Human Power eJournal, article 13, Issue 4, 2007

SDV DRIVE WITH OVAL PEDAL MOTION

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ABSTRACT

This paper presents an overview of the SDV drive with oval pedal motion. The SDV drive is comprised of two sprockets and a chain extended around the sprockets, thus forming an oval track of the chain. A pedal is attached to the chain directly. Bicycles and recumbents with SDV drives have been commercialized and sold by OTEC Research Inc. As for product information, refer to the above web site of OTEC Research Inc.

The presumed force pattern versus time of the SDV drive was verified by the measured data obtained at Waseda University. The output power presumed under certain assumption at the beginning of the development was roughly 1.35 times larger than that of a conventional drive. The test results obtained at National Institute of Advanced Industrial Science and Technology (AIST) were beyond the presumption. The SDV drive tested was of a standard arrangement, which has not been identified yet as optimum for bicycles and recumbents.

This paper is fully rewritten and translated from the previous paper published on the Journal of the Japan Society of Mechanical Engineers, Vol.105 No. 1003[*1].

INTRODUCTION

In the drives currently used for bicycles and recumbents, the riders' consuming energy is not effectively utilized for propulsion of the vehicles because of the fact that the direction of the force applied to the pedal differs greatly from that of rotation of the crank at almost all the crank angles except very limited region of crank angles as shown in Fig. 1. Fig. 1 is a clock diagram of a well trained cyclist of a standard bicycle illustrating the actual and effective forces applied to a pedal, which is arranged for this paper referring to Figure 7.4 of HIGH-TECH CYCLING[*2]. The actual forces exhibit appreciable magnitude in the wide region of crank angles between 90 degrees and 210 degrees from the top, whereas the tangential components of the actual forces, i.e. effective forces, coincide with the actual forces only in very limited regions of crank angles.

All of these forces in the region acts mainly downward. There might be an opinion that centrifugal forces take big part in the normal component of the actual forces, however you can easily realize that this opinion is false to think that the magnitude of the centrifugal forces does not change greatly at all the crank angles. The centrifugal forces are caused by the masses moving together with the pedal which essentially does not change in accordance with crank angles.

Thus, the actual forces measured relate mainly to muscular actions, and it is presumed that the direction which an individual, even a trained cyclist, can apply force to a pedal is not the direction of rotation but straight downward just like the motion of a foot when you just move your foot down unintentionally from the place where your foot is pulled up while you are standing at a place or sitting on a saddle of a stationary bicycle. Fig. 2 is a force effectiveness pattern of a trained cyclist, which is also prepared for this paper referring to Figure 7.3 of HIGH-TECH CYCLING.

