Study on the Stability of Forefoot at Striking Moment in the Table Tennis Competition

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Abstract: In the table tennis competition, the stability of forefoot at striking moment is an important factor affecting the results of competition. However, the analysis of the stability of forefoot in the table tennis competition is mainly through the finite element modeling, but the accuracy of this method is not high. In this paper, a method of analyzing the stability of forefoot in the table tennis competition based on the static analysis is put forward. First, relevant literatures are obtained and relevant data is collected, and the process of analyzing stability of forefoot using static analysis is described. The experiment shows that the method proposed in this paper is of high accuracy and has strong value in use.

Keywords: Table tennis competition; Striking moment; Stability of forefoot

1. Introduction

Table tennis is one kind of sports with strong exercise value, which has a positive effect on improving physical coordination ability, reaction ability and operation ability, and has attracted wide attention. With the rise of table tennis, table tennis competitions are held more often in people's lives. In the table tennis competition, the ball needs to be struck to receiver's court to win the game. In the process of striking, the stability of the forefoot is particularly important, which not only affects the physical stability of player at striking moment, but also affects the direction and power of striking, thus, it has an impact on the results of competition. Therefore, it is very important to analyze the stability of forefoot in the table tennis competition. By analyzing the stability of forefoot in the table tennis competition, the scoring rate of the table tennis player is improved, so as to advance the player's performance. However, most of current analysis methods for the stability of forefoot in the table tennis competition are through the finite element analysis to determine influencing factors, and via the buckling analysis to ensure the maximum load for forefoot while maintaining stability. This method has become the main method to solve the problem because of the high accuracy and good value of research, which has been widely concerned by relevant experts and scholars. With the deepening of the importance of table tennis, a lot of research results are produced.

In the a method of analyzing the stability of forefoot at striking moment in the table tennis competition was put forward. Based on the theory of limit equilibrium and slices method, the stability analysis model of forefoot at striking moment in the table tennis competition was established. The gravitational force of body applied on the forefoot at striking moment was considered as a concentrated force to estimate the additional pressure of gravitational force on the forefoot. Thus, the stability analysis of forefoot in the table tennis competition was established, and the calculation formula of the load stability was given. But this analysis method has more complex process, the data obtained through the analysis has more errors. In the a method of analyzing the stability of forefoot in the table tennis competition based on multi-population genetic algorithm (MPGA) was proposed. Firstly, the finite element method was combined with MPGA to establish a general model for analyzing the stability of forefoot at striking moment in the table tennis competition under the situation of complicated pressures. The load stability coefficient was solved by numerical stress field, and the fitness function of MPGA was constructed. On this basis, the displacement was provided for the calculation of the load stability coefficient by using MPGA. In order to ensure the accuracy of the analysis, according to the development trend of the forefoot displacement at striking moment in the table tennis competition, the initial displacement was dynamically generated and a constraint condition for the displacement was added to realize the analysis. However, this method has the complicated computation process and difficulty in analyzing. In the a method of analyzing the stability of forefoot in the table tennis competition based on the finite element strength reduction method was brought up. First, the UFIELD program of the ABAQUS software was used to define the field variable in the software as the reduction coefficient and the field variables were established. The relationship between the time and the strength parameters was analyzed using the software and the maximum stress of the forefoot was taken as the basis. The strength reduction of the forefoot was simulated and the load stability was determined. But this method has the problem of poor accuracy of analysis.

In order to solve the above problems, this paper presents a method to analyze the stability of forefoot at striking moment in the table tennis competition based on the static analysis. First of all, the relevant literatures are summarized and analyzed, the pressure change data on forefoot at striking moment and forefoot movement during striking process in the actual table tennis competition are collected. On the basis of this, through the establishment of the stability analysis model of forefoot at striking moment in the table tennis competition, and analysis of the overall force and regional force of forefoot at striking moment, the analysis of stability is achieved. Experiments show that the method proposed in this paper has high reliability and has created good conditions for the research and development in this field.

2. Study on the Stability of Forefoot Ai Striking Moment in the Table Tennis Competitions

In the table tennis competition, the stability of forefoot of the player at striking moment directly affect the success rate of striking, thus affecting the competition result. Analysis of the stability of forefoot at striking moment in the table tennis competition is conducive to enhancing the stability, so as to improve the scoring rate. In the process of analyzing the stability of forefoot in the table tennis competition, the literature method, the measurement method and the mathematical analysis method are adopted.

