Innovative design of energy generation and storage devices based on road speed bumps

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Abstract. This paper presents an innovative design that aims to solve the problems of conventional speed bumps. The speed bump is capable of adjusting the cushioning strength in real time according to the speed of the vehicle and is equipped with a power generation facility. When a vehicle passes over the speed bump, the device converts the force exerted by the vehicle into electricity, which is stored in a battery. In low light conditions at night, the LED deceleration warning light provides a warning through the power generation facility, ensuring safe and comfortable driving. In addition, the speed bumps have a sunken design that reduces vehicle bumps, while powering the street lights at night through a sunken drive motor and generator. Each pass can generate 30KJ of electricity, and if 30,000 vehicles pass through each day, it can recover 5,000 watts of electricity per hour, reducing energy loss compared to traditional energy transmission methods. Modular design reduces the system price, low transformation threshold, can be applied to traditional speed bumps, reducing the cost recovery cycle to about one year, expanding the application scope.

Keywords: Reduction belt power generation, Modular design, Energy recovery.

1. Introduction

During the "two sessions" in 2021, china report put forward the goals of "carbon peak" and "carbon neutrality". According to the data, China's coal consumption accounts for about 57 per cent of the country's total energy consumption [1-2]. The power industry is the area with the highest carbon emissions and coal use in China, and its carbon emissions have exceeded 40 per cent. Therefore, promoting the development of a clean and low-carbon energy supply system, as well as the construction of a new power system, is an important part of our efforts to achieve the goals of "carbon peaking" and "carbon neutrality". Actively promoting high-quality low-carbon development is not only an important task for the overall greening of our economy and society and the building of an ecological civilization, but also a core strategy for achieving the "dual-carbon" objective [3].

Looking at the energy use of various industries, Figure 1 shows that in 2018, the share of manufacturing, electric power (including production and supply of electricity, heat, gas and water), and transport (including transport, storage and postal services) in Beijing's total energy use was close to 58%. In particular, the share of energy consumption in the transport sector is much higher than the national level [4].

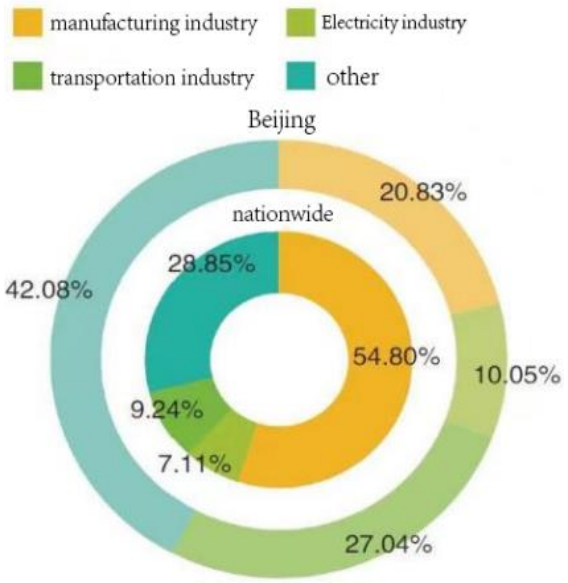

Figure 1. Proportion of energy consumption in Beijing and some industries in China in 2018

As of today, the "carbon emission overload" has seriously affected people's lives, and it has become the responsibility and obligation of every citizen to monitor and reduce carbon emission beams. After years of hard work, China's road construction is booming with an increasingly visible vigour. By the end of 2021, the total length of road surfaces in China will have exceeded 5.28 million kilometres, while the number of registered vehicles in the country has risen to 302 million.

In order to rapidly achieve 'peak carbon' and 'carbon neutral' targets, the design integrates human-centred transport concepts with energy-saving and emission-reduction strategies, taking into account the driving modes of automated vehicles and the existing problems of speed bumps. Innovative design thinking was introduced to successfully integrate the power generator and the speed bumps through the three-dimensional design of the speed bumps and the incorporation of the power generator. The design shows a high degree of plasticity and practicality, with low installation costs, simple maintenance, and a stable operating environment, which is mainly directly affected by traffic flow. The design ensures that the speed bumps play a fundamental role in traffic operation - slowing down and security - while also ensuring the supply of electricity, which can somehow ease the load on the power grid and reduce energy consumption.

2. Design scheme

The device is divided into a mechanical part and a circuit control part.

