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The Jerking Force by Hooked Carp and its Periodicity with the Tail Beat

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낚시에 물린 잉어가 미치는 힘과 꼬리 진동에 의한 주기성

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낚시 漁具 材料의 規格을 정하는 데는 우선 낚시에 물린 고기가 瞬間的으로 잡아채는 衝擊荷重, 疲勞荷重등을 기본적으로 고려하여야 할 것이다.

본 實驗은 釜山水産大學 養魚場에서 잉어가 낚시에 물렸을 때 미치는 힘을 strain gauge를 사용하여 測定하고 아울러 꼬리 振動 測定裝置를 만들어 꼬리의 振動과 힘의 變化를 同時에 記錄하여 分析해 보았다.

잉어가 낚시에 물렸을 때 미치는 最大의 힘 F_m은 고기의 體重 W에 따라

$$F_m=3.23W+105$$

로 나타났다. 시간 t_n에 對한 最大의 힘의 變化 F_n은

$$F_n=a_n(|t_n|+C)^{-b_n} \qquad (\text{단, } C=\left(\frac{a_n}{F_m}\right)^{\frac{1}{b_n}},\ -10T/2\leq t_n\leq 10T/2)$$

에서 $a_n=0.27W-6.52$이고 b_n은 평균 2.10이며 週期 T는 體重 W에 따라 $T=0.000385W+0.193$으로 주어진다. 잉어가 낚인 直後부터의 時間 t에 따라 꼬리 진동에 의한 각 peak점의 힘의 크기 F_p는

$$F_p=(2.23W+105)e^{-\beta t}+W$$

로 表示되는데, 낚시에 물린 初期段階에서는 持續指數 β가 거의 0에 가까우나 마지막 段階에서는 體重에 관계없이 평균 1.7정도 되었다. 또한, 잉어가 미치는 힘의 각 peak 점간의 주기는 꼬리 진동의 주기와 서로 밀접한 相關 關係가 있었다.

Introduction

The jerking force by hooked fish differs not only by various fish species but even among fish belonging to the same species. This dynamic force during jerk depends on their body weight and speed of movement which are related to the tail beat.

Ohshima (1953) measured the maximum jerking force by using several species of marine fish, and Koike (1954) experimented on the subject of pulling force for crucian carp. Sakazume and Kanamori (1971) investigated on the pulling force of fish caught by trolling gears. However, they investigated the maximum jerking force related to the body weight mainly.

The objects of the present study were to investigate the jerking force with durability and periodicity, and also to determine the relationship between the jerking force and the tail beat.

The measurements of the jerking force and the tail beat were carried out for carp by a strain gauge and the tail beat counter at the fish pond from July to August 1981.

The jerking force by hooked carp was changed violently like a wave form of saw blade within a short time as an impact load, and the peaks of the jeking force had a certain periodicity which was apparently related to the tail beat as a fatigue load decreasing gradually.

Materials and Methods

For the experiments about 170 common carp, *Cyprinus carpio* Linne, which were reared in the University pond, were used. Body weight of the fish varied from 60 to 450 *g*. The fish pond (50 m^2 in area, 0.7 *m* in depth) was stocked with carp to be hooked at the simulated natural condition. The water and the air temperature at the pond during the experiments ranged 23 to 27°C and 28 to 30°C respectively.

The measurements of the jerking force were carried out by using the strain gauge (2 *mm* long, KFC-2-C1-11, KYOWA). The strain gauge was attached to a side of the steel ring (30 *mm* in diameter). The upper end of the ring was fixed firmly and the lower end was connected with steel wire to a hook. The strain gauge was connected with lead wire through a strain amplifier (CDV-110A, KYOWA), then to a multi-channel recorder (RMV-550A, KYOWA RAPICORDER).

The calibration of strain gauge was made by using a weight up to 1.5 *kg* at the temperature 29°C. The measurements of the jerking force were made both in water and air for 30 carp under the speed of recording paper 10 *cm/sec* at the pond.

The tail beat movements have been analyzed by using a high speed movie camera (Hunter and Zweifel, 1971; Nashimoto, 1980) and a strain gauge (Yonemori *et al.*, 1979). Present authors devised the tail beat counter, as shown in Fig. 1, to investigate the relationship between the jerking force and the tail beat. It was a framework with short-circuiting switches on its both sides. As soon as the tail of fish pushed a lower part of the device, the switch was shorted and then caused the voltage difference that was recorded with multi-channel recorder.

