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The kinetic analysis of the lifting of waltz's center of gravity based on the mechanical impedance model

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ABSTRACT

This paper studies the lifting technology in the Waltz dance action, by analyzing the human action in the lifting process of the waltz's center of gravity, establishes the transfer function of the lifting process of waltz center of gravity, on the basis of waltz lifting process, establishes the human mechanical impedance model with five degrees of freedom, obtains the body's impedance transfer function of the dancer's head, waist, thigh and calve during the lifting process, uses the overall relationship of the above four transfer functions and the human body system, and establishes the human chain model of waltz dance. Through the established human body's impedance model, this paper tries to produce an illuminating effect for the research of waltz dancers' lift technology.

KEYWORDS

Impedance model;
Transfer function;
Lifting technique;
Chain model.

INTRODUCTION

Waltz originates from the folk Austria, first is popular in 12th century Europe, enters in royal palace in 17th century called as court dance, and its technologies include reflexive, swing, tilt and lifting technology. Lifting technique refers to the body's up and down when dancing, the action is completed in the flexion and extension movements of knee, ankle and toe joints, the study of the technology mostly stays in experience. Based on the lifting technology and mechanical impedance model, this paper analyzes the impedance model in the lifting process of the dancers.

For the research of impedance model many people have made many efforts, on the basis of previous efforts, it studies lifting technology in the waltz action, established he mechanical impedance model with five degrees of freedom, deduces four separate transfer functions through modeling principles, and establishes the human body chain model of the waltz dancer for the human body system.

MECHANICAL IMPEDANCE MODEL OF THE HUMAN BODY

The purpose of the human body's mechanical impedance model is to use theoretical model to represent the human body, the main part of the body is modeled as a complex spring-mass-damper system. The model building is divided into two different methods. One is to consider the entire model as a number of components, and obtain the mathematical model according to the mechanical properties of the components. And the other one is through the experimental method, to study the human body as a whole, this method is also called “black box” approach. The former one is more complex in these two methods, and difficult to achieve; and the latter one has a strong practicability. The modeling method of “black box” is shown in Figure 1:

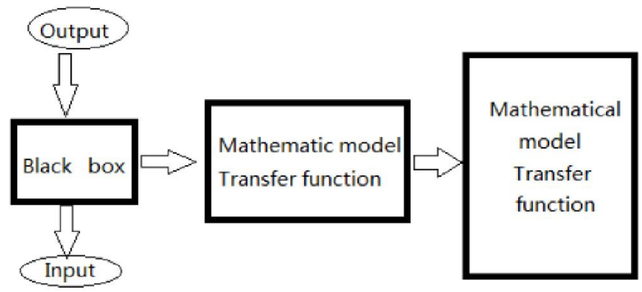

Figure 1 : Mechanical impedance modeling process of the human body

Model building

The human body can be simplified as a system composed of mass-spring-damper. The human vibration model is divided into series, parallel and mixed model from the form. The series model is also known as a chain model. But the international standard mainly uses the parallel model. Figure 2 shows the body’s lifting dynamics model in waltz dance, which is composed of mass-spring-damper after the human body simplification.

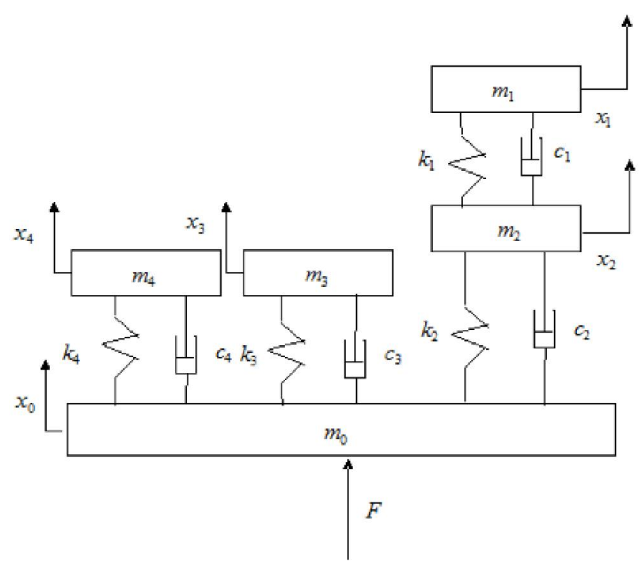

Figure 2 : The human body’s lifting dynamics model of Waltz Dance

Figure 2 shows the posture of a waltz dancer during the lifting process, the establishment of the human body’s dynamics model with five degrees of freedom, the establishment of differential equations based on dynamic theory, as shown in the formula (1):

