300. Loading characteristics of weight stack machines

V. Grigas[1], D. Satkunskienė[1/2], A. Domeika[1], R.-T. Tolocka[1], G. Rimsa[3]
[1] Kaunas University of Technology, Department of Engineering Mechanics,
Mickevičiaus 37, Kaunas
E-mail: ***tadas.tolocka@ktu.lt,*** +370 37 323498
[2] Lithuanian Academy of Physical Education, Laboratory of sport performance management,
Sporto 6, Kaunas, phone (+370) 37 209144.
[3] Baltec CNC Technologies, Raudondvario 148, Kaunas,
phone (+370) 37 314630, fax (+370) 37 314631.

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Abstract. The load characteristics of the weight stack machines, where the resistance is generated by inertia of the stack of masses, are the subject of the paper. The method and means of experimental research are described. The dependencies of inertial resistance load upon the rate of exercises and the stack weight are determined.

Keywords: Inertial load, resistance force, power training, weight stack machines, rate of the exercise

Introduction

Weights, whether free plates with bars or weight stack machines, are the traditional forms of applying muscle loading in strength and power training [1, 2]. Training with free weights and machines is effective in developing strength, muscular endurance and power by appropriate management of the key variables in conditioning programs: intensity, frequency, load, duration and cycling [3]. At the training with inertial loading, when the mass (weight applied to the sliding platform) is large, inherent inertial properties cause acceleration (resultant force) and deceleration to be low. Initial acceleration clearly depends on concentric muscular contraction, which has a definite peak threshold. As training advances or rehabilitation progresses, greater stress is applied to tissue by using a lower weight, which in its turn, corresponds to higher speed of the sliding platform and working joint. As speed increases, both concentric force and eccentric force output also increase, with a large percentage change in the eccentric component [1, 6, 7]. Any changes of motion, whether stopping or starting or changing velocity, are caused by a specific force.

There is a lot of means and methods for improving the performance and reducing injuries during strength training: functional training programs, the care of personal trainers and physical therapists, special food etc. [3]. Still there are some problems concerned with the design (determined?) peculiarities of the equipment. One of them is the relationship between the resisting load and the increased stress (force) applied to the musculoskeletal system.

Methods and means of investigation

An experimental investigation of the load characteristics of weight stack machines was performed with the aim to establish the variation of the resisting load generated by inertia of the stack of masses moved by means of levers, ropes, pulleys and blocks depending on the acceleration of motion during the exercise and the size of inertial mass.

Two separate sessions of exercises were performed when parameters of movements and load characteristics were analyzed on the basis of different equipment and subjects. The evaluation of the dependence of the magnitude of the resisting load upon the velocity of the Machine Bench Press exercise was performed on the base of universal body builder situated in Biomechanics laboratory of the Engineering Mechanics department of KTU, in which a 27 year old not trained man (weight – 75 kg, height – 180 cm) took part. The research of load characteristics during Vertical Chest Press, Seated Row and Leg (Knee) Extension exercises as well as Bench Press performed by a 31 year old very well trained man (weight – 105 kg, height – 181 cm) with different loads were carried out on the universal and specialized stack machines situated in Kaunas fitness center "Linija" (Fig. 1).

2D measurement and analysis system SIMI Motion was used for the measurement and analysis of variation in time of the positions of characteristic points of the stack machines (inertia mass, levers axes, handles) and sportsman (main joints) marked with special light reflective markers. Single digital video camera Canon XM1 (frame frequency 50 Hz) was arranged perpendicularly to the stack machines (to the sagittal plane in which the movement was performed during exercise) at the distance of approximately 4-5 m. After the performance was filmed, the movie was transmitted from the digital video camera to the personal computer and processed by means of motion analysis software SIMI Motion. As a result, the motion patterns of markers, their velocity and acceleration during exercises were obtained with the time step 0.02 second. The magnitude of the resisting load generated by the inertial mass has been calculated according the formula $F = m\cdot(a + g)$, were a – measured acceleration of the mass (m/s^2) (derived by differentiating mass displacement - time dependence), g – acceleration of gravity (g = 9.81 m/s^2), m – the mass of inertial load (kg).

During the first study Machine Bench Press exercise was performed with the 35 kg mass stack at a different rate: low – 24 cycles per minute, medium – 28.6 cycles per minute and high – 34 cycles per minute. Five cycles of each rate were analyzed.