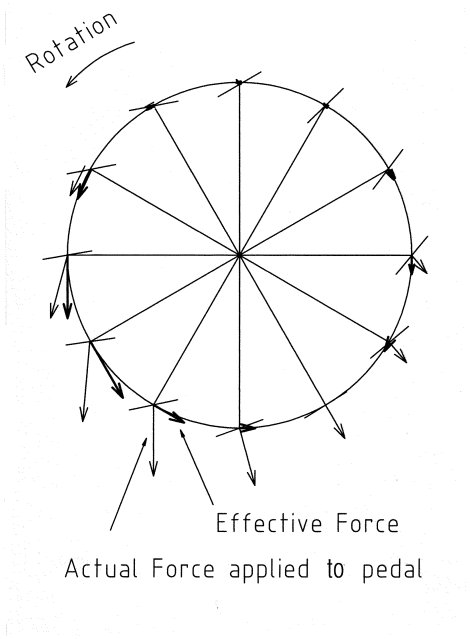

Fig. 1

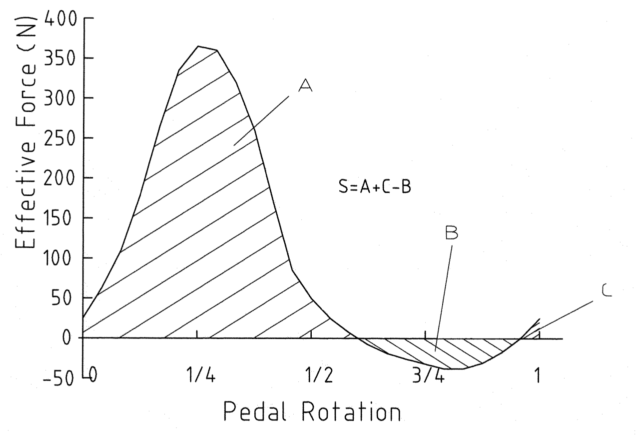

Fig. 2

If the direction of the motion of a pedal in its power phase is designed to coincide with the direction in which a rider can most easily apply force to the pedal while stretching his or her legs, and if there is least loss of momentum at both ends of pedal travel without delayed reapplication of force to the pedal at the beginning of the power phase, it is expected that the energy transmission efficiency from the rider to the machine would increase appreciably.

We can derive a desirable force effectiveness pattern Fig. 3 from Fig. 2 by stretching the peak and bottom points of the effective forces of Fig. 2 in the direction of x axis in a certain period of time and contracting the other parts in the same direction. Then we obtain Fig. 4 corresponding to Fig. 1 of a conventional drive, which we can call an oval clock diagram of SDV drive. The radii of two circles are the same and smaller than that of Fig. 1 according to the contraction ratio of the contracted parts of Fig. 3. A mechanism comprised of two sprockets and a chain is introduced to realize Fig. 4. Fig. 3 was prepared assuming such a combination as two sprockets with 39 teeth and a looped chain comprised of 76 links those of which are avai

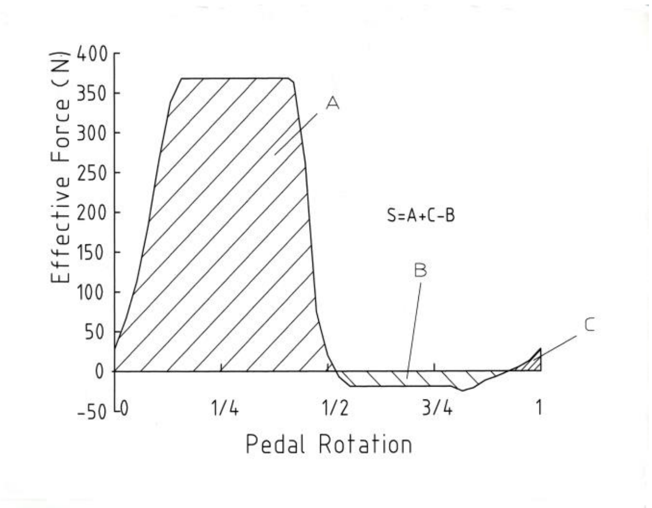

Fig. 3

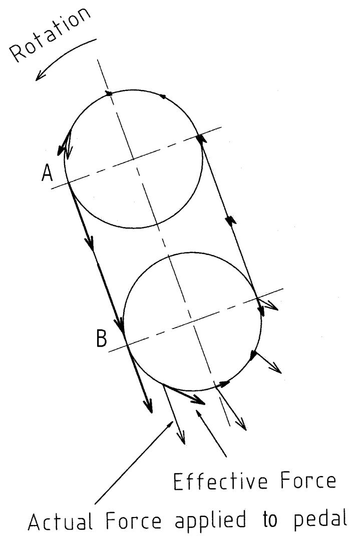

Fig. 4

In Fig. 4, if A – B is disposed in such a direction that you can move your foot down unintentionally, the direction of the forces which you apply to the pedal coincides with that of the motion of the pedal in the power phase. The area S of Fig. 3 is 1.35 times of S in Fig. 1, which means that a SDV drive represented by Fig.3 delivers 1.35 times lager output power than that by a conventional drive represented by Fig. 1 assuming that pedal speeds are equal in both the drives.

EXPERIMENTAL

Force effectiveness patterns

Fig. 5 is a photograph illustrating the laboratory tests employing an SDV bicycle Alpha-ls at Waseda University. The front wheel was detached and the front end of the front fork was fixed to the floor. The rear wheel was exchanged with a flywheel of a mechanical ergometer.

