having the angle of slope proportional to the natural frequency ω_0 of the pipeline. The formation of two additional loops on the phase trajectories $(y,\ \ddot{y})$ is attributed to the fact that the position of the oscillation center in the modulation modes is changes continuously, unlike the situation existing in the previously discussed modes.

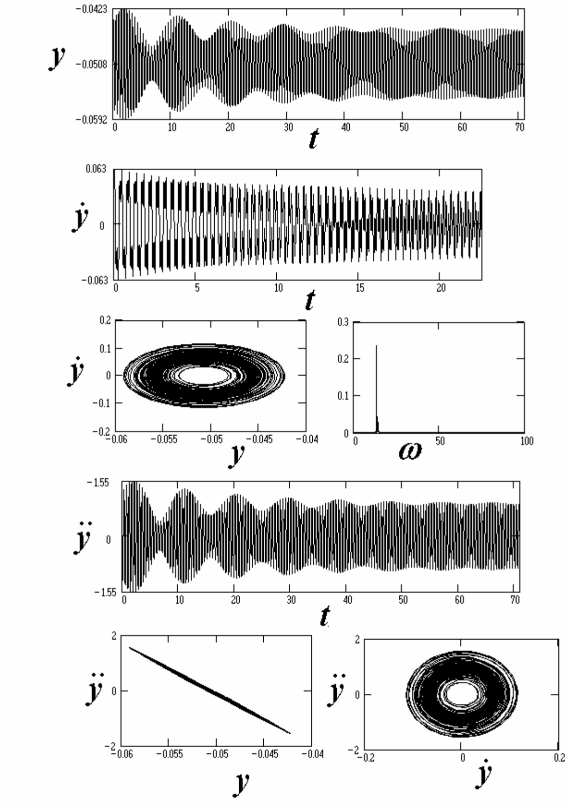

Fig. 2. Time processes, spectral characteristics and phase trajectories of vertical oscillations in a surface sagging pipeline at the velocity of $V = 4{,}5ms^{-1}$ of the uniform wind flow

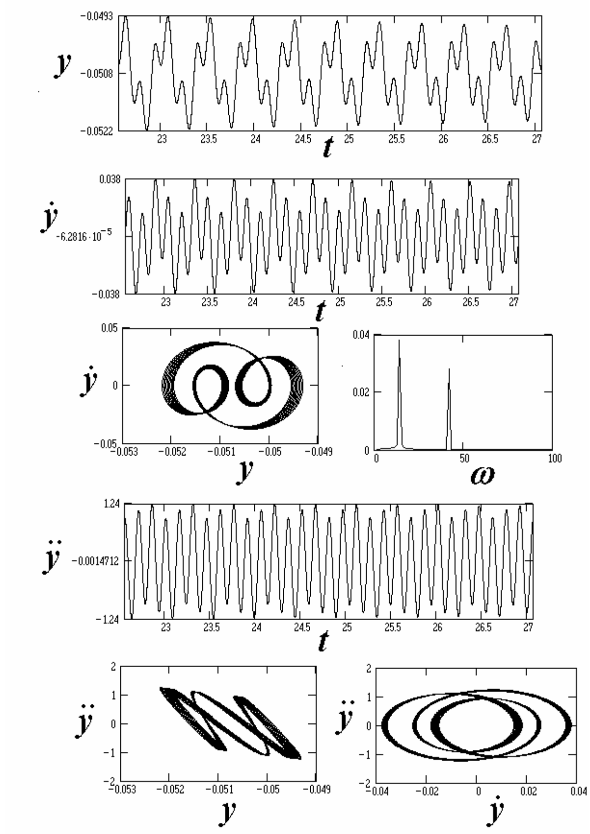

Fig. 3. Time processes, spectral characteristics and phase trajectories of vertical oscillations in a surface sagging pipeline at the velocity of $V = 14{,}165 ms^{-1}$ of the uniform wind flow

All the phase trajectories on both on the plane $(y,\ \dot{y})$ and the plane $(\dot{y},\ \ddot{y})$ have the shape of spirals; but these spirals are convolving at the damping oscillations and unwinding as the oscillations increase.

4. CONCLUSION

The phase trajectories obtained for the modes of "beatings" on the planes $(y,\ \dot{y})$ and $(\dot{y},\ \ddot{y})$ convolve or unwind alternately. The distance between the spiral loops varies, depending on the action exerted by the dissipative forces per cycle of oscillations. The phase trajectories of the modulated oscillations on the planes $(y,\ \dot{y})$ and $(\dot{y},\ \ddot{y})$ consist of three closed curves, which are inversely symmetrical relative to the axes $\dot{y}$ and $\ddot{y}$, respectively.

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