PROPOSAL OF AN ADDITIONAL-INERTIA TUNING METHOD TO VISCOUS LOAD FOR HIGH SPEED MOTION TRAINING

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This research proposes a new training system for high speed motions. In the proposed training system, a relatively small inertia is added to a viscous load in order to increase the load without decreasing the maximum speed. Moreover, in order to increase energy consumption of humans, we artificially make the additional inertia zero during motions. Consequently, the additional inertia is tuned to increase the load torque and the energy with keeping the maximum speed. The effectiveness of the proposed system is verified by some experimental results.

KEY WORDS: Muscle Strength Training, Mechanical Impedance, Variable Load, High Speed Training.

INTRODUCTION: Traditional muscle strength training devices are commonly classified into three types (inertia, viscosity, and elasticity). If inertia, viscosity or elasticity is individually used as a training load, there are basic problems. An Inertia load can give large load values to concentric muscles during accelerating, but during decelerating cannot. A viscous load can give load values in a full range of motions, but the load values become small at the beginning and the ending of motions. An elastic load cannot give large load values in the beginning of motions because this load increases in proportion to the position. Therefore each load has the merit and the demerit.

In this research, we consider training systems for high speed motions. If we base on training specificity, training systems should realize real high speed in order to improve athletic performance. It is reasonable to use viscous loads for high speed motion training because it is expected that viscous loads can easily guarantee safety in comparison with others. However, as mentioned above viscous loads can not make large load values in the beginning and ending of motions.

To solve this problem with viscous loads, this research proposes a new additional-inertia tuning method. In the proposed training system, a relatively small inertia is added to a viscous load in order to increase the load torque without decreasing the maximum speed. Moreover, in order to increase energy consumption of humans, we artificially make the additional inertia zero during motions. Consequently, the additional inertia is tuned to increase the load torque and the energy with keeping the maximum speed.

In recent studies, the effects of variable resistance training (VRT) were examined. However, the load combination patterns are limited and the load values can not be changed during motions because traditional inertia, viscosity, and elasticity devices were utilized (Wallace et al., 2006; Coker et al., 2006).

In order to exquisitely change inertia values, this research uses a variable mechanical impedance device, which was developed by the authors (Shigetoshi et al., 2008). By using this device, the additional inertia load can be suitably tuned in the beginning of motions and can be eliminated in the ending of motions. The effectiveness of the proposed system is verified by some experimental results for elbow flexion.

METHODS: Training System: This system consists of a direct drive motor with rotary encoder, a control computer and a lever arm with a handle grip. The initial angle of the lever arm sets at 0.785 rad from the downward vertical direction. For safety, a stopper is set in order to limit the lever arm rotation from 0 to 2.6 rad. To realize the variable mechanical impedance, this research applied a control method and mechanical impedance (inertia, viscosity, elasticity) could have variable values. More details are shown in (Shigetoshi et al., 2008).

Subject: One adult male (age, stature and body mass: 34 years, 1.78 m and 72.0 kg) participated in this study. Informed consent to participate in this study was obtained from this subject.

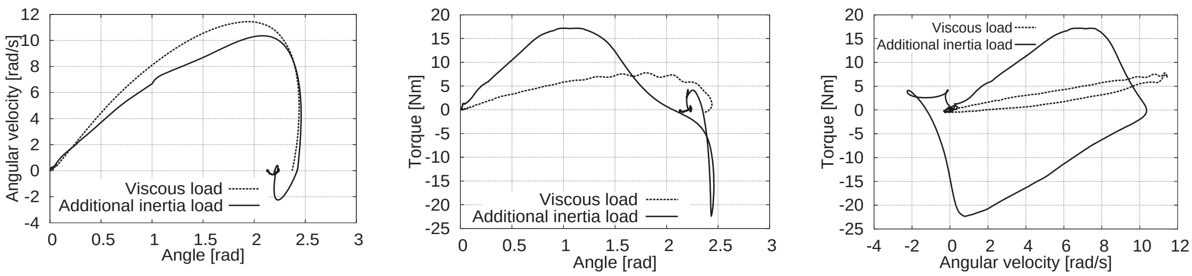
Experimental Conditions: We instructed the subject to generate the maximum muscle strength. Maximal voluntary elbow flexion from full extension to full flexion was measured. The upper arm was put on a stand. The centre of the elbow joint axis was aligned to the axis of the lever arm. Loading patterns we used are as follows.