2.1. Mechanical part

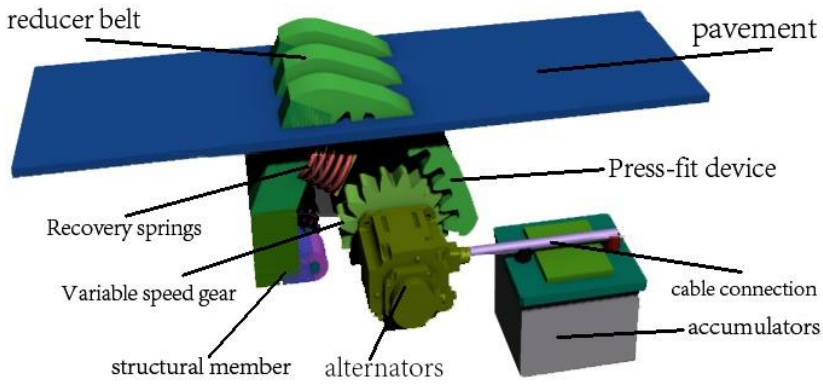

Figure 2. 3D MAX model of the power generation drives of the speed brake

We have developed an energy recovery device - a speed bump plate that drives a generator to produce electricity when the car passes over the speed bump and stores the generated electricity. Such a device relies on a crank-link mechanism. Based on the property of turning linear motion into rotational motion, we constructed a 3D MAX model of the speed bump plate-driven power generator device illustrated in Fig. 2 and investigated its kinematic properties. Based on this model, we designed a solution that allows us to add a tunnel and a device to dampen the spring at the bottom of a normal automotive reduction plate. The device contains components such as springs and crank connecting rods for power generation [5-6].

