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Wind powered plantigrade machine moving against a flow

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Abstract: Dynamics of the Chebyshev plantigrade machine on a rough horizontal plane is studied. The machine has four legs each of which is represented by a so-called λ-mechanism. A wind turbine is installed on the machine. The turbine transmits energy of the upcoming wind flow into the energy of walking motion of the mechanism. The shaft of the wind turbine is connected with the crank of λ-mechanisms by a reduction gear. The system has no any other drive unit except the wind turbine. The machine aims to move against the wind flow using only the energy of the wind. Aerodynamics of the wind turbine is described using a quasi-steady approach. The mathematical model of the mechanism is constructed in the form of second order dynamical system. Attracting periodic solutions of this system are described which correspond to regimes of self-sustained up-wind motion of the machine. Thus, the possibility of the wind powered walking motion in the up-wind direction is shown.

Keywords: Chebyshev plantigrade machine, wind turbine, self-sustained motion, stability.

1. Introduction

The Chebyshev machine with four λ-mechanism-legs became the first plantigrade machine in the world. Now this machine and its modifications are widely used in design of walking robots [1, 2].

Theo Jansen invented a wind powered walking mechanism based on another kinematic scheme. It is also important for robotic applications [3, 4]. Jansen's wind powered machine is intended for the down-wind motion; some modifications can move in the direction orthogonal to the wind.

Here, we introduce a wind powered walking mechanism designed for the up-wind motion. It is the Chebyshev plantigrade machine supplemented with a wind turbine. Such modification is inspired by Jansen's creations and by wind powered wheeled cars performing the up-wind motion, e.g. [5-7].

2. Description of the mechanical system and the main result

A modification of the Chebyshev plantigrade machine is suggested. Its scheme is represented in Fig. 1. The device is located on a rough horizontal plane and is equipped with a wind turbine. The shaft of the turbine is connected with the crank of the machine by a reduction gear. The machine is located in a steady wind flow and can move along the wind. The up-wind motion is the desired one.

It is supposed that all four shins of the mechanism always keep vertical orientation. Under this assumption, the mechanical system has one degree of freedom. The angle φ of rotation of the crank of λ-mechanisms is chosen as a generalized coordinate. Positive angular speed ω of the crank corresponds to up-wind motion of the machine. Vertical displacements of the body are neglected. Kinetic and potential energy of the system are described by the functions $K(\varphi,\omega)$ and $P(\varphi)$ (which are too cumbersome to present here). Equations of motion of the system are derived using the Lagrange formalism:

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$$\frac{d}{dt}\left(\frac{\partial K(\varphi,\omega)}{\partial \omega}\right)-\frac{\partial K(\varphi,\omega)}{\partial \varphi}+\frac{\partial P(\varphi)}{\partial \varphi}=nT(\varphi,\omega)-f(\varphi)\big(D(\varphi,\omega)+c\big(f(\varphi)\omega+V\big)\big),$$

$$T(\varphi,\omega)=0.5\rho Sr\big(f(\varphi)\omega+V\big)^2 C_T(z),\ \ D(\varphi,\omega)=0.5\rho S\big(f(\varphi)\omega+V\big)^2 C_D(z),\quad z=\big(f(\varphi)\omega+V\big)^{-1} nr\omega.$$

Here $f(\varphi)\omega$ is the linear speed of the body of the machine, z is the tip speed ratio of the wind turbine, V is the wind speed, ρ is the air density, S and r are the characteristic area and radius of the turbine, n is the gear ratio, c is the coefficient of the drag force acting upon the body of the machine, $C_T(z)$ and $C_D(z)$ are coefficient of aerodynamic torque and drag force acting upon the turbine (they are approximated using experimental data [8], see Fig. 1).

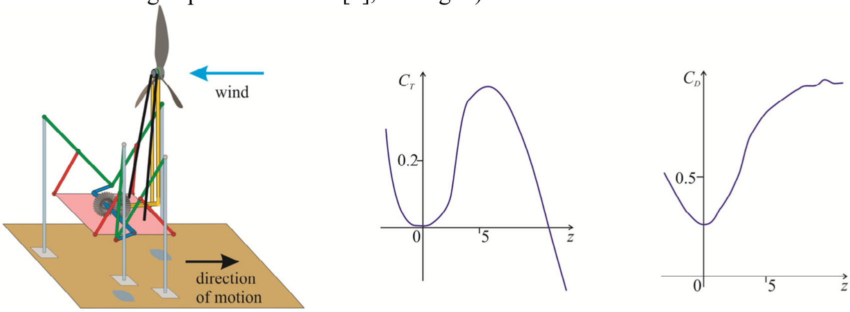

Fig. 1. The scheme of the mechanism. Aerodynamic coefficients.

It was shown numerically that for a wide range of parameters system has an attracting periodic solution with positive ω (reduction coefficient should be larger than a certain limit). Thus, the regime of up-wind walking exists. Parametrical analysis was performed to maximize the speed of the motion. The average speed of the up-wind motion can reach 20% of the wind speed. It is lower than that for a wind powered wheeled cars, but walking motion has advantages in certain areas in applications.

3. Conclusion

The wind powered walking mechanism is suggested that can move up-wind using only the energy of the wind. The average speed of the up-wind motion can be about 20% of the wind speed.

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