1. Viscous Load: 0.5, 0.8, 1.2, 2.0, 3.0, 5.0 Nm/(rad/s) of viscous coefficients were used to obtain the standard data. In fact, it is impossible to perfectly eliminate the inertia and the elasticity because instability of a direct drive motor control occurs. Therefore, the inertia and the elastic coefficients was set 0.02 Nm/(rad/s^2) and 0.2 Nm/rad, respectively.
2. Additional Inertia: To increase the torque of the beginning of the motion and not to decrease the maximum speed, we investigated the suitable additional inertia value. As the result, we found that 0.2 Nm/(rad/s^2) was appropriate as the additional inertia.
3. Inertia Zeroing: The inertia coefficient 0.2 Nm/(rad/s^2) from 0 rad to $\pi/3$ rad of the joint angle was set. After $\pi/3$ rad, the inertia coefficient was set 0.02 Nm/(rad/s^2).

Data Analysis: Values are reported as mean $\pm$ SD. The experimental results for different loading were compared using One-way Factorial ANOVA. The level of significance was set $p \leq 0.05$.

RESULTS AND DISCUSSION:

Experimental Results of Additional Inertia Load: Figure 1 represents the experimental results of the viscosity case and the additional inertia case. The broken line shows the viscous load, and the solid line shows the additional inertia load in each graph. Figure 1 (A) shows the relationship between the angular velocity and the joint angle. It is observed that the maximum speed slightly downs in the case of the additional inertia load. On the other hand, the torque at the beginning of the motion significantly becomes large as seen in Figure 1 (B) and Figure 1 (C). Here, it should be noted that the negative torque is generated by inertia effect.



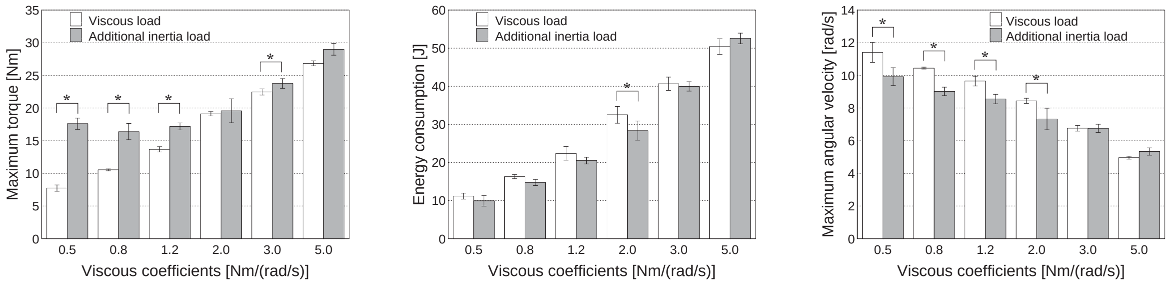
(A) Relationship between angular velocity and joint angle (B) Relationship between torque and joint angle (C) Relationship between torque and angular velocity

Figure 1: Viscous load vs. additional inertia load at low intensity load. Viscous load: inertia=0.02 Nm/(rad/s^2), viscosity=0.5 Nm/(rad/s), elasticity=0.2 Nm/rad. Additional inertia load: inertia=0.2 Nm/(rad/s^2), viscosity=0.5 Nm/(rad/s), elasticity=0.2 Nm/rad

