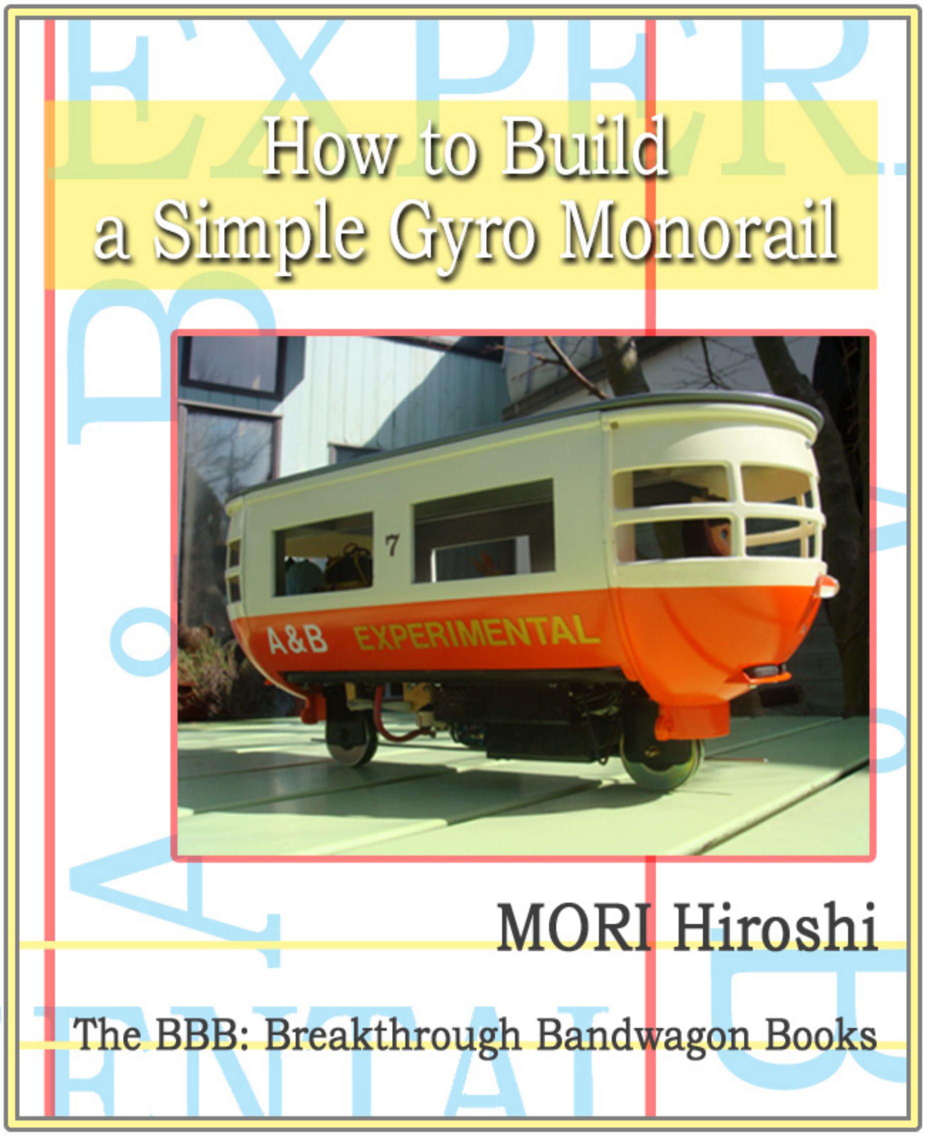
How to Build a Simple Gyro Monorail



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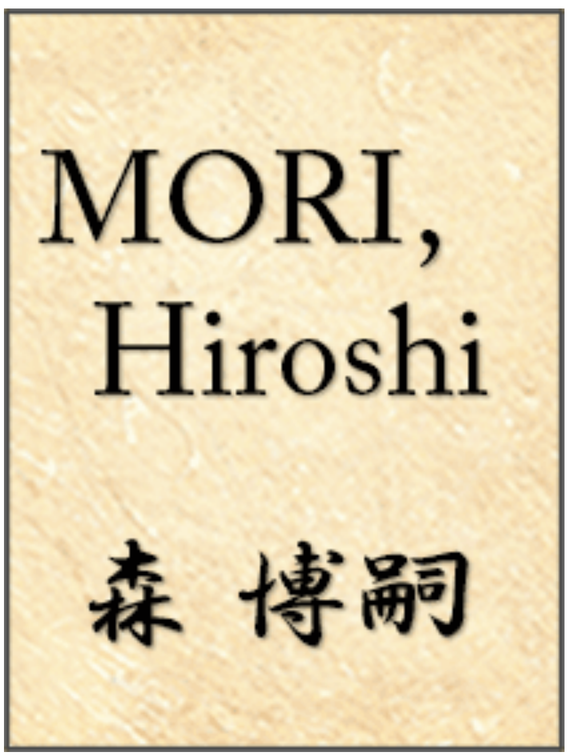

MORI Hiroshi Author Page

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0. About this article

The article first appeared on 2010 August issue of a Japanese monthly magazine “Hobby of Model Railroading” (published by Kigei Publishing). This document is published after the author gained the permission from the publisher and Mr. Kozo Hiraoka (the person who made the drawings for this article).

シンプルなジャイロモノレールの作り方

森　博　嗣
写真・図7共

図：平岡幸三（図7以外）

1. まえがき

ジャイロモノレールの試作９号機がうまく走ったので、原理を解説した内容を今年１月にＴＭＳに投稿した。そのあと、次のステップとして、さらに大型の試作機を製作するつもりだったが、遠方への引越が数ヶ月後に迫り、短時間で完成する簡単なプロジェクトに急遽切り換えた。その結果誕生したのが、今回ご紹介する試作７号機である。

９号機より新しいのに何故７号機なのか……。実は、試作段階でホイールが１つしかないシングルジャイロの車輌を製作していた。ホイールが１つではカーブを曲がれない（９号機のようにツインジャイロにする必要がある）。車輌がヨー軸で回転したときの影響を小さくするためには、ホイールの回転軸もヨー軸に近づけることが有効である。この理屈から、垂直軸回転ジャイロならばシングルでも、ある程度のカーブ走行が可能なのではないか、と推測して実験を行なった。その試作７号機は、実験のあと分解し、次の８号機、９号機へと部品が受け継がれた。

９号機の成功で、バランシングスイッチやサーボのノウハウが得られたので、残っていた部品を掻き集めて、再度７号機を組むことにした。もし製作記事を書くのならば、多く

ホイール用真ちゅう材 φ50×10	700円
ジャイロ用マブチ 380 モーター	1000円
サーボ用マブチ 260 モーター	100円
タミヤウォームギヤーボックス	800円
7.2V ニッケル水素バッテリィ	1200円
5V 2回路リレー ×2個	200円
戸車 ×2個	300円

表-1　使用部品

The actual article appeared on “Hobby of Model Railroading“ (August issue, 2010)

1. Foreword

Since the running of Prototype No. 9 of gyro monorail was successful, I contributed an article that explained the principle, to "Hobby of Model Railroading" in January, 2010. After that, I intended to construct a bigger prototype model as the next phase. However, my moving to a new residence located in a distant place was approaching in a few months, and I had decided to try a simpler project which needed a shorter time to work on. Prototype No. 7 that is introduced in this article is the product of the project.

Prototype No. 7 (August issue, 2010)

Although it was newer than No. 9, why is it named No. 7? In fact, in the trial phase, I was making a single gyroscope car with only one gyroscopic wheel. If it had just one gyroscopic wheel, it could not make a turn at the curve. (Twin gyroscopes like the ones used for Model No. 9 was required.) To minimize the effect on the car when the car rotates about the yaw axis, it is beneficial to bring the rotational axis of the wheel close to the yaw axis. Based on this logic, I guessed that even a single gyroscope might have been able to allow the car to make turns at curves to a certain extent, if the axis of rotation of the wheel was oriented vertically, and I conducted the experiment to verify it. The Prototype No. 7 was dismantled after the experiment, and the parts for it were reused on Model No. 8 and Model No. 9.

