RESEARCH ON THE DEVELOPMENT AND APPLICATION OF THE THREE-DIMENSION DIGITAL SHOT DYNAMOMETRY SYSTEM

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The author has developed the same three-dimension digital shot dynamometry system as international standard shots of sportsmen and sportswomen. Its core is force sensor of inside resistance strain type. This system can carry on wireless measurement alone, and also carry on the synchronous measurement of kinematics and dynamics with the camera, three-dimensional dynamometry platform. It can examine the force, force curve, resultant force value, curve and impulse of human bodies to shot in the three directions of X, Y and Z. This system is high in precision and reacts quickly. This system realizes unimpeded and hurtles check. It is safe and reliable. It can continuously measure, record, display, store, information processing and output and print, etc. Training experiments prove that this system is not only a kind of scientific research instrument but also a kind of training monitoring system. It will offer the strong assurance to coach and athletes' scientific training.

KEY WORDS: force sensor, measurement principle, shot-putter throwing arm force curve of Z direction

PREFACE: The rapid development of science and technology push the rapid improvement of the level of competitive sports. In recent 20 years, people have adopted photographing, video recording and three-dimension dynamometry platform to study kinematics and dynamics about the technology of putting the weight. However, until the year of 2002 there are few articles about instruments which test throwing arm and hand's special effort to apparatus. To explore the studying method in this field and solve the practical problem in physical education, training and scientific research, the Physical Institute of Hebei Teachers' University together with Hefei Institute of Intelligent Machines, Chinese Academy of Science designs and invents three-dimension digital shot dynamometry system. It weights 7.26 kg and 4 kg respectively. It can measure the three-dimension force information which athletes exert on shots during the throwing process in real time. It can be applied to practical sports training successfully.

Measurement principle of the three-dimension digital shot dynamometry system:
Figure 1 is the picture of measurement principle of the three-dimension digital shot dynamometry system. The system measures three-dimension force of X (horizontal), Y (axial) and Z (perpendicular to X, Y direction) from the hand to the shot. We choose the resistance strain gauge sensor which is pasted on the relatively sensitive part of elastic objects, making up three Wheatstone bridges. The three bridges react respectively to the efforts of the three X, Y, Z directions and transform the interactional forces of various directions into strain gauge geometry deformation, and finally get the amount of voltage which has the linear relation to the force. First it is required to return the resistance strain gauge bridge to zero, amplify with the amplifier INA122 and filter the wave from the output voltage. Then sample from the three channels of AD7888 and make the transformation between A and D. The results should be sent into the microprocessor. The data will be stored in static RAMHM628512. After the test, all data in the three-dimension digital shot will be read from the epigynous machine through the USB.

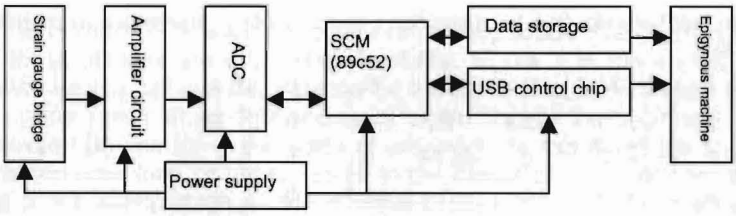

Figure 1 Measurement principle of the three-dimension digital shot dynamometry system.

Structure of the three-dimension digital shot dynamometry system: Figure 2 is the photograph of the material object of the tree-dimension digital shot. The digital shot forms a whole by joining the upper and lower hemisphere with an elastomer. The weight-compensation lump, power, data-gathering and electric circuit are all installed in the cavity of the lower hemisphere closely. The spheroid adopts the steel construction.

Figute 2 The tree-dimension digital shot.

Figure 3 The dynamometry sensitive.

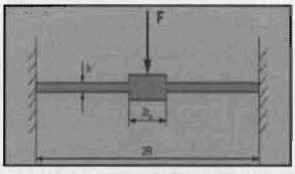

Figure 4 Element of the digital shot.

The spheroid's center of gravity and weight are the same as standard shot.