2.1. Statics of the stability analysis of forefoot at striking moment in the table tennis competition

This paper found 10 relevant materials in the city library, and searches the related literatures in the database, such as China National Knowledge Infrastructure (CNKI) and Wanfang Standards Database (WFSD). The specific search results are shown in Table 1, Table 2 and Table 3.

Table 1. Lookup of relevant materials in CNKI

Search term	Number of search
Striking moment in table tennis competition	56
Analysis of the stability of forefoot before striking	13
Analysis of the stability of forefoot at striking moment	12
Analysis of the stability of forefoot after striking	9

Table 2. Lookup of relevant materials in WFSD

Search term	Number of search
Analysis of the stability of forefoot before striking	10
Analysis of the stability of forefoot at striking moment	10
Analysis of the stability of forefoot after striking	8

Table 3. Lookup of Relevant Materials in Other Database

Search Term	Number Of Search
Striking moment in table tennis competition	42
Analysis of the stability of forefoot before striking	11
Analysis of the stability of forefoot at striking moment	9
Analysis of the stability of forefoot after striking	7

Through lookup in CNKI, WFSD and other database, same relevant materials are removed, a total of 58 references on striking moment in the table tennis competition are found, there are 14 references mentioning analysis of the stability of forefoot before striking, 12 references analyze the stability of forefoot at striking moment, 9 references analyze the stability of forefoot after striking. The reading of these references shows that the forefoot at striking moment is usually left foot, through the lookup in relevant materials to lay the foundation for analysis of the stability of forefoot at striking moment inthe table tennis competition.

2.2. Actual measurement of the stability analysis of forefoot at striking moment in the table tennis competition

During the analysis of stability of forefoot at striking moment in the table tennis competition, the actual measurement is to choose 10 table tennis players, including 5 men and 5 women. The RSscan pressure sensor insoles and test data acquisition device are utilized. The RSscan pressure sensor insoles are placed in shoes, and the acquisition module is carried at the waist. The JVC-9800 digital camera and RSscan foot pressure measurement system are adopted to shoot 10 table tennis players' foot movement at striking moment. The striking moment is started with pressure on insoles generated by foot, and ended with disappearance of pressure. Each player performs 5 striking operations, when collecting data, camera signal and pressure distribution test signal of foot are collected synchronously. After the test is completed, the data in acquisition card is imported into the computer, and the measured data is analyzed with the Semi video analysis software and the system's Rsscan analysis software package. The average pressure peak and the pressure center trajectory of eight regions on the forefoot at striking moment of each player is analyzed, and the pressure center trajectory is standardized. The basic situation of 10 players tested is shown in Table 4.

Table 4. The situation of tested table tennis players

Number	Name	Gender	Height	Weight	Level	Shoe Size
01	Wang	Man	190	72	Level one	45
02	Zhang	Man	187	70	Level one	44
03	Li	Man	189	65	Level two	44
04	Liu	Man	184	69	Level two	44
05	Zhao	Man	179	67	Level two	43
06	Han	Woman	165	51	Level one	39
07	Ma	Woman	168	52	Level one	39
08	Qian	Woman	171	57	Level two	40
09	Zhou	Woman	164	50	Level two	38
10	Wu	Woman	169	56	Level two	39

In this paper, the forefoot at striking moment in the table tennis competition is divided into eight regions, respectively $T1$, $M1$, $M3$, $M5$, $V1$, $V2$, $H1$, $H2$. The specific location shown in Figure 1.

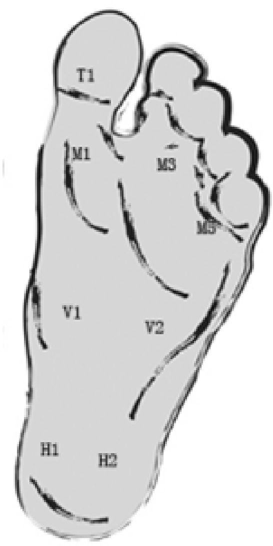


Figure 1. Distribution of eight regions of forefoot

It can be seen from Figure 1 that $T1$ is located at the first toe joint of forefoot; $M1$ is located at the first metatarsophalangeal joint of forefoot; $M3$ is located at the third metatarsophalangeal joint of forefoot; $M5$ is located at the fifth metatarsophalangeal joint; $V1$ is located at the tarsometatumal joint, between the first wedge and the first metatarsal, inside of transverse arch; $V2$ is located between cuboid and the fourth metatarsal, outside of transverse arch; $H1$ is located at the inside of calcaneus; $H2$ $H1$ is located at the outside of calcaneus. In the table tennis competition, these regions bear most of the weight of the human body, and adjust the balance of human body, through the stability analysis of these regions to achieve the stability analysis of forefoot at striking moment in the table tennis competition.