I learned the know-how of balancing switches and servomotors from the success on Model No. 9, so I had decided to collect the leftover parts and assemble Model No. 7 again. Since I was planning to write a report about constructing models, I also thought that the simpler design would be better for many readers to construct the models of their own by basing it on the article. I came up with the design, while, as a concept, putting the emphasis on easy construction, suitable size, requiring no special part, and more than anything else, the figure that is appropriate for railway cars.

In this article, the principles of gyro monorails are not described. It is better for the readers to understand the logic, and to read the article titled "Theories and Experiments for Gyro Monorails" is recommended.

2. Parts That Are Used

Table 1 shows the main parts that were purchased. There was no expensive item. The battery was rechargeable, and it was the most expensive item. The motor for the gyroscope was Mabuchi 380. The servomotor and the motor for traveling were inexpensive Mabuchi 260. 2-circuit relays operated with 5V are available for 100 yen each via mail-order sales.

【Table 1】Parts that are used

Parts List

★Prices are rough standards★

Brass for wheel φ50 X 10	700 yen
Mabuchi Motor RS-380 for gyroscope	1,000 yen
Mabuchi Motor RE-260 for servomotor	100 yen
Tamiya Worm Gear Box (with motor)	800 yen
7.2V Nickel-hydrogen battery	1,200 yen
5V 2-circuit relay X 2 pieces	200 yen
Sash pulley X 2 pieces	300 yen
Others: Plywood, angle materials, iron plates, plastic plates, rods, gears, pulleys, stoppers, batteries, O-rings, screws, switches	

Approximately 6,000 yen in total

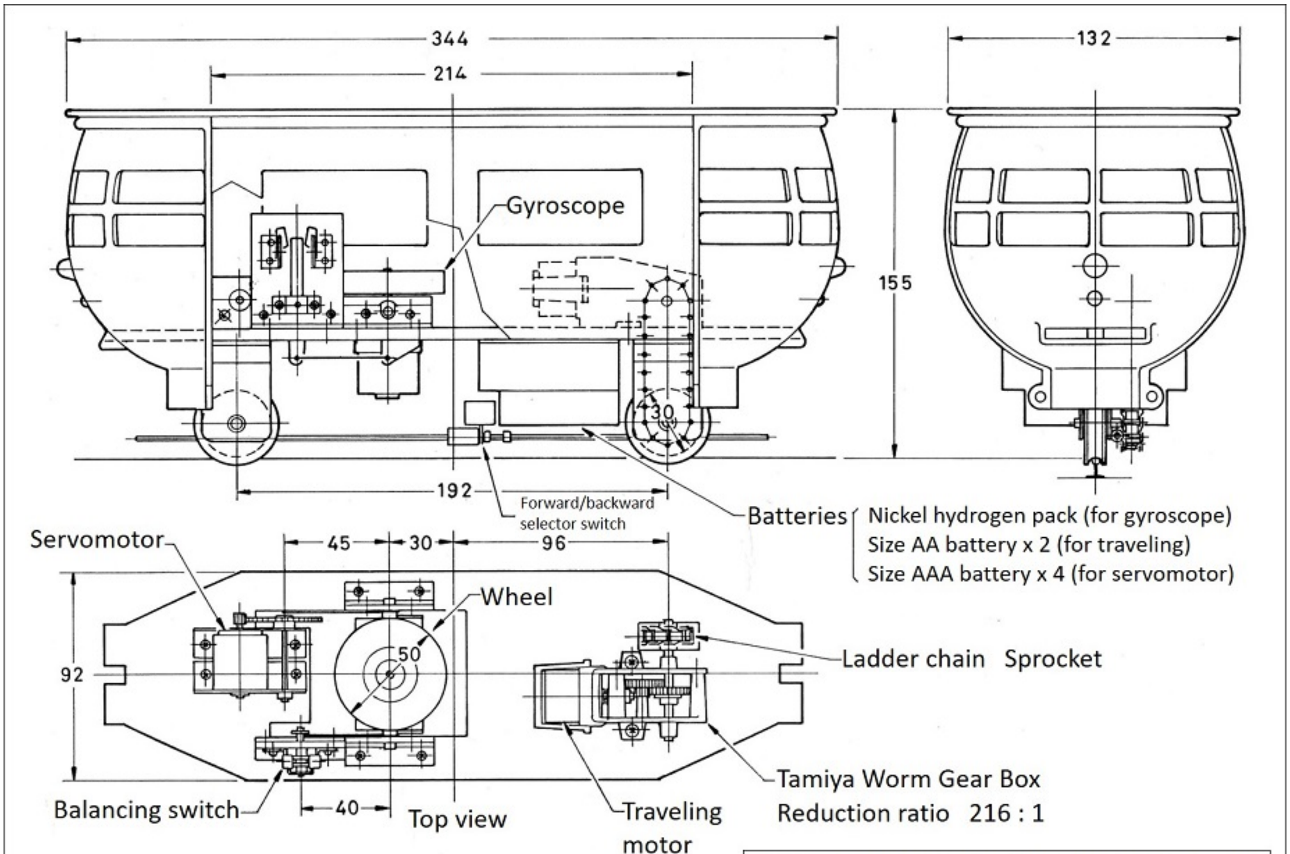
By the way, the craft articles in magazines "Mokei To Radio (Model and Radio)" (once available only in Japan, started as "The Model Craftsman", now discontinued) and "Kodomo No Kagaku (Science for Children)" (available only in Japan) had the parts lists. I always compared the prices of the listed parts with my allowances. The nostalgia inspired me to spend time on making the parts list in this occasion.

I disassembled sash pulleys, which are available at a hardware store, and I used them as train wheels. Also, I used Tamiya-brand parts for mechanisms used for deceleration and conduction, just because I just happened to have them as leftovers. If the car is not powered and it is designed to be pushed manually to go up a slope, then the car can become much lighter and smaller.

For the front and the rear parts of the body, white plastic covers for light bulbs used in construction sites were used. It was convenient because it was divided into two parts from the beginning. I usually make stockpiles of "things which might become useful" all the time, just like beavers would do when they construct dams. The completed models seeing the light of day is such a refreshing sight.

3. Overall Layout

The overall layout is shown in Figure 1. In this car, the chassis works as a frame to support the gimbal of the gyroscope. It elevates the floor height, so the battery, a heavy object, is placed under it. The size of the car is almost identical to that for G gauge railway cars, and it is assumed for the use of one rail of G gauge railways.



