Modelling of Interaction of Human Being – Footbridge

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Abstract

The paper deals with the development of the model of interaction human being walking with flexible footbridge. The improved mechanical characteristics of materials, the new technologies or aesthetic purposes of footbridges result into the unpleasant feeling of the pedestrians or the walking stability lose. The purpose of modelling is to investigate such interaction. First the biomechanical multibody model of human gait is assembled using recursive multibody formalism. Second the interaction of human gait with flexible support is developed. Third the model of flexible footbridge is assembled and interconnected with multibody model of human gait. Finally the control of the interaction is proposed an developed.

Keywords: multibody modelling, biomechanical model, human gait, flexible footbridge

1. Introduction

The proper dynamic response examination of the flexible structures is appropriated great attention in the past few years. The improved mechanical characteristics of materials, the new technologies or aesthetic purposes have enabled to design more slender construction. The lightweight constructions are more sensitive to stability lost due to vibration. The same trend is valid for the very flexible footbridge too. Pedestrians walking on a footbridge exert a dynamic loading with dominant frequency components around 2 Hz in the vertical direction and around 1 Hz in the lateral direction. If the eigen frequency of the construction is in this range, the dynamic response from moving people can be significant. If the walking frequency is synchronized with the frequency of the bridge the resonant regime is activated. Which tend to the unpleasant feeling of the pedestrians or the walking stability lose. In the resonant regime the oscillation amplitude increases and pedestrians are forced to change their way of walking.

For the large oscillation amplitude co called structure-pedestrian synchronization can occurred. This phenomenon has been often experimentally detected and also analyzed in several studies. The involving of the suitable damper to the very flexible footbridge can solved this problem. It is necessary to derive the computational model for the proper design of the damping element. The most computational models that solve the dynamic interaction between subsystems pedestrian – flexible footbridge are based on the experimental data acquired on the concrete constructions. The transferring of these computational models on another construction is very problematic.

The paper deals with the assembly of the computational simulation model that solved the dynamic interaction between pedestrian and very flexible footbridge.

2. Biomechanical multibody modelling

The system of many rigid bodies (MBS) in 3D is used for modeling of the walking human [2]. The bodies are constraint by the spherical or revolving joins. The kinematic admissible variants of the human walking were generated by the optimization process. The inverse dynamic analysis was used for finding of the external forces that are necessary for the prescribed spatial motion of the walking human on the flexible footbridge. The Lagrange equations of the mixed type for the redundant physical coordinates were used for assembling equation of motion of the pedestrian. Due to interaction between separate subsystems the feedback control for the stability human gait was involved to the simulation model. The redundant physical coordinates were transformed to the general independent coordinates by the projection method for the state space.

The 3D biomechanical multibody model of walking human being (Fig. 1) consists of 13 rigid bodies interconnected by 8 spherical joints (1-2, 2-3, 2-6, 4-5, 7-8, 1-13, 1-9, 9-10, 1-11, 11-12) and 4 revolute joints (3-4, 6-7, 9-10, 11-12). The number of degrees of freedom (DOFs) is n=13*6-8*3-4*5=34.

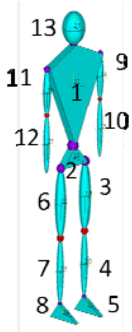

Figure. 1 Biomechanical multibody model

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The multibody model is described by the relative coordinates in the kinematical joints (8*3+4*1=28 coordinates) and by the physical coordinates describing the position of the body 1 (6 coordinates, 3 Cartesian coordinates of the centre of mass and 3 Cardan angles of orientation of the coordinates system of body 1 with respect to the frame). These coordinates are independent ones and therefore there are no kinematical constraints. The equations of motion are assembled by the recursive method of articulated body inertia [1]. This approach is computationally very efficient as the computational complexity of the computation of the accelerations is only O(n) where n is the number of joints. This is valid especially for the larger number of bodies as in the investigated case.