2.2. Circuit part

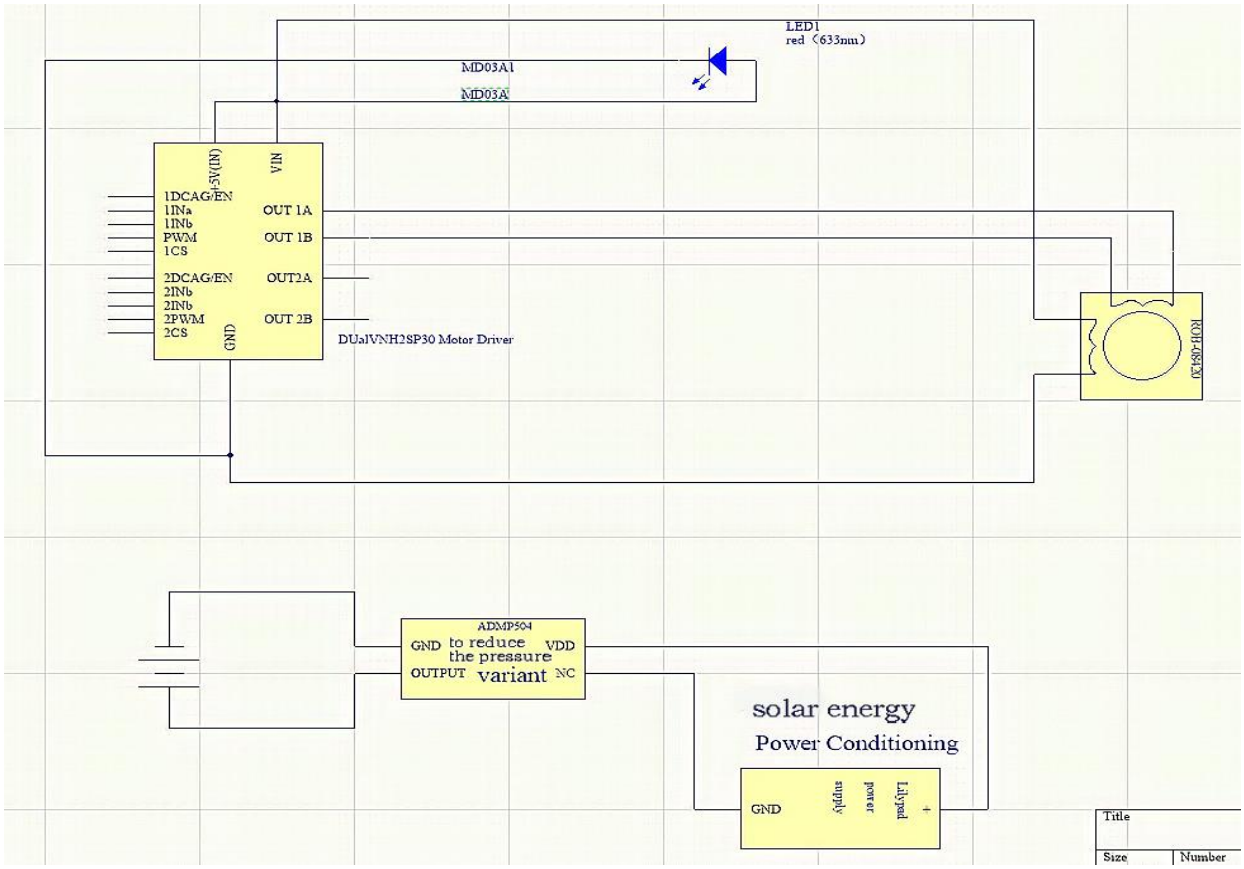

Figure 3. PCB circuit model of a speed brake power generation device

Using the unidirectional conduction qualities of diodes, a single-phase bridge rectifier consisting of four diodes was constructed to rectify and store the sinusoidal current generated by the generator, as shown in Fig. 3. This way of converting current has a simple structure, efficient energy utilisation and reduced power consumption [7].

3. Motion Modelling

3.1. System control design

The system is mainly punished when the deceleration device, warning control device and power generation and storage, the device consists of three parts of the overall control structure of the system schematic diagram shown in Figure 4 below:

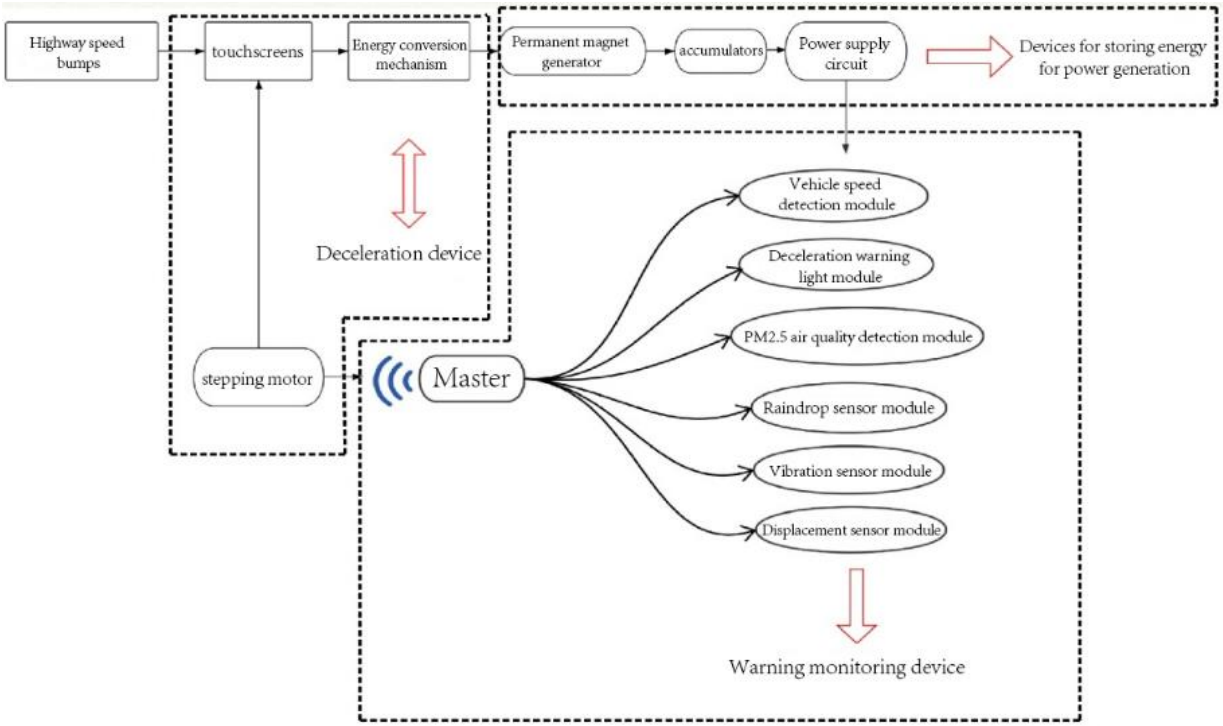

Figure 4. The overall control principle of the system

3.2. Equipment control design

Figure 5 shows the schematic diagram of the design of highway speed bump power generation and energy storage equipment.