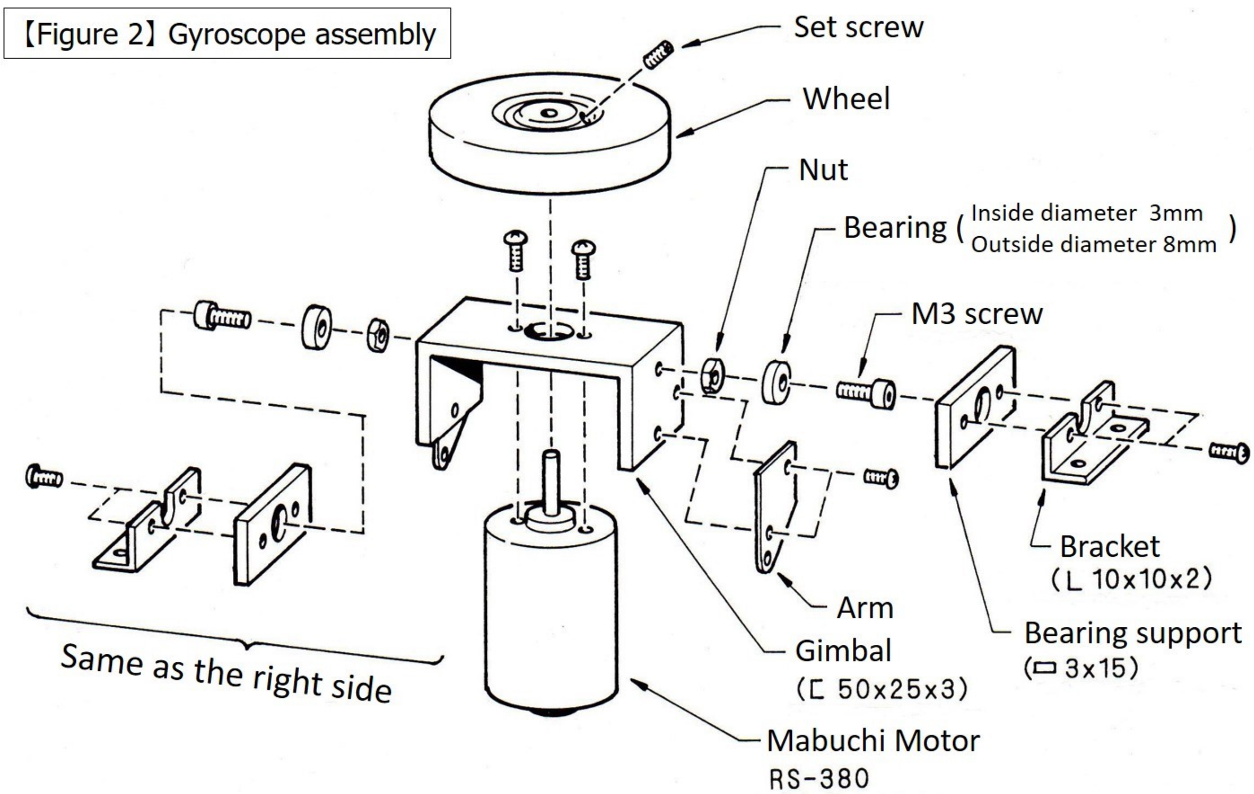
【Figure 1】Overall view of gyro monorail

4. Gyroscopes and Gimbals

When it comes to gyroscope wheels, nothing is better than high precision. With a lathe, crafting such a thing would be easy. If there is no lathe, then purchasing at hardware stores brass materials, the pieces of which are sliced from cylinders, or getting the parts sold separately at specialty stores via the Internet, will do. When punching a hole, whose diameter is the same as the motor axis, at the center of the wheel, it is important to locate the center of the wheel accurately. It is the most difficult obstacle to overcome in this project. Although to drive the motor axis into the narrow hole is a plausible method, using a screw to fix the wheel to the axis is adopted, for easier maintenance. (The screw hole is angled diagonally, and a set screw is used for fixation.)

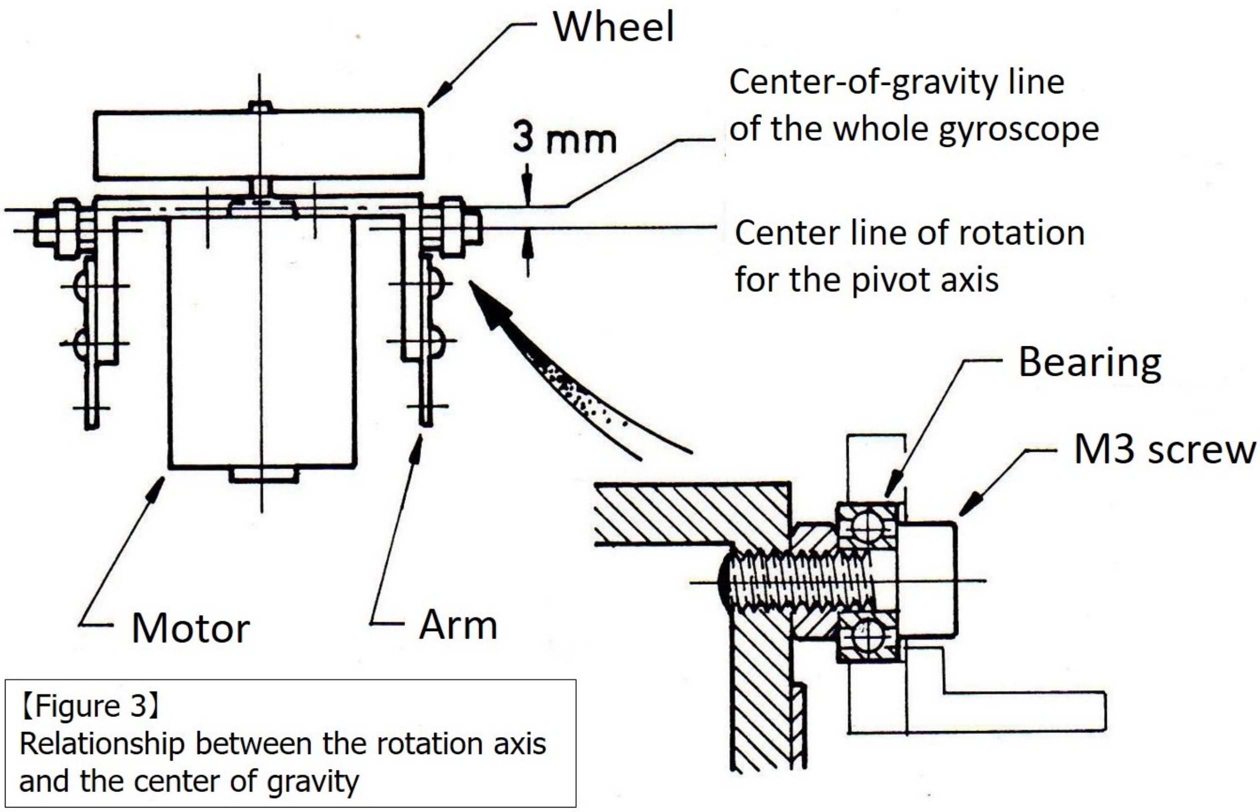
As indicated in Figure 2, the motor is fixed with screws to a piece of aluminum channel member with a U-shaped cross section. This is designed to function as a gimbal. Even though a bearing is used on a rotational axis of the gimbal, the simpler support structure will do as well. It has to move lightly, and there shall be no looseness.

【Figure 2】Gyroscope assembly



The important point is to locate the gimbal axis. Attach the wheel to the motor, check the center of gravity of the entire gyroscope while tentatively fixing the wheel and the motor to the gimbal. And then, the crucial point is that the rotational axis has to be located about 3 mm below the center of gravity (Figure 3). In short, the wheel has to be "unstable" to the extent that it falls forward or backward due to its weight when the gyroscope stops. This is never the right part to make a mistake at. Once the wheel starts rotating, this instability makes the car stable, counterintuitively. Conversely, if the gimbal axis is attached to the higher position of the gimbal, and make the lower part of the gyroscope (motor) heavier, then the gyro monorail would never be able to stand upright on its train wheels.

It is set at about 3 mm. If it is more than that, it would end up gaining the acceleration of the car in the direction of its traveling motion, and the car would fall down when it starts or stops its traveling motion.

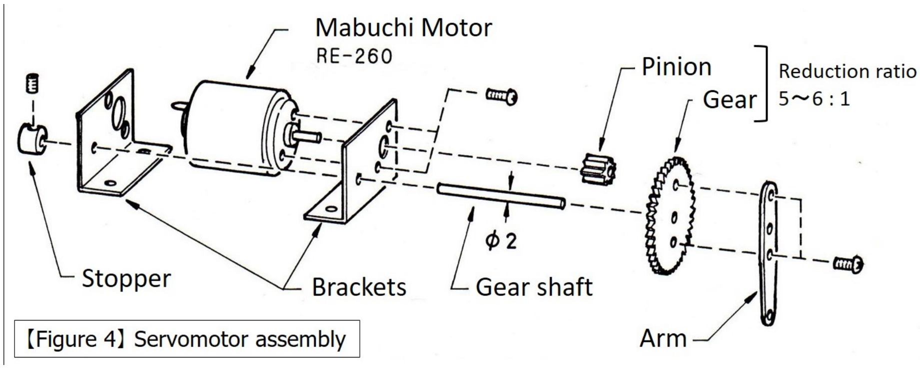


【Figure 3】
Relationship between the rotation axis and the center of gravity

The gyroscope wheel may rotate in either direction. The direction of gyroscope rotation does not matter to other devices and settings.