During the second study the total mass of the stack was increased from 30 to 70 kg for exercises on stack machines and from 90 to 110 kg for bench press exercise. Five cycles of each exercise have been analyzed.

Fig. 1. Seated row, vertical chest press and leg (knee) extension exercises

Results of investigation

During the first study the curves of load force and inertial mass displacement have been obtained for machine bench press exercise performed at different rate with the same (350 N) weight stack mass (Fig. 2). It can be seen that the magnitude of force and weight stack displacement changes depending on the rate of exercise. At the low rate the maximal force is 388 N and the minimal – 305 N, and the normal rate gives quite similar values – 414 N maximal force and 248 N minimal force. Further increase of rate gives considerable (near 1/3) growth of maximal inertial resistant force – up to 518 N and reduction of minimal force (42 N, i.e. near 10 times).

The inertial resistance force - time dependency during the single exercise performed at high rate is presented in Fig. 3. It can be seen that the force reaches its maximum at the very beginning of the cycle (at the moment when the subject starts to press) and drops even lower than the value of inertial mass weight at the end of pressing (when the inertial mass of stack machine is on its highest position). When the inertial mass is released, the load force increases again to its static level and oscillates slightly till the end of cycle, lasting approximately 1,2 sec.

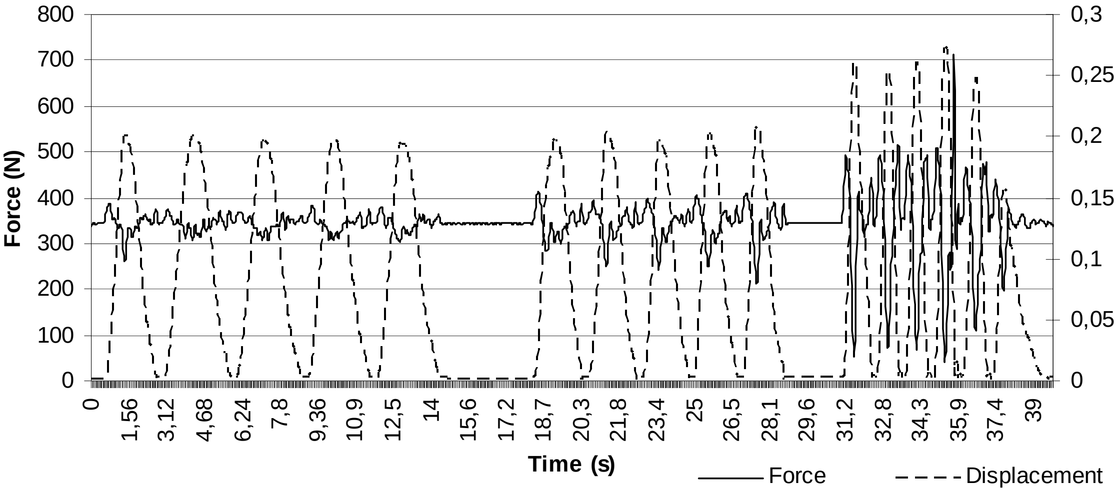

Fig. 2. The load force and inertial mass displacement during machine bench press exercise performed at different rate (low - at the left, medium – in the middle, high - at the right, five times each)

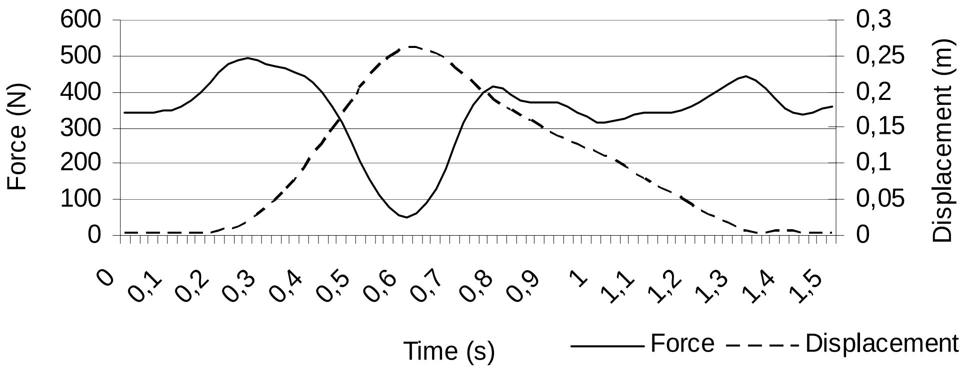

Fig. 3. The variation in time of the inertial resistant force during single exercise performed at high rate