3. Modelling the interaction with flexible footbridge

The FE method was used for the modeling of the flexible footbridge. Due to computational speed the very complex FE model was reduced by the modal method. The fully parametric design of the subsystems pedestrian – footbridge was used. This enables effective modification of the geometric, stiffness and masses parameters of the solved system. In the article are investigated the conditions when the walking stability is canceled. The dynamic forces influenced the subsystems each other are analyzed. The computed dynamic characteristics are compared with the admissible acceleration in the vertical and lateral directions. The model of the interaction is in Fig. 2 [2] and the resulting model in Fig. 3.

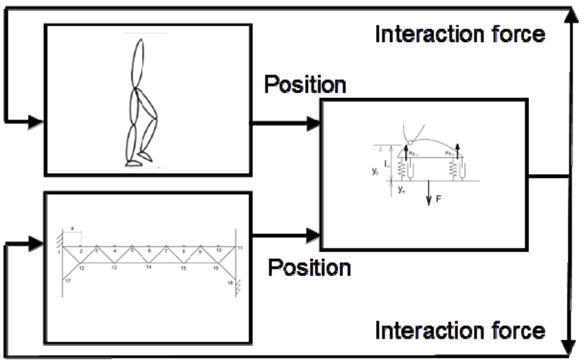

Figure 2. The force interaction

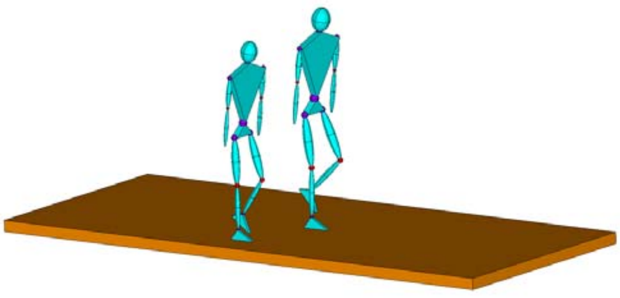

Figure 3. The resulting interaction model

4. Control of biomechanical model for human walking

The biomechanical multibody model of the walking human being is highly nonlinear. Its control is based on the combination of two approaches.

The first one is the usage of the nominal time behavior of the coordinates of the biomechanical multibody model such that they constitute the periodic gait of the walking human being. The suitable time behaviors of the coordinates are described as the spline functions of the time. The result is in Fig. 4.

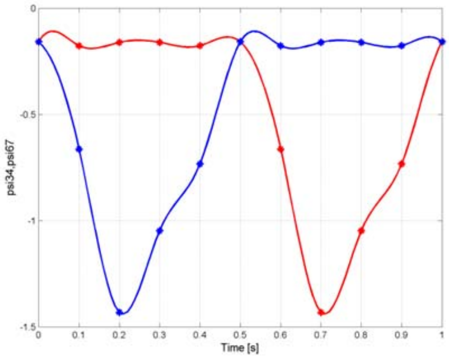

Figure 4. The description of one periodic footstep

The second one is the stabilization of the gait. The derived human gait can operate only within static environment (foundation). The human being can adjust his behaviour according to the unexpected deviation in the environment (foundation). It is realized by the feedback balancing by the control torques in the joints by the control torques. All relative coordinates are actuated by the control torques but the physical coordinates of the body 1 are not actuated. This means that the system is underactuated and this is the main difficulty of the control [3]. In the full generality it is very difficult problem. However, several simplified approaches are available [2]. One approach is the LQR control of time varying linearized model around the nominal trajectory. It usually suffices, but if the time variance of the system matrices is rapid then it is necessary to use the method for pole placement of time varying linear system.

5. Conclusions

The paper describes the development of the model of human gait with flexible footbridge. Its development required solution of many peculiar problems of mechanics and control. The model now enables to investigate many different phenomena such as the different human gaits, different stabilizing feedback laws, the explanation of the footbridge vibrations induced by persons and the influence of bridge design on the human perception.

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