Development of Highly Effective Pedaling Mechanism for Bicycle
Using Link Mechanism

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Abstract
The authors aim to develop a bicycle where it can run more lightly. Recently, from a chronic traffic jam and the rise of environment awareness, movement of positively using the bicycle is seen in the city. Moreover, The electric assisted bicycles are marketed by some companies, and it seems that there are a lot of needs such as less muscular power and lighter riding. Then the authors develop the new pedaling mechanism that uses the leg muscular power measurement, deriving the optimal pedaling path, and the link mechanism, and have made a special frame.

In this paper, the authors briefly aim process until the second trial model. For example, development of measuring instrument of muscular power, Design of pedaling mechanism, and development of special frame are mentioned.

1. Introduction
The pedaling paths in a general bicycle are circles now. Because of the easy structure, this circular path has been used for a long time after the bicycle with the pedaling mechanism is invented. The most efficient pedaling in the bicycle is to always add power in the tangential direction in the pedaling path. However, the result of measuring the expert's pedaling movement in the bicycle is far from the pedaling of the ideal. Recently, according to such a current state, improved bicycles like with SDV oval pedaling path have appeared. This oval path comes from the structure of arranging two sprockets in vertical, and there is no proof that it is the best pedaling path. Then, aiming at the development of more lightly ridable bicycle, the authors assume the search for ideal pedaling path and the development of a highly effective pedaling mechanism using the link mechanism to be a purpose of this research.

2. Simple leg movement model and measurement of muscular strength

2.1 Simple leg movement model
In this research, after deriving the optimal path, the authors will lead feasible approximation path by the link mechanism.
and the policy of the generation muscular power in the riding position. Because the device that was able to measure the generation muscular power in the riding position of the bicycle did not exist, the authors newly developed the muscular power measuring instrument[1]. The measurement scenery with a developed muscular power measuring instrument is shown in Fig.2.

This measuring instrument can be shared by the hip and knee joints, and can correspond to both bending and extending.

### 2.3 Muscular power measurement result

Authors cooperates more than one examinee, and measured relations between the joint angle and muscular power including correlation about the hip joint bending and extending, and the knee joint bending and extending. By doing so, it prevents crumble muscular power of measurement item. The measure result of muscular power of hip joint is shown in Fig.3 and the measure result of muscular power of knee joint is shown in Fig.4.

### 3. Tracks evaluation

#### 3.1 The best tracks deriving policy

As best pedaling paths condition, can advance fast pedaling paths and pedaling paths that kept being rowed for a long term without becoming tired were thought. So, in this research, the authors set condition of best pedaling paths of possible advance fast pedaling paths, therefore, the authors define pedaling paths that can generate bigger pedal drive power longer to the pedaling path revolution as the optimal pedaling paths. And at pedaling path evaluation, the authors decided that a standard path is a circle path. Two joint muscle is included in four items (the hip joint bending and extending, and the knee joint bending and extending) measured this time.

#### 3.2 Method of deriving pedal drive power

In the human body, there are one joint muscles that step over one joint and two joint muscles that step over two joints. In the latter case, it will relate to both of two joint movements. So muscle power is not decided from only one joint angle, but from two variable angles. Two joint muscles are all included in four items (the hip joint bending and extending, and the knee joint bending and extending) measured this time. Therefore, in calculating necessary data for the evaluation, the hell of a time was expected to be required to one by one calculating in various joint angles.

Then, the authors developed the calculation program that would give muscular power of each joint and the resultant force, etc from the pedal position based on the measured data[2]. An output example of this program is shown in Fig.5.

#### 3.3 Use of pull foot

Authors calculated generation muscular power about circle path, oval (elongate circle) path, and ellipse path when developing initial pedaling path evaluating program[3]. The results are shown in Fig.6.

About the average of power for one stroke, circle path is 37.7kgf, oval path is 40.4kgf, and ellipse path is 42.8kgf. Therefore, oblong ellipse path can be expected to be able to generate the driving performance efficiently more than not only circle path but also oval path. Moreover, from the graph of Fig.6, it is understood that there is a big difference in the pattern of the generation drive power in ellipse path.

The authors thought that we would generally generate large power by the push on the pedal stroke.
However, in the three calculated results of this time, the pull on the pedal stroke generated larger power than the push. It is thought that this result was obtained because it was not considered not to be fixed of the leg in a general pedaling. These results show that the use of pull is important in the pedaling, and these are interesting. Therefore, it seems that how to use efficiently not only the push but also the pull is important to pedal the bicycle fast.