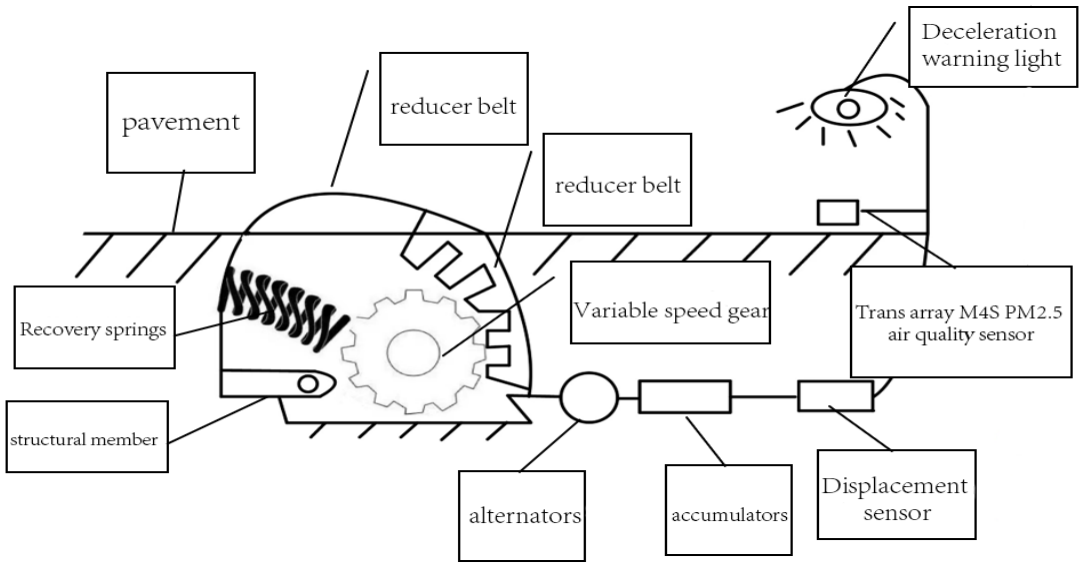

Figure 5. Schematic diagram of highway speed bump power generation and energy storage equipment design

4. Working Principle and Performance Analysis

4.1. Working Principle Analysis

When a vehicle drives through the system, the detection equipment used for speed measurement will detect the speed of the vehicle, which constitutes the fundamental principle of the system to achieve deceleration. It evaluates whether it complies with the traffic speed limit of this road. If this is the case, the control device sends a low-level pulse back to the main controller, which in turn

activates display mode 1, the green warning light. If the vehicle is within 20% of the speed limit, the main controller will activate the display mode [8].

When the number shows 2, it means that the yellow warning light is on, and at the same time, the control device activates the 1st mode of motion of the stepper motor, which makes the whole of the reduction plate rotate by 10°. When the temperature drops to 15°, it demonstrates a clear deceleration effect, while the energy conversion mechanism is used to drive the rotation of the generator spindle in order to achieve the goal of storing electrical energy. Suppose the car exceeds the speed limit. When it exceeds 20%, the main control device will activate display mode 3, which means that a red warning light will be illuminated; in this case, the controller will stimulate the motion mode of the stepper motor. In this case, the controller will activate the stepper motor movement mode, which will make the overall speed reduction plate flip 25°-30°, so as to achieve the purpose of speed reduction and power generation and energy storage.

The overall arrangement of the system is illustrated in Fig. 6. A strong buffer spring is flexibly connected to a speed reduction belt placed at the upper end of the groove, which is held firmly in place by a pressure device. The pressure device is equipped with a recovery spring and a rack, which is then connected to a speed change gear, which is then connected to a steering device. This steering gear is then connected to a generator, which converts mechanical power into electrical power. This power will be stored in a battery reservoir and then converted into suitable alternating current (AC or DC) by means of voltage conversion and AC/DC switching technology, as required.