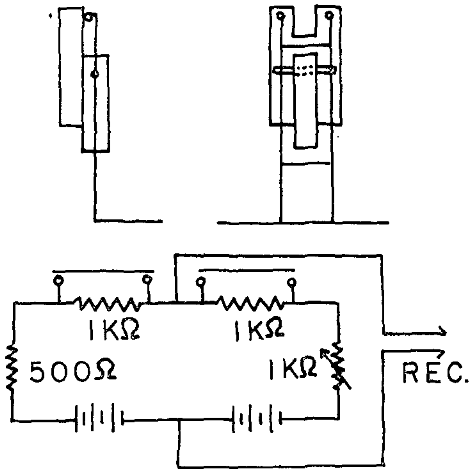

Fig. 1. Schematic diagram of the tail beat counter and its circuit.

Results and Discussion

The maximum jerking force was sustained for a while in the initial state after a fish was hooked, but the jerking force was gradually decreased as a function of the time elapsed until the fish was utterly exhausted, and it converged to the body weight at last.

1. The maximum jerking force by hooked carp

The maximum jerking force F_m (*g*) can be induced with the empirical formula $F_m=KW+F_0$, where K is a coefficient, W (*g*) is the body weight of a carp and F_0 is the value of F_m when $W=0$, shown in Fig. 2 and it can be expressed

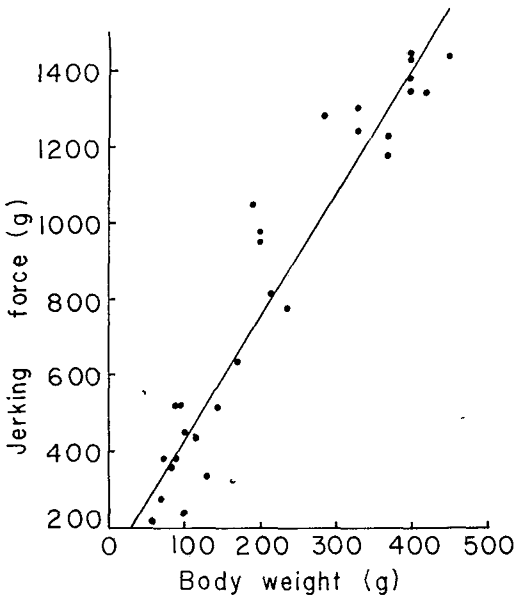

Fig. 2. Relationship between the body weight and the maximum jerking force of a carp.

as follows:

$F_m = 3.23W + 105$ (where correlation coefficient $r = 0.95$, number of sample $n = 30$)

Sakazume and Kanamori (1971) have measured the pulling force of skipjack, T_{max} (*kg*), caught by trolling and expressed the force as following equation:

$T_{max} = 3.21W + 0.51$

Ohshima (1953) has reported that the maximum jerking forces for the several kinds of marine fishes which were hooked naturally or artificially were approximately 4 to 8 times the body weight varing with the species.

The maximum jerking force was greater than the maximum swimming force because of the differences of physical conditions. The maximum swimming force was about the same with the body weight for perch and roach (Steinberg, 1963) and 1.5 times for rainbow trout (Nashimoto, 1980). Nashimoto (1969) has shown the force of rainbow trout swam into a mesh of net by electric shocks was 2 to 3 times the body weight.

The maximum jerking force must be varied by water temperature owing to the physiological condition (Webb, 1978; Yonemori, 1981). It is desirable to measure the jerking force under the different conditions for the other species, too.

2. Dynamic change of the maximum jerking force with time

The jerking force within a period was changed like a wave form of saw blade due to the tail beat as shown in Fig. 3. Dynamic change of the maximum jerking force F_n (*g*) with time t_n (10×sec) can be expressed as follows:

$$F_n = a_n t_n^{-b_n}$$

In the above equation, let F_n has a maximum value F_m at certain time C (10×sec), then, it can be expressed:

$$F_n = a_n(|t_n| + C)^{-b_n}$$

The mean value of the index b_n was 2.10

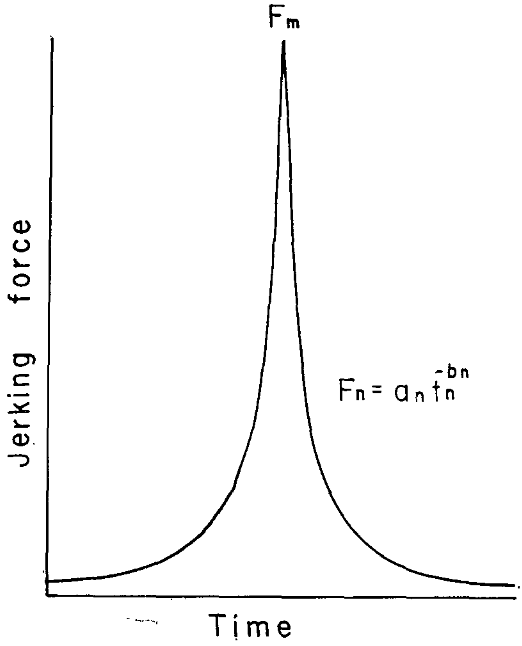

Fig. 3. Schematic recording diagram as a fractional function for the maximum jerking force with a period.