Sensor structure of the three-dimension digital shot dynamometry system: Figure 3 is the dynamometry sensitive element of the digital shot. It is a kind of elastomer which adopts the diaphragm structure of Model E and is made of 40Cr material. Its simplified mechanics-calculating model is the flat diaphragm with hard center under the function of concentrated load (Figure 4). Under the state showed in the figure, the largest deflection W of the diaphragm and the biggest stress σ both appear at the edge of the hard center. The concrete computing approach is shown as the following:

$$W_{max} = \frac{3(1-\mu^2)}{4\pi}\frac{FR^2}{Eh^3}\left[1-(\frac{r_0}{R})^2\frac{1-(\frac{r_0}{R})^2+4\ln^2(\frac{r_0}{R})}{1-(\frac{r_0}{R})^2}\right] \quad (1)$$

$$(\sigma_r)_{max} = \frac{3F}{2\pi h^2}\left[\frac{2\ln\frac{r_0}{R}}{1-(\frac{r_0}{R})^2}-1\right] \quad (2)$$

In the formula, F: the concentrated load; h: thickness of the diaphragm; r_0–radius of hard center; R: radius of the diaphragm; μ: the poison's ratio of diaphragm material; E: elastic mould amount of the diaphragm material.

When w/h < 0.3 and σ< 0.2 σm, the sensor has a good linear state. σm is the maximum of 40Cr material. When σ is bigger, the linear state of the sensor will be destroyed, that is, the change of the resistance is no longer in direct proposition to stress.

According to the range of measurement required by system, sensitivity and formula (1) and (2), optimizedly design the elastomer and finally get h = 2 mm, r_0 = 16 mm, R = 50 mm.

Demarcation of the sensor: The data which the three-dimension digital shot dynamometry system stores in the memory is actually digital voltage amount, so the sensor is needed to be demarcated. In the elastic range, the output voltage signal and the effort of the force sensor of resistance strain type become linear relation. The formula (3) shows that the purpose of demarcation is to work out the transformation relationship between this kind of voltage and effort.

$$\{F\} = [C]\{\varepsilon\} \quad (3)$$

{F}—loaded vector; [C]-revised matrix; { ε }—output voltage amount of bridge circuit.

The demarcation adopts loading in grades in different directions and then works out the revision coefficient of every direction. Because of adopting the special type of combining bridge, the sensor can remove the coupling between dimensions automatically. The final

transformation relationship can be seen from formula (4). Parameters in matrix get through demarcation test.

$$\begin{pmatrix} F_z \\ F_y \\ F_{-y} \\ F_x \\ F_{-x} \end{pmatrix} = \begin{pmatrix} 121.2 & 0 & 0 & 0 & 0 \\ 0 & 45.8 & 0 & 0 & 0 \\ 0 & 0 & 46.96 & 0 & 0 \\ 0 & 0 & 0 & 44.5 & 0 \\ 0 & 0 & 0 & 0 & 45.92 \end{pmatrix} \begin{pmatrix} \varepsilon_{Fz} \\ \varepsilon_{Fy} \\ \varepsilon_{F-y} \\ \varepsilon_{Fx} \\ \varepsilon_{F-x} \end{pmatrix} \quad (4)$$

Fz, Fy, Fx—effort of positive directions of Z, Y, X; $\varepsilon_{F\text{-}y}$ the voltage output of bridge in negative direction of Y; F-y—effort in negative direction of Y.

Synchronous establishment of the three-dimension digital shot dynamometry system and video recording: One light source is embedded in the synchronous mouth of the three-dimension digital shot. The light source is linked to the gathering touch switch of the dynamometric shot. When we carry on the touch measurement each time, the outer light source flickers once. In this way, the video can catch a luminous point and we will know the dynamometry shot's beginning point of gathering data from video picture, thus we can reach the synchronous measurement of dynamics and kinematics.

Main functions and characteristics of the system: Main functions of the system: During the complete process of athlete's pushing shot, this system can get the strength value of human body to shot in X, Y and Z directions in real time; can get the curves of the strength in the three directions which changing with time, the amount of effort of every direction and the curves changing with time, measure the impulse at any time in X, Y and Z directions. It also can conveniently store and read data through USB, output data of force at any time and type such files as curves.

Main technical indicator of the system: (1). The largest measurement range is ±400 N. (2). The precision of measurement is 2%. (3). The greatest overload capacity is 200%. (4). Gathering frequency is 0-100 Hz. (5). Distinguishing ratio is 0.1% F.S. (6). Every data gathering is 5seconds. (7). The most number of throwing can be stored is 20. (8). It can gather the groups from 1 to 12. (9). A 9V nickel hydrogen charge battery installs inside. (10). Working temperature is -40℃—80℃.