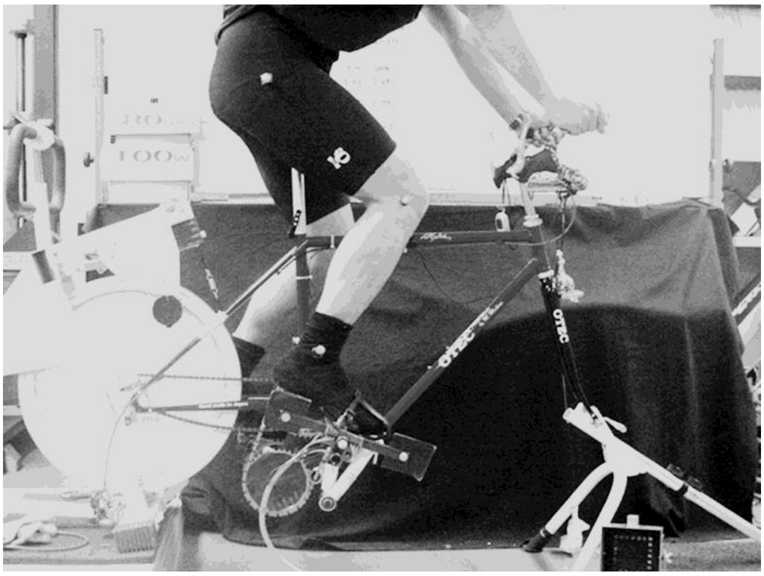

Fig. 5

The force acting to the pedal was measured by piezoelectric instruments attached to the pedals. Note that the saddle is disposed at such a position that the rider can move his foot naturally along the chain. The seat post angle and pedal path angle in the rectilinear portion is 86 degrees and 71 degrees from the ground respectively. The SDV drive tested was comprised of two sprockets with 39 teeth and a bicycle chain with 70 links. The dimension of the oval track of the drive was radius 78.9 mm at the corners and the distance between the centers of both sprockets was 196.9 mm, resulting in total length of the track of 889 mm and total stroke of 354.7 mm. As for a conventional drive, the ergometer was used with the pedals. The length of the crank was 170 mm. The total length of the circular pedal path is 1068 mm.

Fig. 6 and Fig. 7 show the obtained force effectiveness patterns versus pedal location for a student pedaling at 200 W, 60 rpm of the conventional and SDV drives respectively. The pedal location (x - axis) 0 and 100 are the top position of the pedal. Y- axis shows the magnitude of the force in Newton.