5. Servo and Balancing Switch

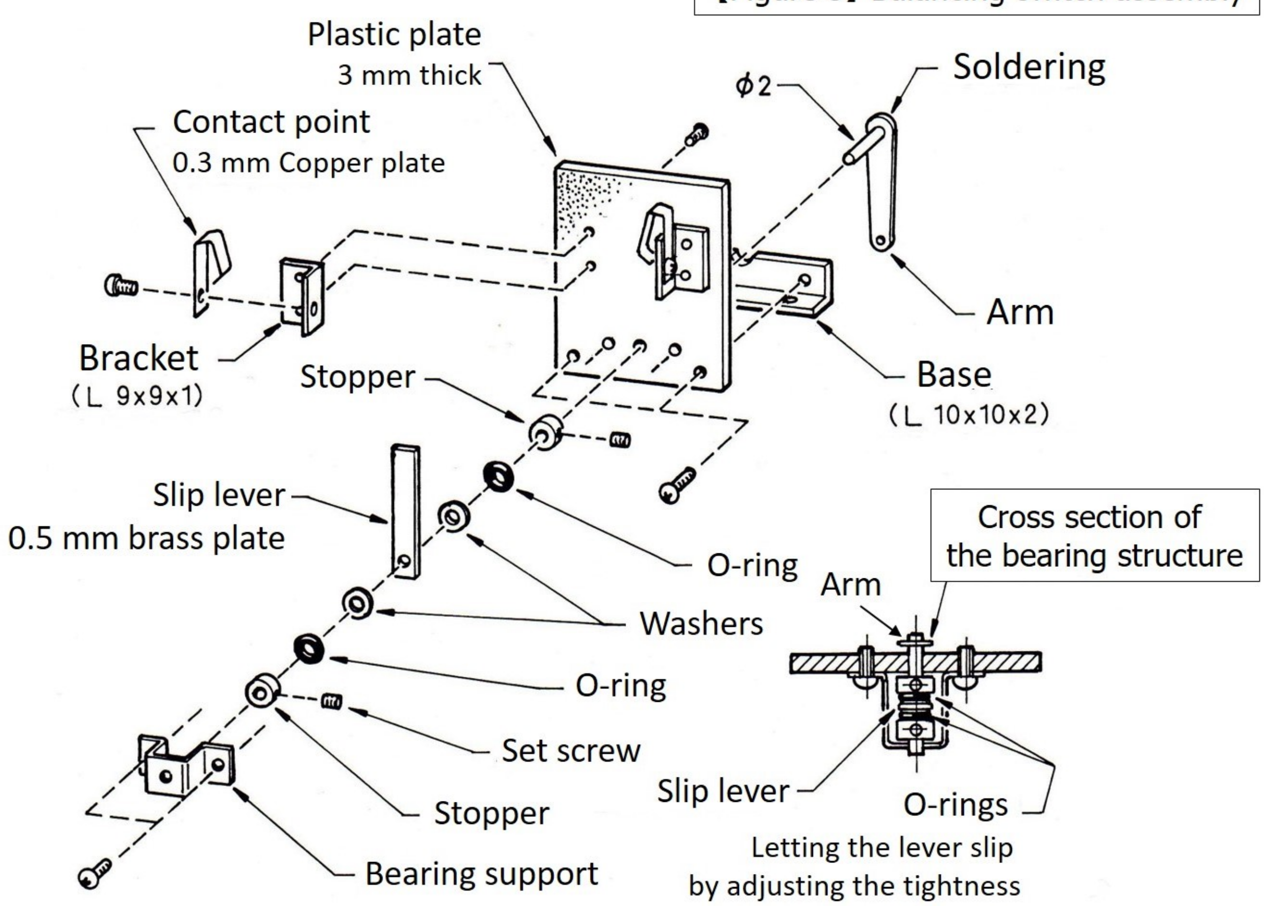
As for the servomotor to control the gimbal's motion, a simple mechanism, with which the spur gear just reduces the speed of Mabuchi 260 motor, is incorporated. As indicated in Figure 4, the gear box is made with an iron plate or a brass plate of about 0.5 mm in thickness. The rotation angle is approximately 120 degrees at most, so the arm is directly attached to the spur gear. Then, the arm and the gimbal are linked with a piano wire.



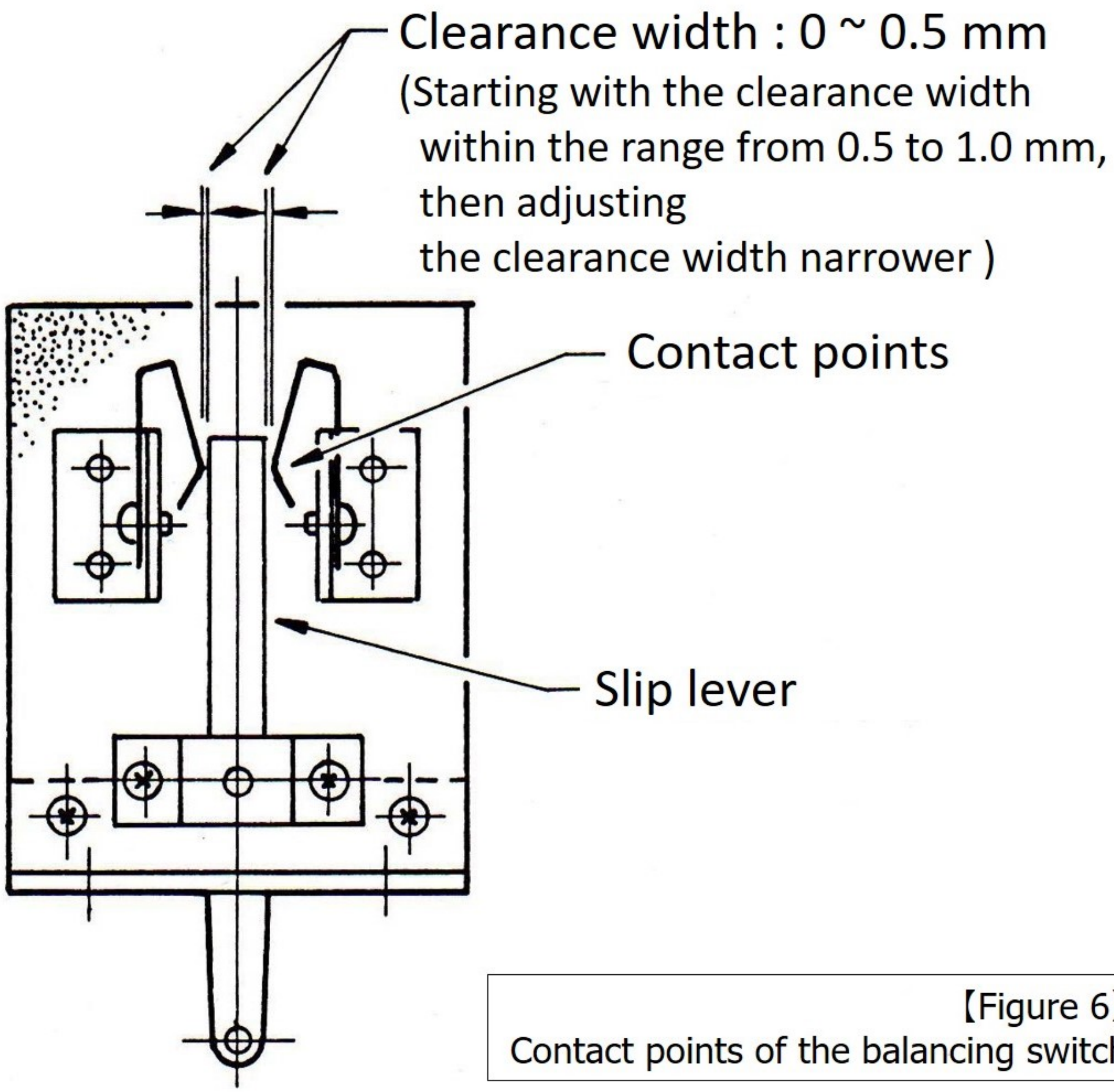
【Figure 4】Servomotor assembly

The rotational direction of the servomotor is flipped with the balancing switch. The axis of the balancing switch is linked with the gimbal motion. Then, a lever that slips and yet moves with friction is attached to the axis. Specifically, as shown in Figure 5, the lever is sandwiched with O-rings, and the friction is adjusted with the stoppers.