Then, the authors first attempt the highly effective pedaling by use of the pull at the sport bicycle with fastening devices of binding in this research.

3.4 Evaluation of various paths

Even if the path shape is similar, the driving performance generated by the pedaling is different depending on the size. When the pedaling paths are evaluated, we have decided to compare by the generated power per the path length because the path shape is a research object in this research.

The path shapes evaluated in this research are shown in Fig.7, and each largest value of the generated power per the path length are shown in Table 1. In the evaluated paths, the ellipse path has obtained the largest value in generated power per the path length. Moreover, from these results, the authors have understood that the ellipse path obtains larger than the oval path, the oval path is not optimal, and the pull is important to pedal the bicycle.

<table>
<thead>
<tr>
<th>Path shape</th>
<th>Generated power [kgf/m/s/m]</th>
</tr>
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<tbody>
<tr>
<td>Circle</td>
<td>38.53</td>
</tr>
<tr>
<td>Oval</td>
<td>41.34</td>
</tr>
<tr>
<td>Ellipse</td>
<td>71.61</td>
</tr>
<tr>
<td>Trochoid 1</td>
<td>50.67</td>
</tr>
<tr>
<td>Trochoid 2</td>
<td>54.25</td>
</tr>
</tbody>
</table>

The authors judge that the ellipse path is an appropriate path, though the authors were not able to judge that the ellipse path was the optimal path because the authors did not evaluate other paths from the difficulty of expressing by the equation. So, in the mechanism development in the future, the authors have decided to adopt the ellipse path.

4. Design of pedaling mechanism

4.1 Selection of link mechanics

On selecting the link mechanism for the pedaling mechanism, the authors set being able to lighten, dustproof, and waterproof, as design conditions. Then, in this research, the authors selected a four link mechanism, that is comparatively easy mechanism, as a pedaling mechanism.

As an approximation method of an ellipse path, the authors decided to approximate by using the coupler curve of the crank lever mechanism that is a kind of four link mechanisms. The reasons to use the crank lever mechanism are the complete rotation of one link, besides the coupler curve becomes shape near the ellipse. In the bicycle, the gyration of the gear that is called a sprocket to drive the rear wheel is transmitted by the chain. At least one link of the pedaling mechanisms has to rotate completely to rotate the sprocket.

4.2 Link mechanism design program

The authors have developed the link mechanism design program by misappropriating the pedaling path evaluating program previously developed. The authors dealt by expressing the coupler curve of the crank lever mechanism by the equation. An output result of this program is shown in Fig.8.

4.3 Deriving of mechanism constant

The mechanism constants are derived by using the link mechanism design program. As the deriving method, the calculation of generated power per the path length, that is the evaluation item of the path, is repeated while changing the mechanism constants of the crank lever mechanism. The values in which the largest power value is indicated in the calculation are decided to be the mechanism constants of the mechanism that will be produced. Here, the mechanism constants are derived giving priority to actually producing and making power per the path length larger, without giving priority to the approximation of the pedaling path to the ellipse path.
The skeleton chart of the derived mechanism is shown in Fig.9.

In this chart, the path shape is an ellipse lacked in the upper part. The pull that is important on pedal stroke is used the under part of pedaling path, and only small power is generated in the upper part. Therefore, pedaling path need not become complete an ellipse.

### 4.4 Examination of derived mechanism

The authors examined the derived mechanism. As a result, the authors have understood that the distance from the mechanism to the front wheel becomes 20mm and the distance from the pedaling path to the front wheel becomes 40mm. These values mean it is likely to come in contact with the front wheel, considering a link thickness and considering pedaling with the foot on the pedal. Therefore, the authors attempted improving by changing the mechanism constants, and taking space greatly. As a result, the authors were able to adjust the distance from the mechanism to the front wheel to 40mm, and the distance from the pedaling path to the front wheel to 80mm[4]. These values are almost equal to a general bicycle and they are thought enough space. The skeleton chart of the improved mechanism is shown in Fig.10.

### 4.5 Detail design

The model of the bicycle that installs the manufactured pedaling mechanism is shown in Fig.11, and the closeup of the mechanism is shown in Fig.12.

The authors used SolidWorks to detail design of the mechanism. To compose the pedaling mechanism of four link mechanism, the authors manufactured the connecting rod, the crank, and the lever. The frame of four link mechanism is good in easy fixed parts because it only has to separate the crank edge and the lever edge. And the sub link extended from the connecting rod to the pedal was integrated with the connecting rod.