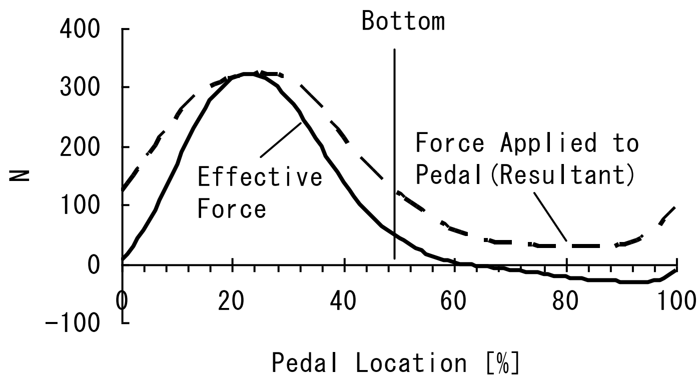

Fig. 6

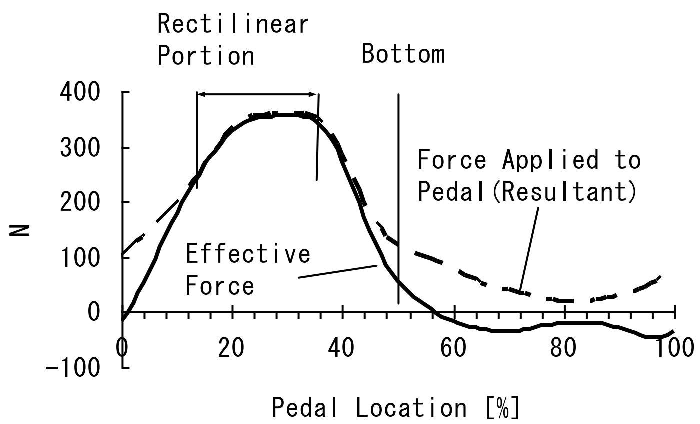

Fig. 7

When comparing the areas surrounded by the lines of effective force and x-axis of Fig. 6 with that of Fig. 7, the area of Fig. 7 is larger than that of Fig. 6. The ratio of these areas is inversely proportional to the ratio of the pedal paths of both drives because the output powers and pedal revolutions per unit time are kept equal in the experiments as mentioned above. In Fig. 6, the line of the force applied to the pedal touches that of the effective force at a point 23% of pedal location which almost accords with Fig. 1. In Fig. 7, the line of the force applied to the pedal overlaps with that of the effective force between 14 % and 42 % of pedal locations which corresponds to the rectilinear portion of the oval track in the power phase, which we had expected at the beginning of the development. Comparing Fig. 3 with Fig.7, in Fig. 7 the forces of the overlapped portion increases gradually and level off, then decrease rapidly as the pedal moves in the power phase. The gradual increase of the forces just after the transition from the circular portion to the rectilinear portion corresponds to the process in which the knee joint of the student is being extended. There is a possibility to have more sharp increase of the forces by making the angular velocity smaller in the circular portion by exchanging the sprockets of 39T with those of larger number of teeth such as 42T or 43T.

Local maximum output power (LMP)

To find out the difference in output powers between a SDV and a conventional drive, a local maximum output power against cadences (LMP) for a certain heart rate was searched for both the SDV drive and conventional drive by employing a mechanical ergometer, thus obtaining sets of LMPs for different heart rates. An SDV bicycle Alpha-ms of smaller frame size than Alpha-ls was employed to acquire the data at AIST. As for a conventional drive, the ergometer was used. Two test subjects, an experienced cyclist and non cyclist, were involved in the experiments. LMPs versus heart rates of the subjects were chosen as the criterion for comparing the performance of the drives. Fig. 8 and Fig. 9 show the obtained LMPs versus heart rates for the non cyclist and the experienced cyclist respectively. Logarithmic approximation lines are added in the figures.