($S.D=0.30$, $n=32$) and had no relation with the body weight. The coefficient a_n and the period T (*sec*) shown in Fig. 4 at the maximum jerking force in accordance with the body weight W (*g*) are given in regression as follows:

$$a_n=0.27W-6.52 \qquad (r=0.82,\ n=32)$$
$$T=0.000385W+0.193 \qquad (r=0.77,\ n=23)$$

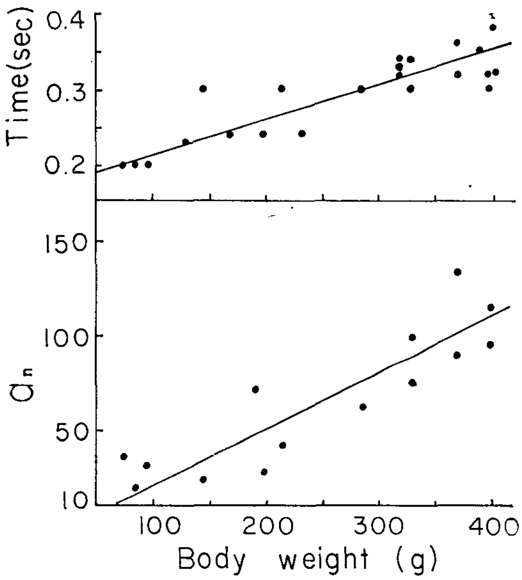

Fig. 4. The abscissa indicates the body weight and ordinate indicates the coefficient a_n and the period T.

The given time t_n ranged between $-10T/2 \leq t_n \leq 10T/2$. When the time t_n is zero, F_n equals to F_m, and then C can be given as follows:

$$C=\left(\frac{a_n}{F_m}\right)^{\frac{1}{b_n}}=\left(\frac{0.27W-6.52}{3.23W+105}\right)^{0.476}$$

It was clearly found that the jerking force changed violently from the minimum to the maximum peak point in a moment as an impact load. Further investigations are necessary to define the b_n and the a_n as an impact factor in consideration of physiological and enviromental conditions.

Yonemori *et al.* (1979) have observed the head movement of swimming carp by the use of strain gage imbedded in fish body and shown the record of strain of muscle with time like a wave form of saw blade. But they did not analyze the relationship between the strain and the period.

3. The periodicity of the jerking force

The jerking force at each of the peak points F_p (*g*) and its period were gradually decreased with the time elapsed t (*sec*), which were shown in Fig. 5. It can be expressed as following formula:

$$F_p=\alpha e^{-\beta t}+W$$

When t is infinite, F_p converges to the body weight W (Fig. 5-B), but it approximates to zero in water so that the body weight can be neglected.

When F_p was kept almost steady in the initial state (refer to Fig. 5-A), the value of durability index β was nearly zero, while when F_p was changed quickly in the exhausted state (refer to Fig. 5-B), β was about 1.5. Although the num-

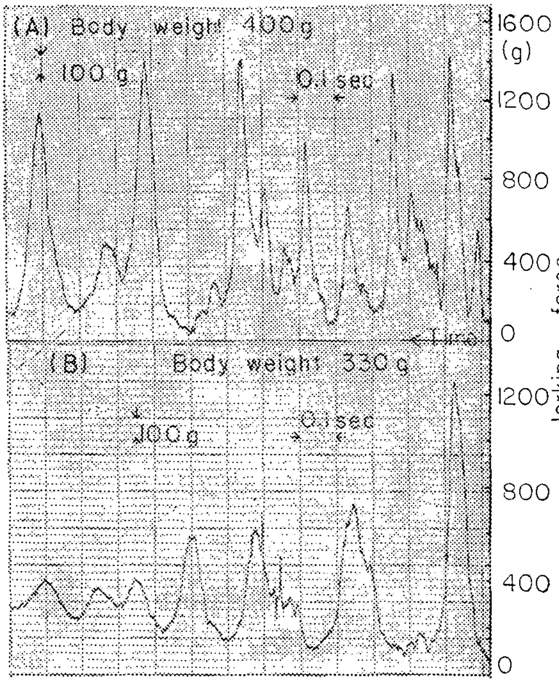

Fig. 5. The example of recording paper obtained from the experiments for the jerking force.
A represents the initial state after a carp was hooked and B the exhausted state at last.

ber of measurements was insufficient, the mean value of β in the exhausted state was about 1.7 ($S.D=0.5$, $n=7$).