During the measurement process, because the player is moving to the ball, the body is moved forward, and the pressure on the forefoot becomes larger, with the intervening of the ball, the pressure on the forefoot tends to moderate. Through the test data acquisition device to collect the pressure and pressure peak of eight regions of forefoot at striking moment, starting and ending time of pressure change, and the percentage of it takes in the entire support time. Height, weight, foot length data of all players are collected.

Through the above discussion, the forefoot data at striking moment in the table tennis competition is acquired.

2.3. Stability analysis of forefoot at striking moment in the table tennis competition based on static analysis

Through the above method to achieve the data collection of forefoot at striking moment in the table tennis competition, on this basis, the stability of forefoot is analyzed, the specific analysis process is as follows.

There are three displacements of forefoot in the table tennis competition: u, v, θ, where u, v respectively represent the displacement of forefoot at the x, y direction in the table tennis competition, θ denotes the rotation angle of forefoot in the xy plane. Assuming that the displacement of forefoot at the x, y direction is expressed by the node discrete and orthogonal polynomial method, the displacement can be expressed as:

$$\begin{cases} u = \sum_{m=1}^{r} [\phi]\{u\}_m X_m(y) \\ v = \sum_{m=1}^{r} [\phi]\{v\}_m Y_m(y) \\ \theta = \sum_{m=1}^{r} [\phi]\{\theta\}_m \Theta_m(y) \end{cases} \quad (1)$$

In the above formula, $[\phi]$ denotes that the spline node is discretized, $\{u\}_m$, $\{v\}_m$ and $\{\theta\}_m$ denote spline node displacement arrays respectively, and $X_m(y)$, $Y_m(y)$ and $\Theta_m(y)$ denote the structural deformation function. The above formula is written in matrix form:

$$\{u\} = \begin{Bmatrix} u \\ v \\ \theta \end{Bmatrix} = [N]\{\delta\} \quad (2)$$

In the above formula, it means that displacement array of any point on forefoot at striking moment includes three components, u, v, θ, $[N]$ represents the shape function matrix of forefoot, $\{\delta\}$ is the generalized displacement vector of forefoot. $[N]$ and $\{\delta\}$ can be obtained with formula (1):

$$\{N\} = \begin{bmatrix} X_m(y)[\phi_0(x) & 0 & 0 & \phi_1(x) & 0 & 0 & \cdots & \phi_N(x) & 0 & 0] \\ Y_m(y)\,[0 & \phi_0(x) & 0 & 0 & \phi_1(x) & 0 & \cdots & 0 & \phi_N(x) & 0] \\ \Theta_m(y)[0 & 0 & \phi_0(x) & 0 & 0 & \phi_1(x) & \cdots & 0 & 0 & \phi_N(x)] \end{bmatrix} \quad (3)$$

$$\begin{cases} \{\delta\} = [\{\delta\}_1^T \quad \{\delta\}_2^T \quad \cdots \quad \{\delta\}_r^T]^T \\ \{\delta\}_m = [\{\delta\}_{0m}^T \quad \{\delta\}_{1m}^T \quad \cdots \quad \{\delta\}_{Nm}^T]^T \end{cases} \quad (4)$$

According to the formula (3) we can see:

$$\begin{cases} \{N\} = [\{N\}_0 \quad \{N\}_1 \quad \cdots \quad \{N\}_N]^T \\ \{N\}_i = [\{N\}_{i1} \quad \{N\}_{i2} \quad \cdots \quad \{N\}_{ir}]^T \end{cases} \quad (5)$$

$$[N]_{im} = \begin{bmatrix} \phi_i(x)X_m(y) & 0 & 0 \\ 0 & \phi_i(x)Y_m(y) & 0 \\ 0 & 0 & \phi_i(x)\Theta_m(y) \end{bmatrix} \quad (6)$$

For any region of forefoot, the displacement array consists of the displacement array of node i and j, that is:

$$\{\delta\}_e = \begin{Bmatrix} \{u\}_i \\ \{u\}_j \end{Bmatrix} = [u_i \quad v_i \quad \theta_i \quad u_j \quad v_j \quad \theta_j]^T \quad (7)$$

With the formula (2) we can see:

$$\begin{cases} \{u\}_i = [N]_i\{\delta\} \\ \{u\}_j = [N]_j\{\delta\} \end{cases} \quad (8)$$

Then the displacement of any region of forefoot can be expressed as:

$$\{\delta\}_e = [N]_e\{\delta\} \quad (9)$$

In the above formula, $[N]_e = \left[[N]_i \ [N]_j\right]$.