$$\begin{cases} m_2\ddot{x}_2 + k_1(x_2 - x_1) + c_1(\dot{x}_2 - \dot{x}_1) + k_2(x_2 - x_0) + c_2(\dot{x}_2 - \dot{x}_1) = 0 \\ m_3\ddot{x}_3 + k_3(x_3 - x_0) + c_3(\dot{x}_3 - \dot{x}_0) = 0 \\ m_4\ddot{x}_4 + k_4(x_4 - x_0) + c_4(\dot{x}_4 - \dot{x}_0) = 0 \end{cases} \quad (1)$$

The matrix form of Formula (1) is as formula (2):

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = [B]\{q\} \quad (2)$$

In Formula (2) $[M]$ represents the mass matrix, as shown in the formula (3):

$$[M] = \begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & m_4 \end{bmatrix} \quad (3)$$

In Formula (2) $[C]$ represents the stiffness matrix, as shown in the formula (4):

$$[C] = \begin{bmatrix} c_1 & -c_1 & 0 & 0 \\ -c_1 & (c_1 + c_2) & 0 & 0 \\ 0 & 0 & c_3 & 0 \\ 0 & 0 & 0 & c_4 \end{bmatrix} \quad (4)$$

In Formula (2) $[K]$ represents the damping matrix, as shown in the formula (5):

$$[K] = \begin{bmatrix} k_1 & -k_1 & 0 & 0 \\ -k_1 & (k_1 + k_2) & 0 & 0 \\ 0 & 0 & k_3 & 0 \\ 0 & 0 & 0 & k_4 \end{bmatrix} \quad (5)$$

In Formula (2) $[B]$ represents the coefficient matrix, as shown in the formula (6):

$$[B] = \begin{bmatrix} 0 & 0 \\ k_1 & c_1 \\ k_2 & c_2 \\ k_3 & c_3 \end{bmatrix} \quad (6)$$

Therefore conduct Fourier transform on the $q\{x_0 \quad \dot{x}_0\}^T$ in formula (2) as shown in the formula (7):

$$Q(\omega) = \{X_0(\omega) \quad j\omega X_0(\omega)\} \quad (7)$$

Conduct Fourier transform on the formula (2) as shown in the formula (8):

$$\omega^2[M]\{X(\omega)\}+j\omega[C]\{X(\omega)\}+[K]\{X(\omega)\}=[B]\{Q(\omega)\} \quad \textbf{(8)}$$

If $[A]=-\omega^2[M]+j\omega[C]+\|K\|$ then we have the relation shown in formula (9):

$$\begin{cases} [A]\{X(\omega)\}=[B]\{Q(\omega)\} \\ \{X(\omega)\}=[A]^{-1}[B]\{Q(\omega)\} \\ \{X(\omega)\}=[A]^{-1}[B]\begin{Bmatrix} 1 \\ j\omega \end{Bmatrix}\{X_0(\omega)\} \end{cases} \quad \textbf{(9)}$$

The transfer function of the human response is in formula (10):

$$H(\omega)=[A]^{-1}[B]\begin{Bmatrix} 1 \\ j\omega \end{Bmatrix} \quad \textbf{(10)}$$

If $[E]=\{1 \quad j\omega\}$ then we have the simplified expression of the formula (10) as shown in the formula (11):

$$H(\omega)=[A]^{-1}[B][E] \quad \textbf{(11)}$$

The transfer function of Waltz dancer's various body parts

Formula (11) represents the general formula of the human body's transfer function; the transfer function $H_1(s)$ of the dancer's head is in formula (12):

$$H_1(s)=\frac{X_1(s)}{X_0(s)}=\frac{(c_1s+k_1)(c_2s+k_2)}{\Delta(s)} \quad \textbf{(12)}$$

In Formula (12), $s=j\omega$.