### 5. Trial manufacturing and evaluation of the pedaling mechanism

#### 5.1 Manufacturing of mechanism

The authors manufactured the lever, the crank, and the connecting rod from the aluminum material by wire-cut electrical discharge machine[5]. The steel board was used for the fastening device fixing the mechanism to the frame of the bicycle in consideration of a big load. And we manufactured the shafts that tied each part from steel by lathe.

The authors were able to confirm the assembled pedaling mechanism operated. The photograph of the mechanism is shown in Fig.13.

#### 5.2 Evaluation of mechanism

The authors built the pedaling mechanism into a market bicycle, and tested[5]. As a result, probably because the positions such as the saddles and pedals were not appropriate, the mechanism was not stroked easily. Therefore, the authors decided improvement mechanism.
6. Development of special frame and improvement of pedaling mechanism

6.1 Examination of relationship saddle and pedal position

In the pedaling mechanism made for the first trial, it seemed that the pedal position was not appropriate because a market bicycle frame was misappropriated, and caused the following problems.

1) difficulty on pedaling
2) contact with the front wheel and toes

Then, the authors decided to do the design and manufacturing a special frame that strokes easily more, and to advance the practical use of the new pedaling mechanism as the next stage.

Because the easiness of pedaling is sense, it is very difficult to set an appropriate design index. Then, the authors manufactured the evaluation instrument that was able to adjust the saddle position, and adopted the method "Testee evaluates in sense"[6]. Saddle position evaluation instrument is shown in Fig.14.

The authors examined the saddle position with this instrument. On the evaluation, we took the average of data of multiple (five) people because the height of human and the balance of the muscle were different in each person. The result is shown in Fig.15.

6.2 Development of special frame

The authors designed special frame based on result of examination at saddle position[6]. Jwcad was used for CAD according to the frame builder at the order. The photograph of completed frame is shown in Fig.16.

A big difference point with a general bicycle is that the center of gyration of the crank is not corresponding to the center of the pedaling path. Thereby, the saddle position, the bottom position, and each pipe length were changed.

When the bicycle is manufactured, the method, brazing, is adopted by the joint of each pipe that composes the frame. Besides, there is a welding method for the joint method. The production of steady welding jig is needed to weld though it is general in a market bicycle. The material of the frame is limited to steel on the brazing, though the brazing cannot be used for the aluminum frame, it is no problem for steel as the material of the prototype.

6.3 Improvement of pedaling mechanism

Redesigned pedaling mechanism according to special frame[7] is shown in Fig.17.

The authors used SolidWorks for the design of links. The links manufactured in this time applied R to the corner for the safety design. The lever was made shape that the angle attaches, the fixed shaft between a fixed link and the lever was shortened, and it aimed at the cancellation of the trouble that came in contact with the leg in the pedaling. And, the part where the stress was not large was machined to thin for lightening.

Completed second trial model[7] is shown in Fig.18.

6.4 Evaluation of second trial model

In the first ride, the impression that it was easy to ride more greatly than the first trial model was received. Then, as an evaluation, we measured the lap time, the average speed, the average cadence (rotational speed), and maximal cadence of three riders about the market sports bicycle and the second trial model by using surroundings circuit (4km) of Natori cycle sports center[7]. The results are shown in Table 2 and Table 3.
The tendency that the second trial model slows was seen as time as savvied to compare Table 2 to Table 3. But all testees were opinions that feet were not more tired than the market bicycle. The reason seems not only from the slowed time but also from the improved efficiency of the pedaling as for this. And, because the pedaling path of the second trial model are about 40 percent small, it becomes a high rotation type that uses lungs than the muscle, so it becomes stronger aerobics. The cause of the fall of time is torque shortage that comes from the small size of the path. This is a cause of the weakness to the acclivity. It seems that the speed and efficiency can be united if the path is designed more greatly in the future.

7. Conclusions

The authors aim at the development of the bicycle where it can run more lightly, develop the new pedaling mechanism that uses the leg muscular power measurement, deriving the optimal pedaling path, and the link mechanism, and have made a special frame. The authors developed the second trial model, and the research was able to be advanced to the place where practical use was seen. The authors want to be going to improve the mechanism in the future, and to attempt putting to practical use immediately.

Finally, this research is received the assistance of science research expense subsidy base research (C) 20500569, we tender our thanks here.

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