Taking into account the difference of local coordinate system of any region of forefoot and overall coordinate system of forefoot, coordinates need to be transformed, the unit displacement array in complete local coordinate system is:

$$\{\bar{\delta}\}_e = [T][N]_e\{\delta\} \quad (10)$$

The coordinate transformation matrix $[T]$ can be expressed as:

$$[T] = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 & 0 & 0 & 0 \\ -\sin\alpha & \cos\alpha & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos\alpha & \sin\alpha & 0 \\ 0 & 0 & 0 & -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (11)$$

Total potential energy fonctionelle of each region of forefoot is:

$$\Pi_e = \{\delta\}_e^T([k]_e\{\delta\}_e - \{f\}_e) \quad (12)$$

Substituting formula (10) into the above equation:

$$\begin{aligned} \Pi_e &= ([T][N]_e\{\delta\})^T([k]_e[T][N]_e\{\delta\} - \{f\}_e) \\ &= \{\delta\}^T[N]_e^T[T]^T[k]_e[T][N]_e\{\delta\} - \{\delta\}^T[N]_e^T[T]^T\{f\}_e \end{aligned} \quad (13)$$

The above formula can be converted to:

$$\Pi_e = \{\delta\}^T[K]_e\{\delta\} - \{\delta\}^T\{F\}_e \quad (14)$$

In the above formula, $[K]_e$ and $\{F\}_e$ can be expressed as:

$$\begin{cases} [K]_e = [N]_e^T[T]^T[k]_e[T][N]_e \\ \{F\}_e = [N]_e^T[T]^T\{f\}_e \end{cases} \quad (15)$$

Total potential energy fonctionelle of displacement of forefoot at striking moment in table tennis competition is equal to total potential energy of each region of forefoot, namely:

$$\begin{aligned} \Pi &= \sum_e \Pi_e \\ &= \sum_e(\{\delta\}^T[K]_e\{\delta\} - \{\delta\}^T\{F\}_e) \\ &= \{\delta\}^T\sum_e([K]_e\{\delta\} - \{F\}_e) \end{aligned} \quad (16)$$

From the above discussion, the overall displacement matrix $[K]$ and the total load array $\{F\}$ can be expressed as:

$$[K] = \sum_e [K]_e \quad (17)$$

$$\{F\} = \sum_e [F]_e \quad (18)$$

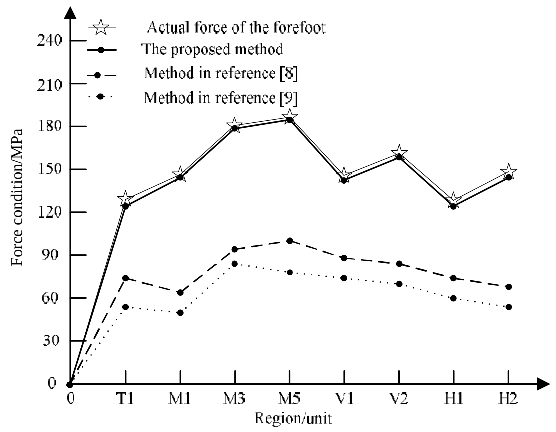
Therefore, the stability analysis of forefoot at striking moment in table tennis competition can be implemented based on static analysis.

3. Experiment Results and Analysis

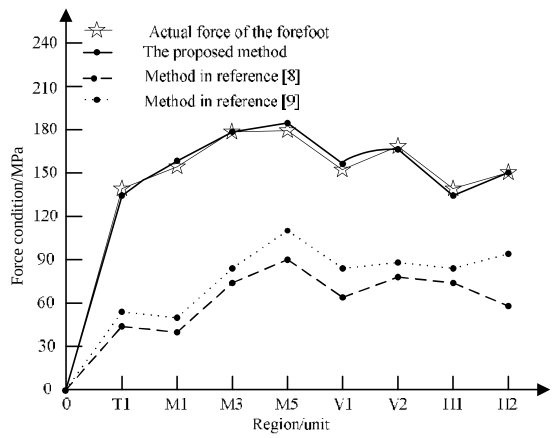
In order to prove the validity and feasibility of the method proposed for analyzing the stability of forefoot in the table tennis competition based on the static analysis, an experiment was carried out. The experiment was conducted under the operating system Windows 7 Ultimate, the CPU model is 3.2Ghz Intel Core I3, running platform is Microsoft Visual Studio.NET 2010. Based on the data collected in section 2.2 of this paper, the method proposed in this paper and in and were adopted to analyze the stability of forefoot in table tennis competition. The results are compared and analyzed to complete the experiment.