Figure 2 represents the comparison of the viscous load with the additional inertia load for the maximum torque, the energy consumption and the maximum angular velocity. Figure 2 (A) shows the maximum torque on each load. From the figures, it is clear that the additional inertia load realizes much higher torque than the viscous load at 0.5 – 1.2 Nm/(rad/s) of viscous coefficient because the additional inertia becomes dominant at low viscous coefficients cases. Figure 2 (B) shows the energy consumption from the motion start to the end on each load. That was calculated by Eq. (1).

$$E = \int_0^T \tau_h(t)\dot{\theta}dt \qquad (1)$$

where T, $\tau_h(t)$, $\dot{\theta}$ denote the terminal time of motions, subject's exerted torque, angular velocity, respectively. From 0.5 to 3.0 Nm/(rad/s) of viscous coefficient, the energy consumption of the additional inertia load intends to be low as compared with the viscous load because negative torque is induced in the ending motion by the additional inertia. Figure 2 (C) shows the maximum angular velocity on each load. From 0.5 to 2.0 Nm/(rad/s) of viscous coefficient, the maximum angular velocity is significantly low as compared with the viscous load.



(A) Maximum torque (B) Energy consumption (C) Maximum angular velocity

Figure 2: Comparison between viscous load and additional inertia load for maximum torque, energy consumption and maximum angular velocity (* indicates significant difference at 0.05 level). Viscous load: inertia=0.02 Nm/(rad/s^2), viscosity=0.5-5.0 Nm/(rad/s), elasticity=0.2 Nm/rad. Additional inertia load: inertia=0.2 Nm/(rad/s^2), viscosity=0.5-5.0 Nm/(rad/s), elasticity=0.2 Nm/rad

Experimental Results of Inertia Zeroing: Figure 3 represents the characteristics of the inertia load. Figure 3 (A) shows a torque element induced by acceleration. Figure 3 (B) and Figure 3 (C) show angular velocity and power calculated by multiplying the torque and the angular velocity, respectively. This simply demonstrates the reason why the negative energy consumption is generated in deceleration phase.

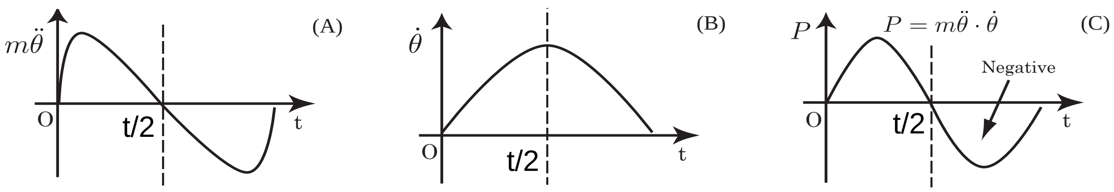
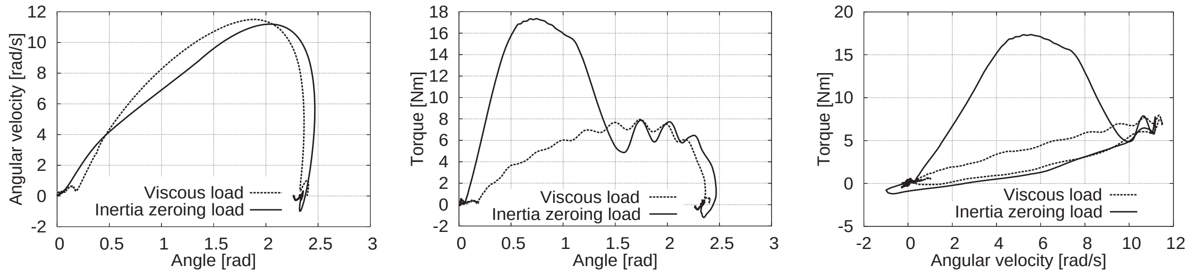


Figure 3: Characteristics of the inertia load

Figure 4 represents the experimental results of the viscosity case and the inertia zeroing case. The broken line shows the result of the viscous load and the solid line shows the result of the inertia zeroing load in each figure. Figure 4 (A) shows the relationship between angular velocity and joint angle. As seen in Figure 4 (A), the two peaks of speed are almost identical even though the phase of the peak is moved. It is understood that the angular velocity can increase after inertia zeroing. Figure 4 (B) and (C) demonstrate the effectiveness of the elimination of the negative torque.