【Figure 5】Balancing switch assembly

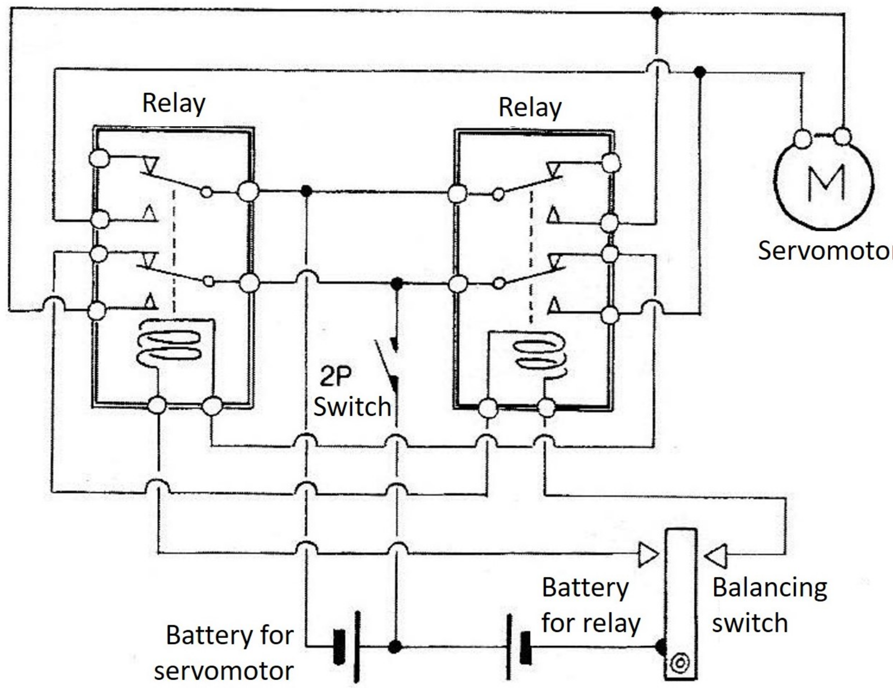


The slip lever is the point of electric contact, which activates two relays. Even though the circuit just changes the rotational direction of the motor, the clearances of the contact point have to be as narrow as possible (Figure 6), without turning on both of the relays simultaneously (in order to prevent the short-circuiting.) Figure 7 shows the circuitry. Although the graphical description is omitted in the figure in this article, the relays are attached to the upper parts on the other side of the balancing switch.

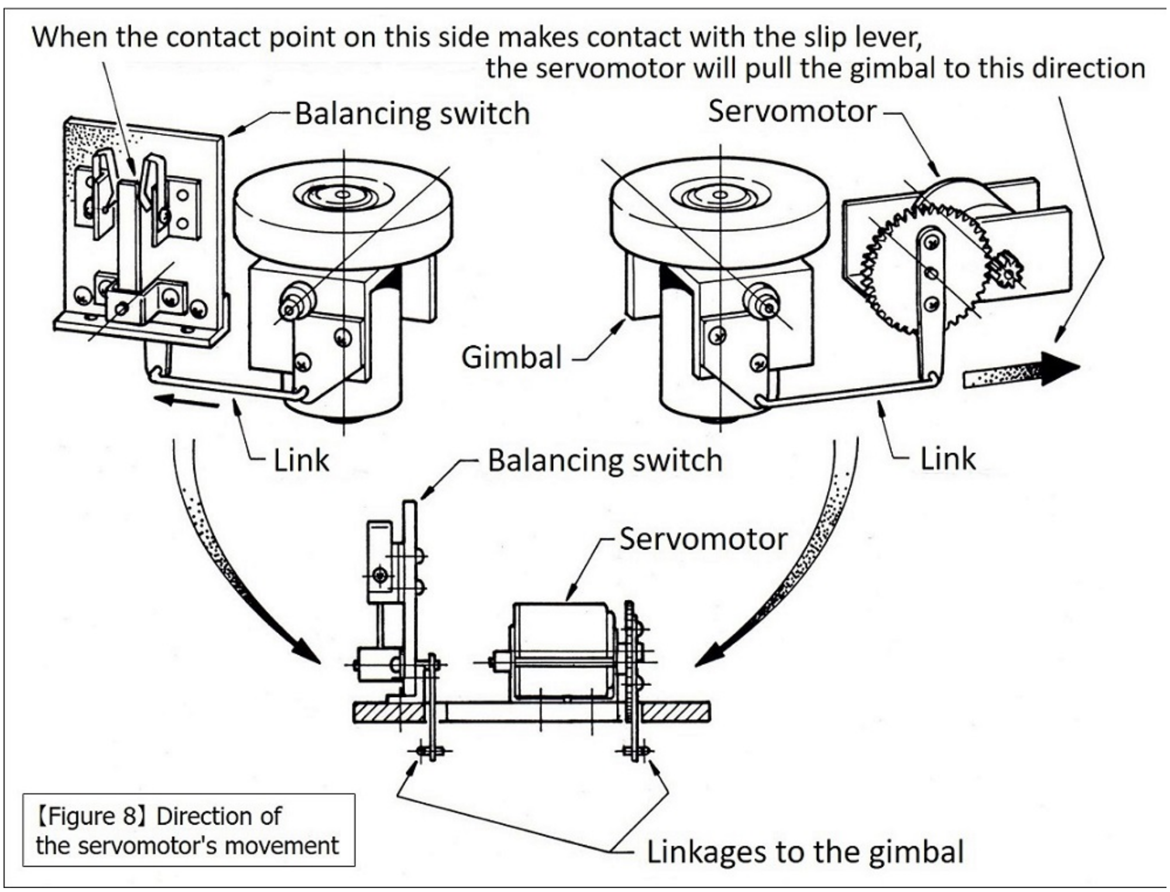


【Figure 6】
Contact points of the balancing switch

【Figure 7】Balancing system circuit diagram



The gimbal moves, the slip lever moves, the relays are activated, and the servomotor starts running. The important thing in this situation is to have the servomotor rotate to the same direction as the gimbal moves. In short, the force is applied to the direction to which the gimbal motion is assisted (augmented). (Figure 8)



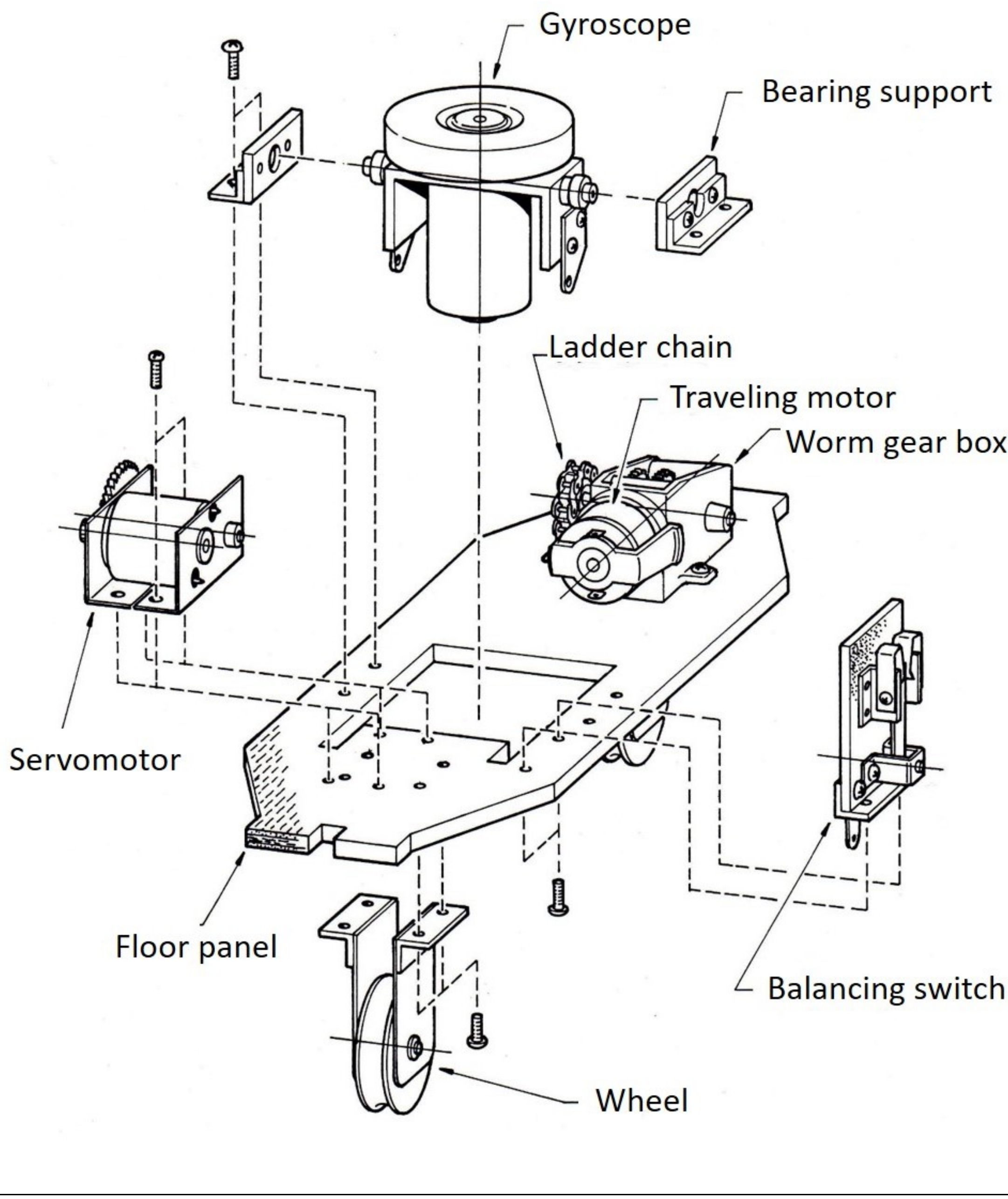
【Figure 8】Direction of the servomotor's movement