First, the block method mentioned in 2.2 was used to divide regions of forefoot at striking moment in the table tennis competition, and the force situation of forefoot before striking, at striking moment and after striking are analyzed. Three methods are used to analyze the force situation of forefoot, the analysis results shown in Figure 2.

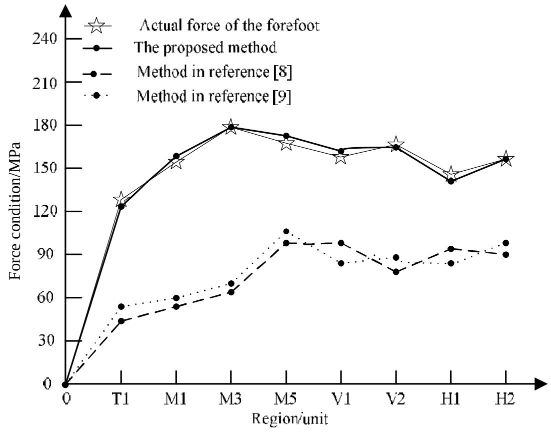
It can be seen from Figure 2 that the method proposed in this paper has force situation analysis closest to the real force situation, which shows that the method proposed in this paper has better accuracy. In this paper, the method of studying divided regions and then combining has greatly improved the accuracy of analysis, so as to improve accuracy of force situation analysis.



(a) The force situation of forefoot before striking



(b) The force situation of forefoot at striking



(c) The force situation of forefoot after striking

Figure 2. The force situation analysis of forefoot at striking moment in table tennis competition

Then, in order to ensure the accuracy of the experiment, 50 experiments were carried out in the table tennis competition to collect the displacement (cm) of each region of forefoot before and after striking, and the average of experimental data was taken as the displacement of each region of forefoot before and after striking. Comparison of displacements obtained with three stability analysis methods is shown in Figure 4.

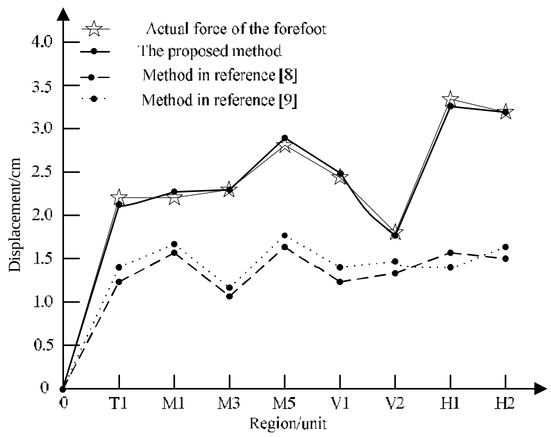


Figure 3. Displacement changes of forefoot before and after striking

Through the above figure we can see that the displacement change situation of forefoot analyzed with the proposed method is the closest to the actual situation. Because of the actual situation and forefoot movement in the competition during data collection, the accuracy of displacement analysis is improved.

Finally, we compared the accuracy (%) of the stability analysis of forefoot at striking moment in the table tennis competition. The comparison result is shown in Figure 4.

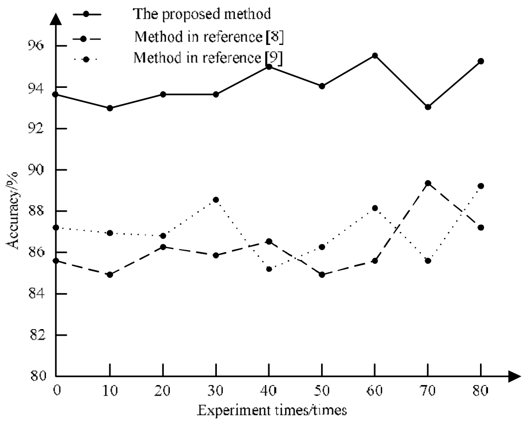


Figure 4. Comparison of the accuracy of stability analysis using different methods

It shows that the proposed method has better analysis accuracy. In summary, the method proposed in this paper can better achieve the analysis of stability of forefoot in the table tennis competition, and has strong value for application.