TRAINING EXPERIMENT AND ANALYSIS:

Examinees and approaches: In the stadium of Physical Institute of the Hebei Teachers' University in May of 2003 and November, we use the three-dimension digital shot dynamometry system, two JVC9800 videos, three pieces of three-dimensional dynamometry platform to test 7 shot-putters' kinematics and dynamics synchronously. See Table 1.

Table 1 The basic situation of examinees.

Athlete	Sex	Top Results (m)	Birth	Height (m)	Weight (kg)	Rank
Lv wen	male	14.70	1982	1.85	90	Second grade
Wang Yunfeng	male	13.70	1979	1.85	110	Second grade
Wang Sen	male	12.90	1985	1.88	115	Second grade
Li Meiju	female	18.78	1979	1.73	90	Master of sports
Wang Yawen	female	19.22	1973	1.79	98	Master of sports
Li Li	female	16.76	1987	1.73	110	First grade
Su Yumei	female	16.54	1985	1.75	102	First grade

Result of the test and analysis:

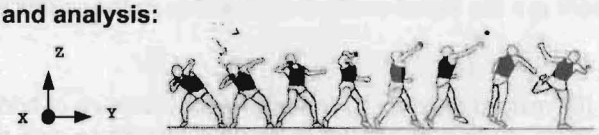

Figure 5 The curve graph of the three-dimensional dynamometry shot.

We analyze the technology of each athlete's best testing result. The force curves in three directions of these athletes are unanimous basically. Figure 5 is the sketch of Lv Wen's backsliding and pushing ball and the instance for the curve. The curve before (a) is to show from turning up the synchronous light source of digital shot to the beginning of pre-swing. The curve between (a) and (b) is the stage of pre-swing. In this stage the shot's receiving effort in Z direction rises form 101 N to 126 N. In the instant of right foot's leaving ground at the beginning of the sliding stage shown in curve of (b)-(c), the shot's receiving effort in Z direction rises from 126 N to 171 N. Z curve will be milder afterwards. (c)-(d) is transition stage. In this stage, the shot's receiving effort in Z direction rises from 171 N to 189N because of turning to right-heel knick, pushing and turning hip to move forward, left foot's rapid landing, left leg supporting hard, and the upper part of the body has a certain lifting. (d)-(e) is the last exerting stage with the left foot landing on the ground and the body keeping bow-shape, that is, the instancy of right hand's (holding hand) leaving right shoulder. In this stage, the shot's receiving effort in Z direction rises from 189 N sharply to 318.4 N. (e)-(f) is the stage from right-hand's leaving right shoulder to the shot's being thrown out. Because of the transmittance of supporting reactive force from foot, leg, hip, truck, throwing arm to hand, the shot has certain speed. Accordingly the shot's receiving strength value in Z direction reduces from 318.4 N to 120 N gradually. It is again the strength value in Y direction increases from 45 N to 48 N because of the forward stretch of the throwing arm. Since the athlete's last snapping of wrist and flicking the ball, the shot's receiving strength in Z and Y directions separately increases 11 N and 10 N. Y reaches the biggest of 58 N. Stage (f)-(g) is the athlete's buffer stage after releasing the shot, namely the shot's flying course after being released. The strength of three directions is minimum. Its curve is a low straight line. (g)-(h) is the shot's falling stage. The touching of shot and ground causes great strength value. This has nothing to do with shot-putting technology and is not analyzed here.

CONCLUSION: The core of the three-dimension digital shot dynamometry system is a shot with the three-dimension force sensor of resistance strain type installing inside. Its weight, diameter, etc. are all the same as shots of sportsmen and sportswomen of international standard.

This system can gather athletes' signals of exerting force during the complete pushing-shot process in real time. It can measure the strength value of human body to shot in X, Y and Z directions in real time; can get the curves of the strength changing with time, the amount of effort and the curves changing with time, measure the impulse at any time in X, Y and Z directions.

This system can not only carry on wireless measurement solely but also take synchronous measurement on kinematics and dynamics with video, three-dimension dynamometry platform.

This system is high in precision and reacts quickly. This system realizes unimpeded and hurtles check. It is safe and reliable. It can continuously measure, record and display. It can use computer to calculate, store, information process and output and print, etc.

This system is not only a kind of scientific research instrument but also a kind of training monitoring system. By this system coaches can find the advantages and disadvantages on athletes' technology. It will offer the strong assurance to coach and athletes' scientific training.

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