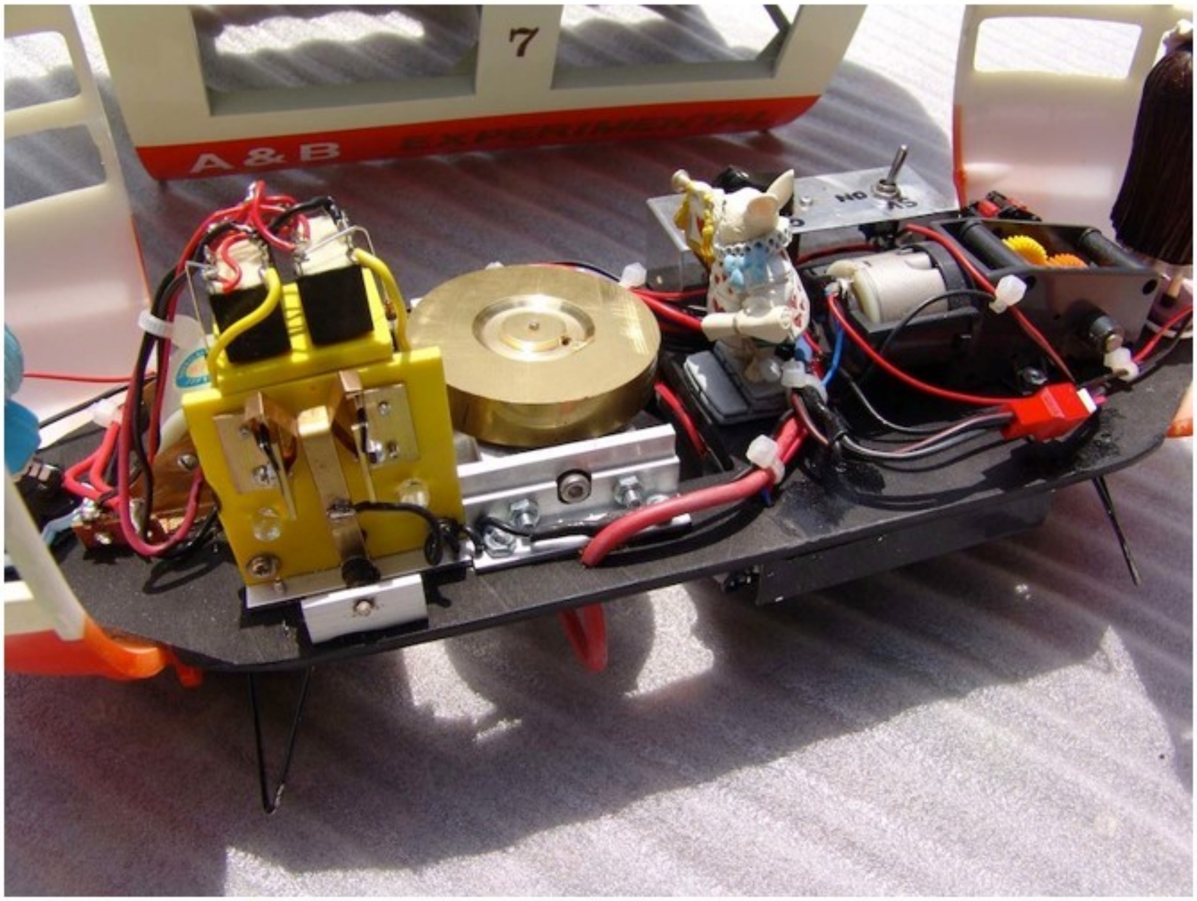
The role of the servomotor is to dampen the gyroscope's precession. In other words, the servomotor is for stopping the gimbal's motion. Based on the convention, when the gimbal starts moving, it is easy to think that putting a brake on the gimbal by applying the force against the motion is a natural reaction. However, it is the opposite of what has to be done. Making the upper part of the gimbal heavier and keeping it unstable, as mentioned before, are based on the same logic. Making the gimbal unstable is the core of the technique to obtain the stability of the gyro monorail.

The adjustment of the balancing switch is essential. The pilot lamp makes the adjustment procedure easy. Connecting light-emitting diodes that are designed to glow when one of the relays is turned on, in parallel to the coil of each relay is recommended.

I show the draw plan in Figure 9 and the system inside in Photograph 1.

【Figure 9】Attaching the main units



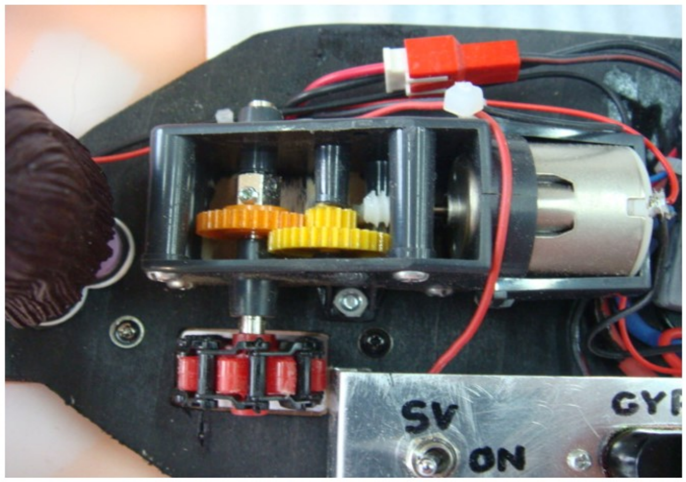


【Photograph 1】Car interior

Two relays are attached to the balancing switch.
At the center of the car is a rabbit figure.

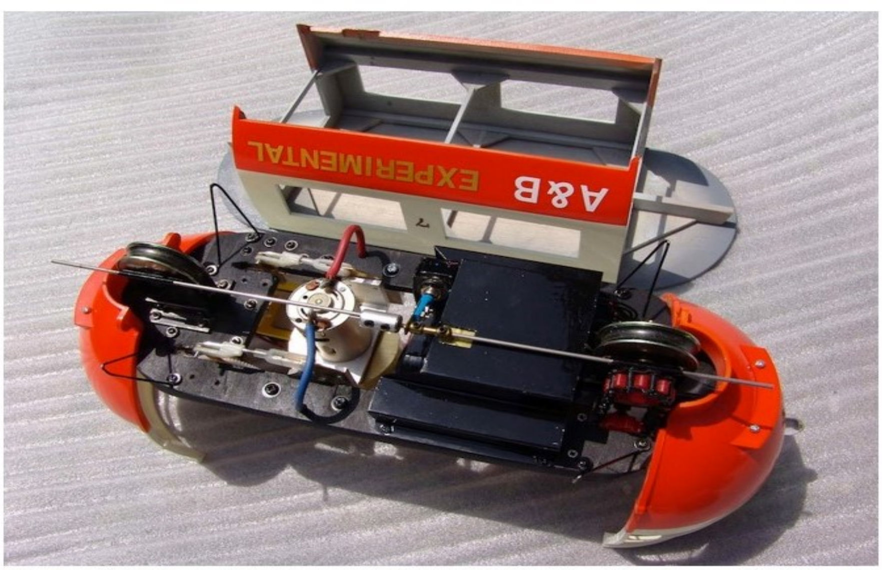
6. Traveling Mechanism

It is natural to crave for the mechanism to allow a monorail to run on its own power. Even though having an all-wheel drive is ideal, a one-wheel drive is used in this occasion for simplicity. Since the car has a single gyroscope and cannot turn the curve, it is designed and set up to run slowly on a straight line, going back and forth. Tamiya worm gear box (with Mabuchi 260 motor) was available, and was used. Then, Tamiya ladder chain was used to transmit the force to the driving wheel. Using pulleys would probably make the procedure much easier (Photograph 2).