The average value and a standard deviation of the maximal and minimal resistance force generated by the inertial mass loading system of the weight stack machines are presented in Table 1. These values are obtained when performing the seated row, vertical chest press and leg (knee) extension exercises with the 300, 600 and 700 N size weight of the stack mass as well as the bench press exercises with the 900, 1100 and 1300 N weight barbell.

It can be seen that the average maximal resistant load value varies between 682±24.7 N and 1608 ±101.3 N for exercises performed on the weight stack machines (both by hands and by legs) and between 1858±24.7 N and 1951±101.3 N for the bench press exercise. In turn, the average minimal resistance load value varies between 22±12.7 N and 199 ±40.9 N for exercises performed on the weight stack machines (both by hands and by legs) and between 2±92.3 N and 611±192.3 N for bench press exercise, that is similar as in the first study.

The maximal resistance force generated both by the inertial mass loading system of body builder machine and by the barbell in all cases was larger than that of inertial mass moved by the athlete during the exercises. The minimal difference was ~1.5 times for the bench press exercise with 1300 N barbell, the maximal ~3.08 times for the leg (knee) extension exercise with 300 N weight mass stack.

In all the cases (i.e. for all the exercises) the average maximal resistance force exceeds the size of the inertial mass stack weight more than twice when the inertial mass is the smallest (300 N on the weight stack machines and 900 N barbell). When the inertial mass is increased, the average maximal resistance force exceeds it differently for the different exercises:

- in the case of the vertical chest press it is 2.3, 1.5 and 1.6 times larger than the inertial mass (300, 600 and 700 N correspondingly);
- in the case of seated row it is larger than the inertial mass ~2.2-2.3 times for all inertial masses (300, 600 and 700 N);
- in the case of leg (knee) extension it is ~3.1, 1.9 and 2.2 times larger than the inertial mass (300, 600 and 700 N correspondingly);
- in the case of bench press average maximal resistance force exceeds the weight of barbell 2.0, 1.8 and 1.5 times in case of 900, 1100 and 1300 N barbell correspondingly.

The minimal resistance force depends on the inertial mass in the same manner – the smallest mass of stack gives the smallest resistance force (almost near 0 for bench press exercise with 900 N barbell, 50 N for vertical chest and seated row exercises with 300 N weight mass stack and 20 N – for the leg extension exercise with the same load).

In all the cases the minimal resistance force was lower than the size of inertial mass stack weight: from 2 to 9 times for exercises performed by hands, from 9 to 17 times for leg extension exercise and 2-4 times for the bench press (except the 450 times difference in case of 900 N barbell).

Table 1. The magnitudes of the resistant load and their standard deviations for the different exercises performed with different weight

	Stack mass weight (N)	Average Max force (N)	STDV	Average Min force (N)	STDV
Vertical chest press	300	682	24,7	52	25,7
	600	998	54,3	199	40,9
	700	1061	98,0	195	13,1
Seated row	300	692	44,1	46	39,5
	600	1314	82,2	67	35,8
	700	1608	101,3	122	75,9
Leg (knee) extension	300	925	95,4	22	12,7
	600	1146	195,9	36	23,6
	700	1541	386,3	76	43,1
Bench press	900	1858	121,8	2	92,3
	1100	1931	92,9	247	27,2
	1300	1951	247,4	611	192,3

Discussion

Body building machines where resistance force is generated by the weight of mass stack moved in vertical direction and depends on its vertical acceleration is one of the most popular types of such equipment. The load is generated similarly in exercises with free weights (barbells), with the difference that in this case the weight is moved by the athlete directly, without the help of kinematic circuit of machine, and that the athlete should also ensure the trajectory of movement of the mass (guided by way in the stack machines).

There is a lot of research done when establishing the influence of various intrinsic parameters of system athlete-machine, for instance, relationship between the force generated by muscle and the velocity or duration of the movement [1, 2], however the technique of the exercise (especially – the rate) and extrinsic parameters (for instance – acceleration of the inertial mass generating resistant force) is generally not taken into account. Thus recommendations are usually delivered regarding only the intensity, frequency, duration of the exercises and the size of mass stack [1, 4-6].