The F_p equals to F_m when t is zero in the above equation and α can be expressed by rearranging the equation on the F_p and the F_m as follows:

$$\alpha = W(K-1)+F_0$$

Substituting α into F_p, it can be also expressed as follows:

$$F_p = \{W(K-1)+F_0\}e^{-\beta t}+W$$
$$= (2.23W+105)e^{-\beta t}+W$$

The fatigue time until the carp was utterly exhausted, after hooked up from the water, was about one minute. The sustained swimming time of a carp (Tsukamoto *et al.*, 1975) and the fatigue time of the fishes (Brawn, 1960; Brett, 1965; 1967; Webb, 1978) have been reported in consideration of their physio'ogical and physical factors.

4. Relationship between the jerking force and the tail beat

An example of recording paper for the jerking force and the tail beat with time was shown in Fig. 6.

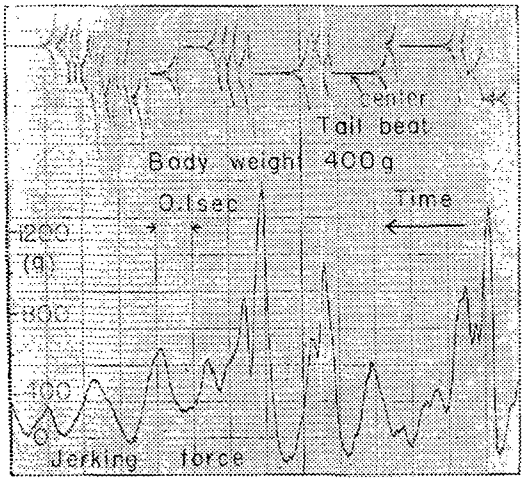

Fig. 6. An example of recording paper for the jerking force and the tail beat simultaneously.

Table 1. The correspondence of the time intervals between the peak points of the jerking force to the tail beats

Body weight (*g*)	No. of intervals	Time interval(*sec*)		*Time delay (*sec*)
		F_p	Tail beat	
235	3	0.48	0.49	0.23
400	3	0.45	0.46	0.18
〃	2	0.25	0.27	0.09
〃	2	0.42	0.37	0.15
〃	2	0.45	0.39	0.13
〃	3	0.36	0.31	0.20
270	2	0.35	0.36	0.15
400	2	0.33	0.29	0.14
〃	1	0.20	0.17	0.09
〃	1	0.17	0.19	0.12
Total	21	3.46	3.30	1.48
Mean		0.165	0.157	0.048

*Time delay is time difference between the peak point and the tail beat. Number of peak points is 31.

A paired difference *T*-test was employed to clarify the relationship between the jerking force and the tail beat with the data given in Table 1. Each of the time intervals between peak points of the jerking force was paired with the period of each tail beat. The observed value of $t=1.546$ was smaller than the critical value of $t=1.833$ for *T*-test at significance level 0.1 and 9 degrees of freedom. Hence, it was shown that the jerking force by hooked carp was closely related to the movement of the tail beat and one peak point of the jerking force was occurred by one tail beat.

The swimming speed and the power were related to the amplitude and frequency of the tail beat of fish (Hunter and Zweifel, 1971; Nashimoto, 1980). For this problem, it becomes necessary to investigate the relationship between the change of the thrust and the tail beat in swimming performance.

It was inferred from the above results that the period of the tail beat at the maximum jerking force (refer to Fig. 4) was increased with body weight of a carp, and it seemed to be shorter than the pericd for the swimming carp by Yonemori *et al.* (1979). The movement of head of crucian carp with cinecamera by Kawamura *et al.* (1978) was shown very irregular.

The tail beat counter was not considered to get a high sensitivity so far as the apparatus was constructed involving mechanical defects such as short-circuiting switch and wire frame, etc. A detailed tail beat counter using such as electric (strain gauge), magnetic or optic method would be desirable to cover up such defects.

Summary

The measurements of the jerking force and the tail beat by hooked carp were carried out using a strain gauge at a fish pond from July to August 1981.

The maximum jerking force was sustained for a while in the initial state after a carp was hooked, but the jerking force was gradually decreased as a function of the time elapsed until the fish was utterly exhausted, and it converged to the body weight at last. The results are as follows:

1. The maximum jerking force F_m (g) can be expressed with empirical formula:

$$F_m=3.23W+105$$

where W (g) is the body weight.

2. Dynamic change of the maximum jerking force F_n (g) by one tail beat with time t_n $(-10T/2\leq t_n\leq 10T/2)$ can be induced with the equation as follows:

$$F_n=(0.27W-6.52)(|t_n|+C)^{-2.10}$$

where the period T (sec) is given by the following equation with the body weight:

$$T=0.000385W+0.193$$

3. The jerking force at each of the peak points F_p (g) varies with the time elapsed t (sec) as following equation:

$$F_p=(2.23W+105)e^{-\beta t}+W$$

The value of durability index β was nearly zero in the initial state and about 1.7 in the exhausted state at last.

4. It was clearly shown that the change of jerking force by hooked carp was closely related to the tail beat from a paired difference T-test.

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