【Photograph 2】Traveling mechanism

A long bar that spans the entire longitudinal length of the car, from the front to the rear, is attached to the base of the car, to activate the switch to reverse the traveling direction. If an obstacle is placed on the railway, the tip of the bar collides with it and the traveling direction is reversed automatically to allow the linear round trip, going back and forth on the straight track (Photograph 3).



【Photograph 3】Underbelly of the car

On the left side of the center is the gyroscope.
On its right is the forward/backward selector switch for traveling.
It is operated with the bar that pierces the car from front to rear.

7. Body

The front and rear parts of the car (can be interpreted as the faces of the car) are, as mentioned earlier, made of the lampshades for light sources used in construction sites. Conveniently, it has a rectangular hole. The floor panel is inserted into the hole, and then it is fixed with wood screws (Photograph 4).

【Photograph 4】Front side of the car

To lower the center of gravity, the entire body of the car has to be light (The whole weight of this car was about 1.2 kg). The frame is assembled with aircraft plywood and rectangular block pieces. The side panels and the roof were made with balsa wood. After sanding and spraying surfacer several times, it is painted with urethane (Photograph 5).

【Photograph 5】Completed Model No. 7

A light-emitting diode (10 mm in diameter) is used for the headlight. Also, light-emitting diodes, whose colors change between green and red with the polarity, are used for the auxiliary lights. Just by connecting the light-emission circuitry with the traveling motor in parallel, the headlight to the traveling direction is lit, and the auxiliary lights turn green in the front and red at the rear.

8. Power Source

Three motors were used in total. To make the entire body lighter, nickel hydrogen battery pack (7.2V) was used for the gyroscope motor. For the servomotor, four AAA batteries (6V). Since this motor does not rotate well, a large electric current tends to flow, and ordinary manganese batteries with high internal resistance are suitable only in this case. For the traveling motor, two AA nickel hydrogen batteries are used.

The power source to operate the relays was shared with the servomotor in the early phase. However, there were accidents such as malfunctioning of the relays due to voltage drops. To solve the problem, the design was changed to allow the relays to share the power source with the gyroscope.

The power switches of the gyroscope and the servomotor are attached to the panel installed inside the car, to be operated through the windows. The power switch for the traveling motor is placed beneath the floor panel, and it is operated by pushing the bar. The general designs for the switches depend on the preference of the builder. Therefore, the diagrams do not show the details, such as the specific locations to attach certain parts.

9. Adjustments

First, the attachment of auxiliary legs to prevent the car from being capsized completely even when it tilts sideways is recommended. It is also for not ruining the paint job. Alternatively, to place cushions on both sides of the railroad track will do the job.

It is important to confirm the following items in advance.

(1) The gimbal moves without resistance. (The resistance to some extent exists, for the gimbal is linked to the servomotor gears and the balancing switch.)

(2) The servomotor's movement. (Shake the gimbal by hand, without rotating the gyroscope. Make sure that the little perturbation will cause the gyroscope to swing to the direction all the way, and that the way it swings is the same, whether to the front or to the rear.)

(3) The rotation count per unit time and the vibration of the gyroscope. (Usually, it is about 8000 rpm. Check it with a tachometer. If the vibration is intense, then pinpoint the cause and solve the problem.)

Under these conditions, activate all mechanisms (except for traveling) and make sure that it can stand on its own. The part to adjust is the friction of the slip lever for the balancing switch. Adjust the stoppers that sandwich the O-rings. Additionally, after observing the behavior, change the clearance distance of the contact point and the elasticity of the lever.

If it stands on its own, even if it may be wobbly to the lateral direction, it can be considered to be moderately successful. As the adjustment procedures are repeated, the condition with little to no wobbling can be achieved. However, it will put more strain on the servomotor, and will exhaust the battery quickly. The battery gets overheated at times. Check the condition of the batteries occasionally.

As a side note, the gyroscope of this is not completely enclosed. The noise from the rotation can get loud, and make sure not to disturb the neighbors.

Prototype No. 7 test-running in the garden

(https://www.youtube.com/watch?v=AqWw3pW3mRM)

10. Afterword

Compared to Model No. 9 with twin gyroscopes, which was completed earlier, this Model No. 7 is not completely calibrated. (I had to relocate the residence and move before that.) Since the center of gravity is a little high, the wobbling does not stop completely. The problem is that the situation changes according to the battery's conditions.

The fact that the car cannot make turns at curves theoretically due to its being a single-gyroscope car is repeatedly emphasized. After giving it a try, it barely managed to turn the curve, up to about 180 degrees. (It was wobbling laterally, while appearing to struggle in agony.) It is a problem that has more to do with the angles of the cumulative curves than the simple radius of the curve. There is no problem if the track is a gentle S-shaped curve, for the course is set in just one direction in the larger picture. If a car that makes a complete lap on a loop is desired, the only option is to attach the second gyroscope that rotates to the other direction and then to link with rods or gears to let the both gimbals move symmetrically. If the car has twin gyroscopes, it will run through the curves at high speed.

It is impossible to predict how things work to what extent, just from theoretical formulas. The actual factors that come into play in reality are very complex. To continue to accumulate more know-hows is essential. I sincerely hope that more people will try to study gyro monorails and exchange information with each other.

Finally, all the drawings (except for Figure 7) were drawn by Mr. Kozo Hiraoka. I imagine that my models would have exploited their potential even more fully, if they were made more accurately according to the drawings. However, the point (which I want to emphasize to allow the readers to interpret) is that the functional gyro monorails can be built with relative lack of craftiness (refer to the photographs).

Looking back, the key to making the gyro monorail successfully is my belief that I can absolutely do anything that I try to do. Without that, I would have given up in the middle of the process. Belief is born from the theory of determination. (Written in March, 2010.)

References

(1) The railway model website of the author
(http://www.ne.jp/asahi/beat/non/loco/loco00.html)

(2) The video website of the author
(https://www.youtube.com/user/AkubiLR)

This article first appeared on 2010 August issue of a Japanese monthly magazine "Hobby of Model Railroading" (published by Kigei Publishing) and was translated in 2017 for The BBB: Breakthrough Bandwagon Books.

MORI Hiroshi Works List at The BBB

The Sky Crawlers

http://thebbb.net/ebooks/the-sky-crawlers.html

The Sky Crawlers: Prologue, Episode 1

http://thebbb.net/ebooks/the-sky-crawlers-prologue-episode-1.html

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The Sky Crawlers: Episode 2, Episode 3

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The Sky Crawlers: Episode 4, Episode 5, Epilogue

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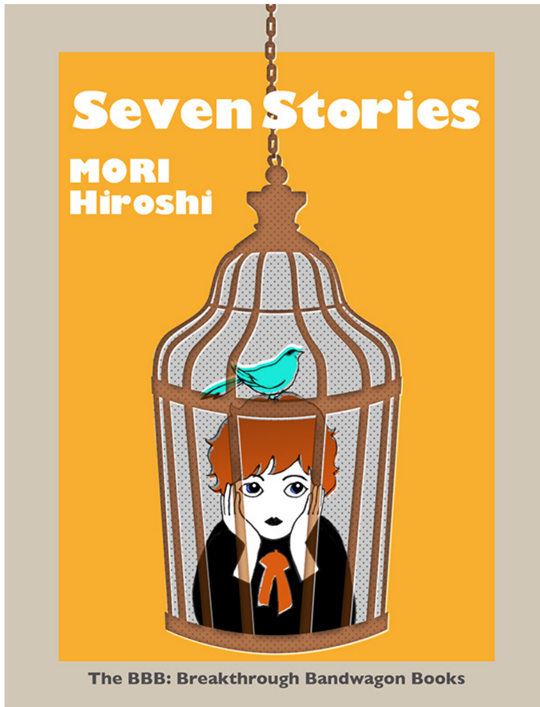