Figure 5 represents the comparison of the viscous load with the inertia zeroing load for the maximum torque, the energy consumption and the maximum angular velocity. It is worth to compare Figure 2 with Figure 5. At first, the maximum torque can be effectively increased in both Figures 2 (A) and 5 (A). Next, the energy consumption can be significantly increased in low viscosity areas because of the elimination of the inertia as seen in Figures 2 (B) and 5 (B). Finally, the maximum angular velocity of the zeroing inertia (Figure 5 (C)) becomes closer to that of the viscosity load than that of the non-zeroing load (Figure 2 (C)).

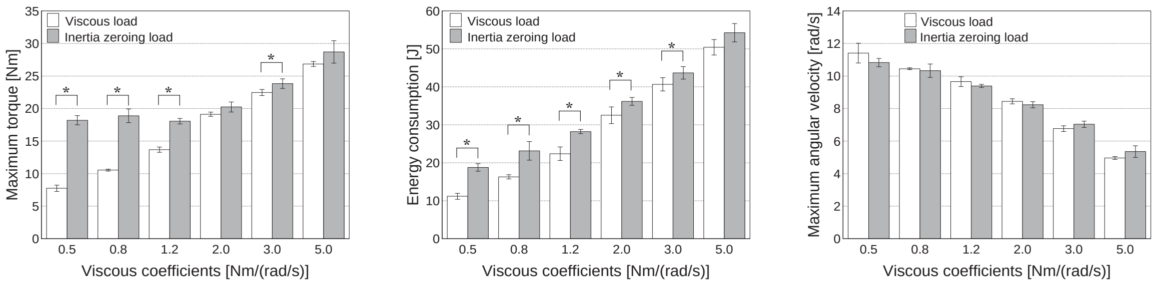


(A) Relationship between angular velocity and joint angle

(B) Relationship between torque and joint angle

(C) Relationship between torque and angular velocity

Figure 4: Viscous load vs. inertia zeroing load at low intensity load. Viscous load: inertia=0.02 Nm/(rad/s^2), viscosity=0.5 Nm/(rad/s), elasticity=0.2 Nm/rad. Inertia zeroing load: inertia=0.2 to 0.02 Nm/(rad/s^2), viscosity=0.5 Nm/(rad/s), elasticity=0.2 Nm/rad



(A) Maximum torque

(B) Energy consumption

(C) Maximum angular velocity

Figure 5: Comparison between viscous load and inertia zeroing load for maximum torque, energy consumption and maximum angular velocity(* indicates significant difference at 0.05 level). Viscous load: inertia=0.02 Nm/(rad/s^2), viscosity=0.5-5.0 Nm/(rad/s), elasticity=0.2 Nm/rad. Inertia zeroing load: inertia=0.2 to 0.02 Nm/(rad/s^2), viscosity=0.5-5.0 Nm/(rad/s), elasticity=0.2 Nm/rad

CONCLUSION: In this paper, we proposed a new strength training system for high speed motions. This research investigated how inertia should be added to viscous load in order to increase torque and energy consumption and not to decrease maximum speed of motions. From the experimental results, simple additional inertia to viscous load can increase the maximum torque but the energy consumption and the maximum angular velocity decrease. Therefore, we introduced the inertia zeroing method. It was experimentally verified that the inertia zeroing method can increase the maximum torque and the energy consumption without decreasing the maximum angular velocity.

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