The transfer function $H_2(s)$ of the dancer's waist is in formula (13):

$$H_2(s)=\frac{X_2(s)}{X_0(s)}=\frac{(c_2s+k_2)(m_1s^2+c_1s+k_1)}{\Delta(s)} \quad \textbf{(13)}$$

The transfer function $H_3(s)$ of the dancer's thigh is in formula (14):

$$H_3(s)=\frac{X_3(s)}{X_0(s)}=\frac{c_3s+k_3}{m_3s^2+c_3s+k_3} \quad \textbf{(14)}$$

The transfer function $H_4(s)$ of the dancer's calf is in formula (15):

$$H_4(s)=\frac{X_4(s)}{X_0(s)}=\frac{c_4s+k_4}{m_4s^2+c_4s+k_4} \quad \textbf{(15)}$$

In Formula (12) and (13) the expression of $\Delta(s)$ is in the formula (16) below:

$$\Delta(s)=[m_2s^2+(c_1+c_2)s+(k_1+k_2)](m_1s^2+c_1s+k_1)-(c_1s+k_1)^2 \quad \textbf{(16)}$$

Human body chain model

The apparent mass of dancer's body model is obtained by the ratio of the exciting force acting on the mass piece m_0 and the acceleration of the driving point, as shown in the formula (17) below:

$$m(s)=\frac{F(s)}{\ddot{x}(s)} \quad \textbf{(17)}$$

The force balance equation of the mass piece m_0 is shown in formula (18):

$$m_0\ddot{x}_0+\sum_{i=2}^{4}c_i(\dot{x}_0-\dot{x}_i)+\sum_{i=2}^{4}k_i(x_0-x_i)=F \quad \textbf{(18)}$$

By the formula (2) and formula (18) the formula (19) can be obtained:

$$F=\sum_{i=0}^{4}m_i\ddot{x}_i \quad \textbf{(19)}$$

The apparent mass of the model responsiveness is in formula (20) below:

$$M(s)=\frac{F(s)}{s^2X_0(s)}=m_0+\sum_{i=1}^{4}\frac{m_iX_i(s)}{X_0(s)} \quad \textbf{(20)}$$

Depending on the quality apparent mass we can obtain the mechanical impedance $Z(s)$ of the driving point of the human body model, as shown in formula (21):

$$Z(s)=\frac{F(s)}{sX_0(s)}=sM(s) \quad \textbf{(21)}$$

When the body is exposed to whole-body vibration, it will typically exhibit nonlinear characteristics. If the applied vibration acceleration is less than 4m/s2 when determining the mechanical driving point's impedance of the human body, the human body can be approximated seen as a linear system. For a linear system, the transfer function of the human body's chain model is defined as formula (22):

$$H(p)=\frac{\sum_{i=0}^{n}\alpha_i P^i}{\sum_{i=0}^{m}\delta_i P^i} \tag{22}$$

In Formula (22) $\alpha_0=\delta_0,\alpha_1=\delta_1,$, n indicates the number of degrees of freedom.

The lifting human body model of the waltz dancer studied in this paper is a chain model with 5degree of freedom, and the transfer function is in formula (23) below:

$$H(p)=\frac{\sum_{i=0}^{5}\alpha_i P^i}{\sum_{i=0}^{7}\delta_i P^i} \tag{23}$$

CONCLUSIONS

This paper studies the application of the principles of mechanical impedance model in the human movement, and establishes the transfer function of the lifting process of waltz center of gravity; on the basis of waltz lifting process, establishes the human chain model with five degrees of freedom; calculates the body's impedance transfer function of the head, waist, thigh and calve during the lifting process, and uses the overall relationship of the above four transfer functions and the human body system, establishes the human chain model of waltz dance. The model established in this paper can be applied to other analysis of simple human movement.

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