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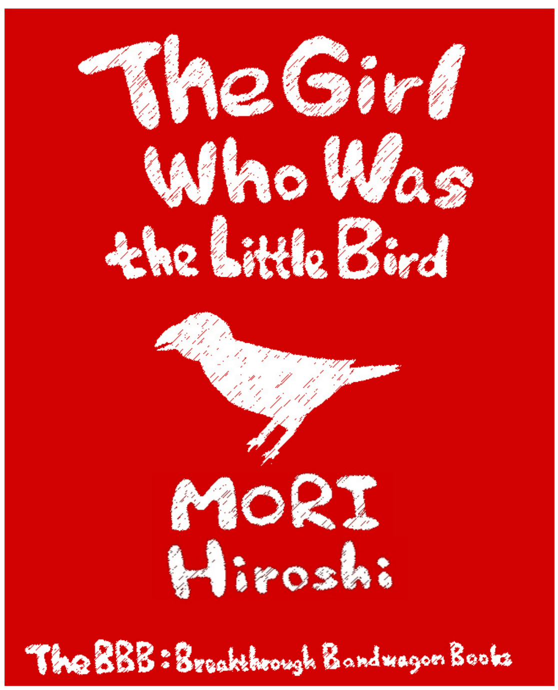

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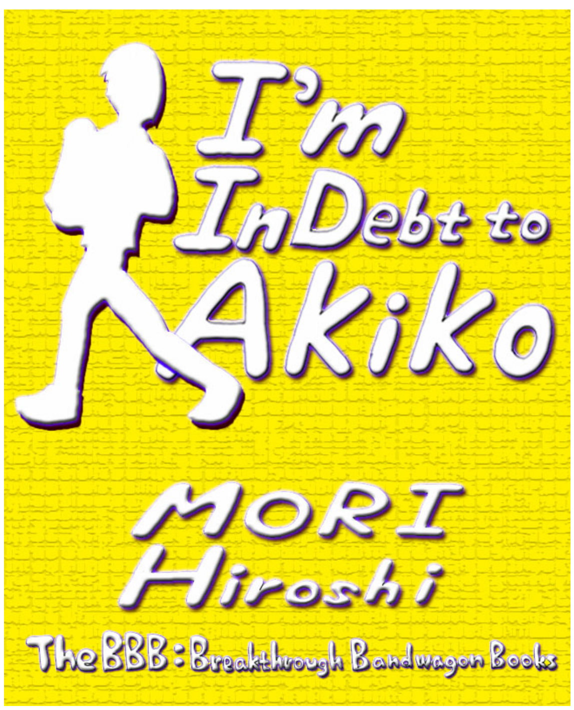

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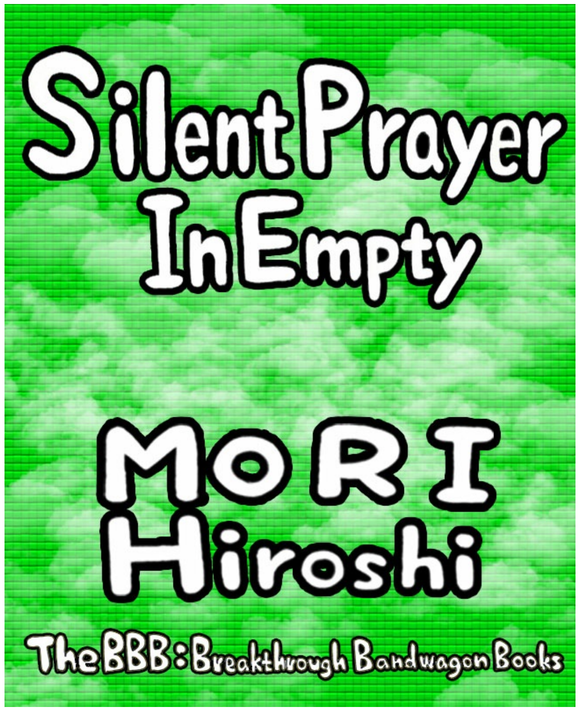

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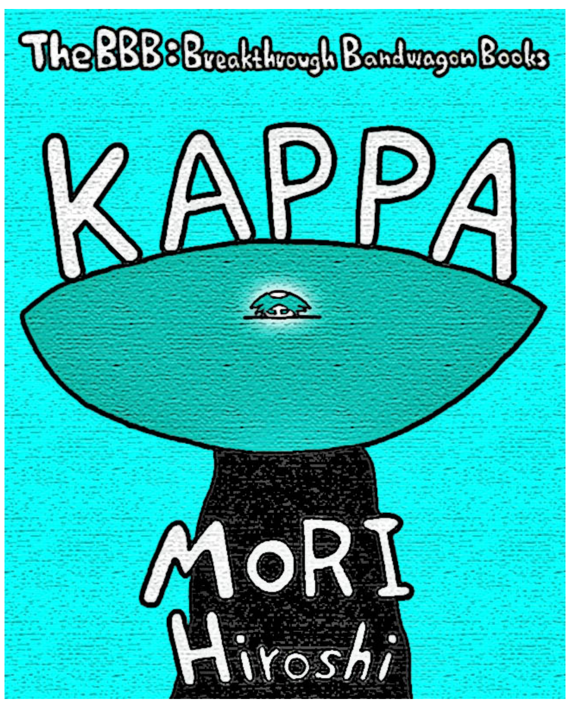

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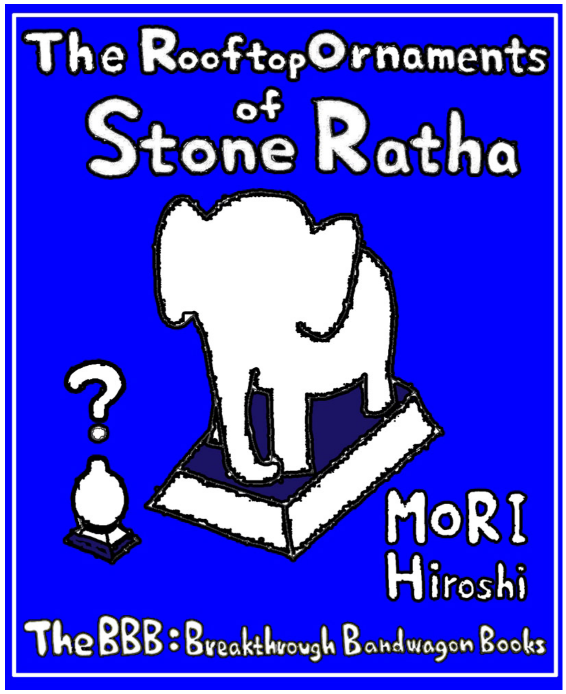

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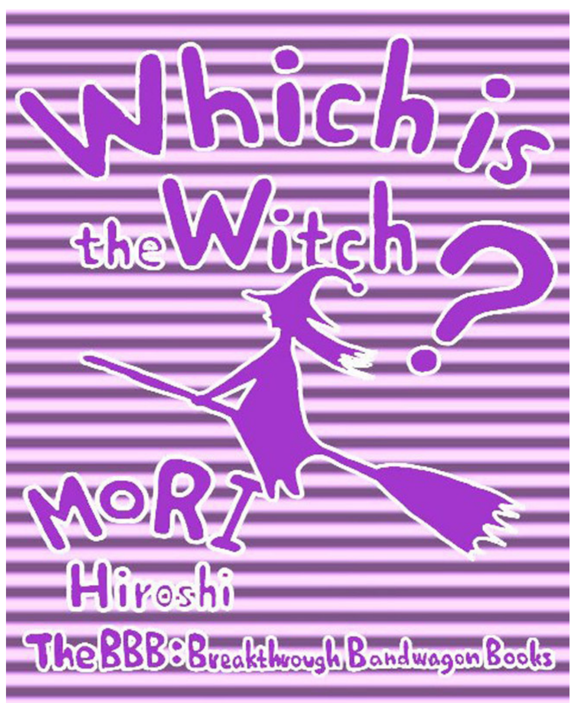

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