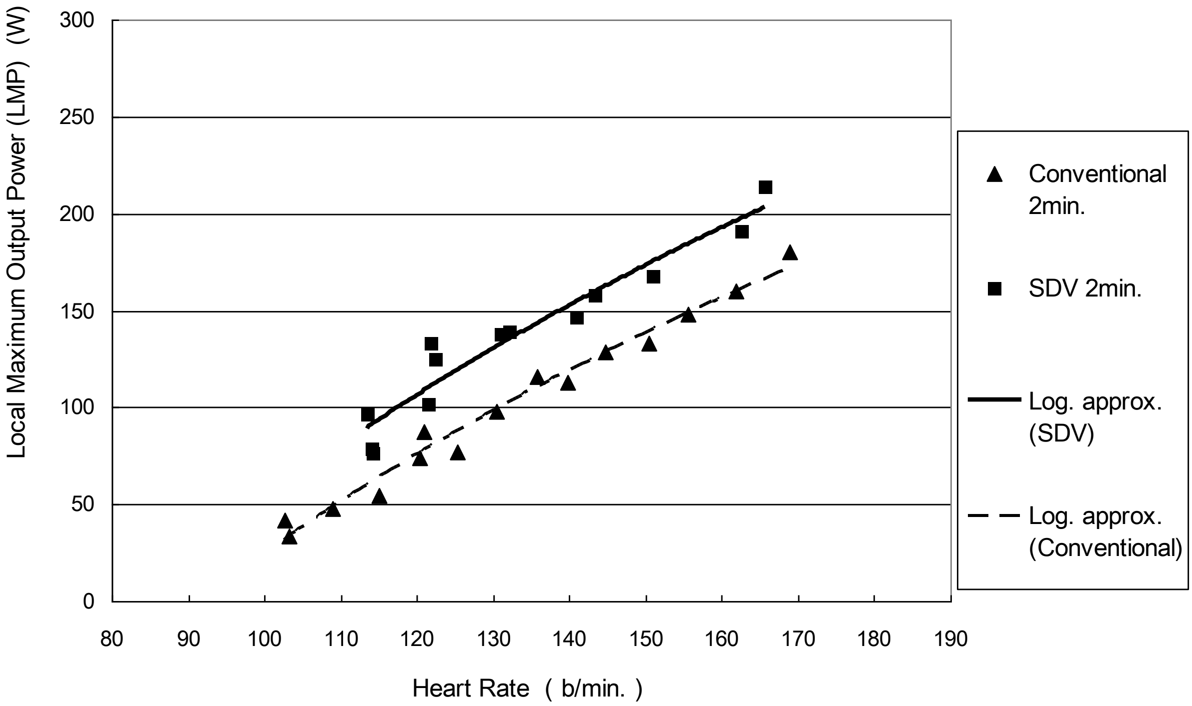

Fig. 8

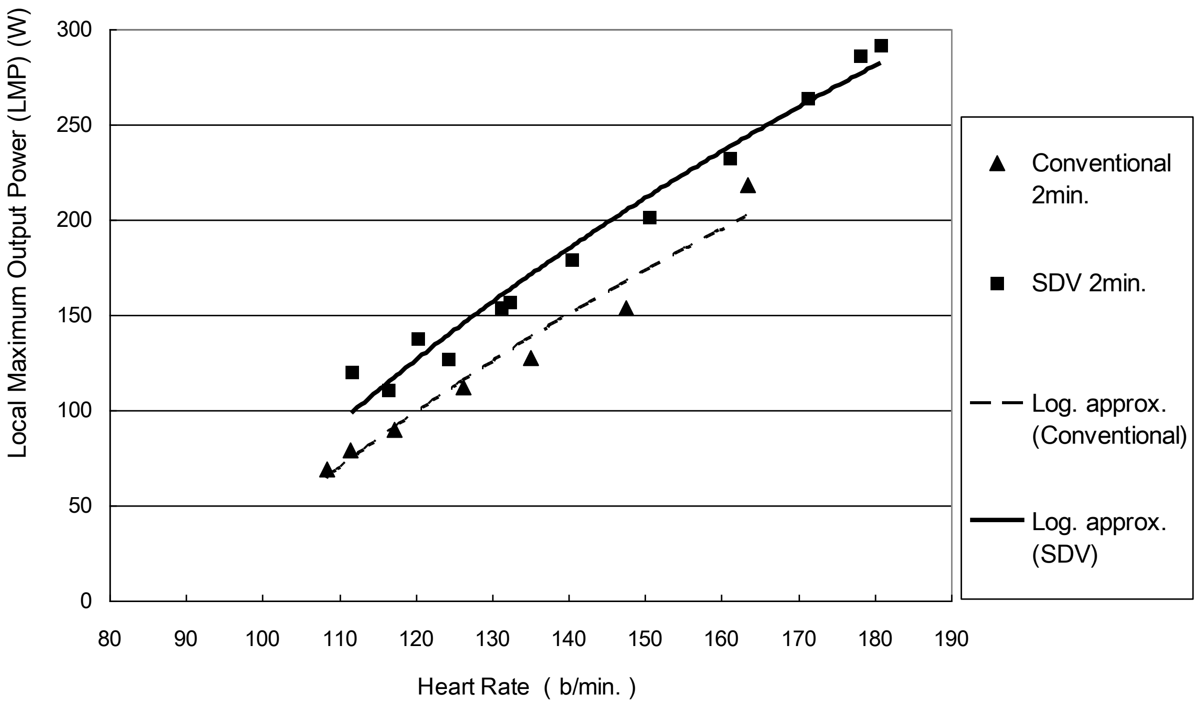

Fig. 9

The duration of each experiment was two minutes. Each experiment was started with stabilized condition of heart rate after the test subject has warmed up. It took them about two weeks to obtain relatively stabilized data both for the conventional and SDV drives. However, in case of the SDV drive, both test subjects showed a tendency of gradual increase in LMP as they repeat experiments with the corresponding cadence for LMP becoming lower even after the preparatory period of two weeks. Thus, so far as the SDV drive is concerned, the data might not have stabilized for the test subjects.