4. Conclusion

In table tennis competition, the stability of forefoot at striking moment impacts the table tennis player's physical stability, the direction and power of striking, thus affecting the competition results. The analysis of stability of forefoot in the table tennis competition, is conducive to improving the player’s performance. This paper presents a stability analysis method based on static analysis. Experiments show that the method proposed in this paper has high reliability and has created good conditions for the research and development in this field.

References

[1] Brereton R.C., Modi V.J. Periodic solutions associated with the gravity- gradient-oriented system. II - Stability analysis]. Aiaa Journal. 2015, 7(7), 1217-1225.

[2] Hou Ling, Xue Haibin, Zhou Zehua, et al. Research on the strength reduction FEM of the slope by applying the secondary development platform of ABAQUS. Journal of Xi'an University of Technology. 2016, 32(4), 449-454.

[3] Hu Bin, Yao Wenmin, Yu Haibing, et al. Stability analysis of slopes with interbedding of soft and hard rocks under the action of multistage excavation unloading. Science Technology and Engineering. 2016, 16(29), 281-286.

[4] Jin Jing, Yu Yuanliang. Slope stability research and analysis of highway. Bulletin of Science and Technology. 2016, 32(2), 193-196.

[5] Kamyar R., Peet M. Polynomial optimization with applications to stability analysis and control - alternatives to sum of squares. Discrete and Continuous Dynamical Systems - Series B (DCDS-B). 2017, 20(8), 2383-2417.

[6] Li Zhong, Yang Jun. Stability analysis of slope under complex stress conditions based on multi-population genetic algorithm. Rock and Soil Mechanics. 2015, 36(5), 1488-1495.

[7] Likins P.W., Lindh K.G. Infinite determinant methods for stability analysis of periodic-coefficient differential equations. Aiaa Journal. 2015, 8(4), 680.

[8] Ma Yuanyuan, Yang Lei. Modeling of Optimization Screening Mining for Optimal Table Tennis Athletes Physical Characteristics. Computer Simulation. 2015, 32(6), 382-385.

[9] Meirovitch L. A method for the liapunov stability analysis of force-free dynamical systems. Aiaa Journal. 2015, 9(9), 1695-1701.

[10] Rodden W.P., Bellinger E.D. Unrestrained aeroelastic divergence in a dynamic stability analysis. Journal of Aircraft. 2015, 19(9), 796-797.

[11] Seiler P. Stability analysis with dissipation inequalities and integral quadratic constraints. IEEE Transactions on Automatic Control. 2015, 60(6), 1704-1709.

[12] Tan Shichuan, Zhu Xueping,Yang Jun. Research on stability analysis of parasitical loop and guidance control related design method.Computer Measurement & Control. 2016, 24(9), 149-151.

[13] Telfer S., Erdemir A., Woodburn J., et al. Simplified versus geometrically accurate models of forefoot anatomy to predict plantar pressures: a finite element study. Journal of Biomechanics. 2016, 49(2), 289.

[14] Thompson M.A., Lee S.S., Seegmiller j, et al. kinematic and kinetic comparison of barefoot and shod running in mid/forefoot and rearfoot strike runners. Gait & Posture. 2015, 41(4), 957-959.

[15] Wan Yunxia, Wang Hongxia, Gao Ning, et al. A step-up converter based on the vertical parallel switch-capacitor network. Electronic Design Engineering, 2016, 24(17), 181-184.

[16] Wang C Y, Chai Y M, Wen G, et al. Superficial peroneal neurocutaneous flap based on an anterior tibial artery perforator for forefoot reconstruction. Annals of Plastic Surgery. 2015, 74(6), 703.

[17] Wang D.Q., Ye S.H., Zhu Y.P. Stability analysis of soil nail-anchor compound support structure with additional prestress. Journal of Lanzhou University of Technology. 2015, 41(1), 122-127.

[18] Wang H., Yu Y., Wen G. Stability analysis of fractional-order hopfield neural networks with time delays. Neural Processing Letters. 2015, 55(2), 98-109.

[19] Wen B., Boroyevich D., Burgos R., et al. Small-signal stability analysis of three-phase ac systems in the presence of constant power loads based on measured d-q frame impedances]. IEEE Transactions on Power Electronics. 2015, 30(10), 5952-5963.

[20] Zeng H.B., He Y., Wu M., et al. Free-matrix-based integral inequality for stability analysis of systems with time-varying delay. IEEE Transactions on Automatic Control. 2015, 60(10), 2768-2772.