The results of the first study show that the magnitude of maximal resistant force generated by the inertial mass loading system of a body builder machine is in close relation with the rate of exercise. Even when the exercise is performed by not a sporty man, the maximal resistance force magnitude, obtained at the very beginning of the cycle, is apparently (1.3 times) larger in the case of higher rate. The drop of resistance force to the level lower than the weight of stack mass, having place at the end of press (when the inertial mass of stack machine is in its highest position), typical for machines with such type loading, is also dependent upon the rate of exercise (is deeper in case of higher rate). It is also obvious that a more advanced sportsman is able to reach an even larger amplitude of force by producing higher acceleration of inertial mass.

It can be seen from the results of the second study that the weight of the stack has also a significant influence on the maximal and minimal resistance force generated by such type equipment. The initial 300 N mass was quite low for the subject who was able to achieve maximal resistance force twice or even three times larger than the weight of the stack when performing the exercise with the appropriate rate (and naturally acceleration of inertial mass). When the weight of stack was increased up to 600 N and further to 700 N, the sportsman was able to produce resistance force only 1.5–2 times larger than the stack weight. Concerning the minimal resistant force, small size of the mass stack led to the situation when at the end of the first phase of exercise cycle resistance force dropped more than 10 times in comparison with the weight of the stack.

The differences in variation of the inertial resistance force for different exercises can also be seen quite clearly – thus vertical chest press with both 600 and 700 N weight of stack gave quite similar results (near 1000 N resistance force), the situation was similar with a bench press (near 1940 N with 110 and 1300 N barbell) while seated row and leg (knee) extension gave significantly larger inertial resistance force in case of 700 N weight of the stack (especially – during the leg extension exercise) in comparison with the exercise when the weight of the stack is 600 N. In all the cases, the exercises with minimal weight of the stack gave the highest maximal resistance force and lowest minimal resistance force.

Such a variety of the magnitudes of maximal and minimal resistance force is determined by the principle of generating it and the kinematics of weight stack machines and supports the findings of other authors.

The dependencies between the rate of exercise and the size of resistance force can be used for different purposes. The knowledge about real forces generated by such type machines depending on the type of exercise and its parameters should be useful for optimizing training programs, reducing risk of injuries and developing existing or creating new design of the stack machines.

Conclusions

1. The magnitude of the resistance force generated by the inertial mass loading system of a body builder machine is in close relation with the rate of exercise: nearly 30 % larger resistance force was obtained when performing machine bench press exercise at 10 % higher rate;

2. The magnitude of the resistance force generated by the inertial mass loading system of a body builder machine depends also upon the weight of the mass stack. Depending on the exercise type, the maximal value of the resistance force reaches from 150 to 300 % of the size of stack mass, while the minimal resistance force decreases in some cases even more than 10 times.

References

[1] **Zatsiorsky V. M.** *Science and Practice of Strength Training*. Human Kinetics, 1995, p. 243, ISBN 0-87322-474-4.

[2] **Hill A. V.** *The Mechanics of Active Muscle*. Proceedings of the Royal Society of London. Series B, Biological Sciences, 1953, Volume 141, Issue 902, pp. 104-117.

[3] **Boyle M.** *Functional Training for Sports*. Human Kinetics, 2004, p. 195. ISBN 0-7360-4681-X.

[4] **Baechle T. R, Earle R. W.** *Essentials of strength training and conditioning*/ National Strength and Conditioning Association. 2nd ed. Human Kinetics, 2000, p. 657. ISBN 0-7360-0089-5.

[5] **Dintimann G. B., Ward B., Tellez T.** *Sports speed*. 2nd ed. Human Kinetics, 1997, p. 243. ISBN 0-88011-607-2.

[6] **Zatsiorsky V. M., Kraemer W. J.** *Science and Practice of Strength Training*. 2nd ed. Human Kinetics, 1995, p. 251, ISBN 0-7360-5628-9.

[7] **Hardyk, A. T. T.** *Force- and power-velocity relationships in a multi-joint movement*. Thesis (Ph. D.) - Pennsylvania State University, 2000.