Here if we imagine a three dimensional coordinate system comprising heart rate axis, cadence axis and output power axis, these approximation lines correspond to the watersheds of the three dimensional curved surfaces which specify local output power for a given heart rate and a cadence. In Fig. 8, the data for the SDV drive include those obtained in three days and those for the conventional drive include those obtained in five days. The cadences for LMPs of the SDV drive vary from 21.5 rpm to 35.1 rpm as heart rate increases and those for the conventional one vary from 22.6 rpm to 65.6 rpm as heart rate increases. In Fig. 9, the data for the SDV drive include those obtained in two days and those for the conventional drive are obtained in a day. The cadences for LMPs of the SDV drive vary from 20.8 rpm to 38 rpm as heart rate increases and those for the conventional one vary from 35.3 rpm to 88.9 rpm as heart rate increases.

Judging from the plotted points,

1) At lower heart rate regions, the LMPs of the SDV drive are 1.5 – 1.8 times of those of the conventional drive,
2) At higher heart rate regions, the LMPs of the SDV drive are 1.1 – 1.2 times of those of the conventional drive.

Judging from the logarithmic approximation lines, the LMPs of the SDV drive are 1.2 – 1.4 times of those of the conventional drive, however it is uncertain that logarithmic application is appropriate for this case.

DISCUSSIONS AND FURTHER STUDIES AS CONCLUSIONS

When comparing LMPs versus heart rates for both systems, the SDV drive delivers more power than the conventional drive. As heart rate has a close correlation with energy expenditure of an individual, above conclusion is valid from the standpoint of gross efficiency which is the ratio of the useful work performed to the energy expenditure[*3].

There are other estimates of efficiency, one which is termed work efficiency which is the ratio of the useful work performed to the rest of the energy expenditure after subtracting the energy just moving the legs. According to the gross efficiency, optimum cadences are very low and according to the work efficiency, optimum cadences are much higher[*3]. In fact, in some racing conditions, riders prefer higher cadences such as 80 – 100 rpm for conventional bicycles and 50 -70 rpm for SDV bicycles. These values are much higher than those obtained at the laboratory tests described in the previous section. It is also the case that among recreation oriented cyclists there are many who prefer lower cadences less than 60 rpm even in conventional bicycles. In the SDV, judging from a limited experience, we feel the cadences of 50 – 70 rpm is also the case for recreation oriented cyclists.

The reason of lower cadences of the SDV drive than those of the conventional drive in general are that in SDV you can apply bigger, effective, sustained force to the pedals due to the geometry of the pedal paths and the saddle position, resulting in higher ratio of output power to cadence. We think the geometry of SDV makes riders to use bigger muscles, which is also the reason for lower cadences than we expected.

Regarding the influence on knee joint, troubles have not been reported among about 80 SDV bicycle users including enthusiastic cyclists.

SDV research and application are just at the threshold. The geometry has not been optimized yet. As a further study, we would like to pursue optimum SDV geometries corresponding to the purposes by changing angular velocities at the circular portions and the stroke of the rectilinear portion from the standpoint of the gross efficiency and work efficiency. We would also like to investigate the effect of the direction of the gravity on the riders' position. Obtaining data on SDV recumbents are another area of interest.

ACKNOWLEDGEMENT

The authors would like to thank Prof. Hidetsugu Suzuki of Faculty of Human Sciences of Waseda University, Prof. Isao Muraoka of School of Sport Sciences of Waseda University, Mr. Hidetoshi Hoshikawa of Musashigaoka College and Mr. Shigeyuki Hayashi who previously was a student of the Graduate School of Human Sciences of Waseda University for their collaboration. We also gratefully acknowledge Mr. Kotaro Horiuchi for his helpful suggestions when preparing this paper.

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