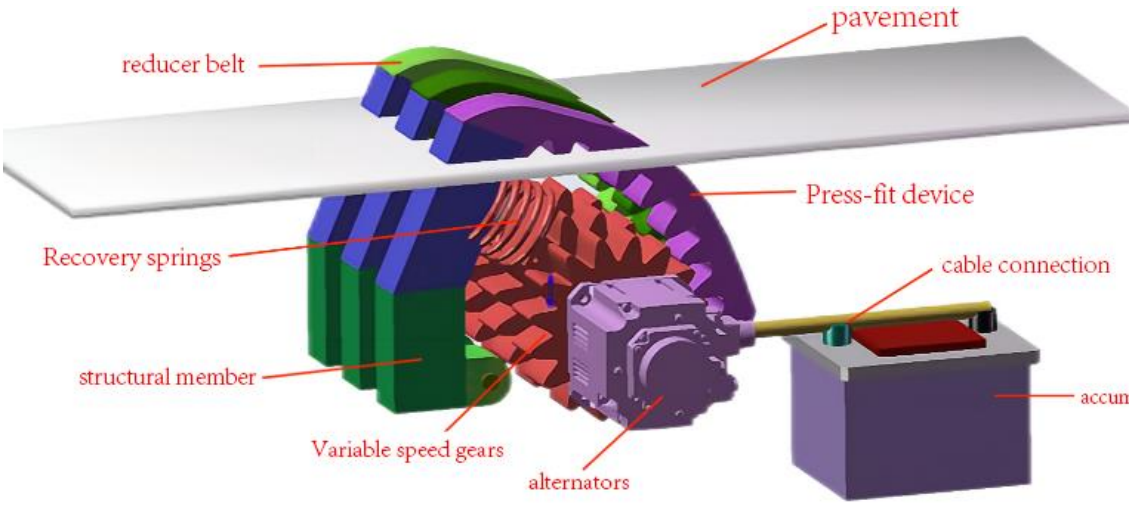

Figure 6. SolidWorks model of highway speed bump power generation and energy storage equipment

When an external circuit transmits current to the excitation coil, a magnetic field is generated which allows the claw pole to acquire the magnetic properties of the south and north poles. The rotor rotates at a certain speed n (rpm) and this rotational process results in an alternating change in the magnetic flux rate in the stator coils. Based on the principle of electromagnetic induction, a stator fitted with three-phase coils generates an AC induced electromotive force. The rotor is a synchronous generator pulled and rotated by a prime mover (or engine), which operates by inducing an AC voltage in the three-phase stator coils. Once the stator coils are linked to an electrical load, the motor generates and outputs AC electrical energy. The generator contains a rectifier that converts the generated AC energy into DC and outputs it from the output connector. During rotation, the 5V voltage regulator module stores the DC energy in the battery and connects the excitation coil to the negative terminal of the iron storage battery via the battery positive charging indicator regulator contact.

4.2. Mathematical model of road speed bump power generation device

In the interaction between the vehicle and the speed bump, the "vehicle-transducer" system can be regarded as a multi-degree-of-freedom complex vibration system composed of "vehicle-speed bump-

hydraulic system". In order to improve the efficiency of problem solving, we choose to deal with this complex vibration system by means of model simplification [9].

(1) During the interaction between the vehicle and the speed bump, the vehicle basically does not undergo sideways oscillation. Since the car passes through the speed bump in a very short time, its pitch fluctuation can be basically ignored, and the main vibration that occurs when the car passes through the speed bump is the vertical vibration.

(2) Comparing the vertical motion of the speed bump, the effect of its horizontal motion can be regarded as insignificant.

(3) The width of the speed bump is very narrow in comparison with the wheelbase of the vehicle, so that the interference between the front and rear axles of the vehicle is negligible in the process of its effect.

(4) During operation, all parts of the vehicle are considered to be completely rigid except for the tyre suspension part of the vehicle.

Overall, the vehicle converter system is simplified as a two-degree-of-freedom model as shown in Fig. 7. And in Fig. 7, m2 represents a quarter of the car. The corresponding representation symbol for the spring-loaded mass is m1; the stiffness and damping of the vehicle suspension are represented by k1 and c1, respectively; the unsprung mass is different, as well as the stiffness and damping of the wheels are represented by k2 and c2, correspondingly. m3 is defined as a depiction of the mass of the transducer of the movable speed bump power generator device; k3 and c3 are the descriptions of the stiffness of the springs and the damping of the structural elements; F is the force applied by the system to the speed bump representation; x1 describes the partial displacement of the sprung mass; x2 is a symbol of the partial displacement of the unsprung mass; and x3 represents the vertical displacement of the wheel at the contact of the speedbelt [10].

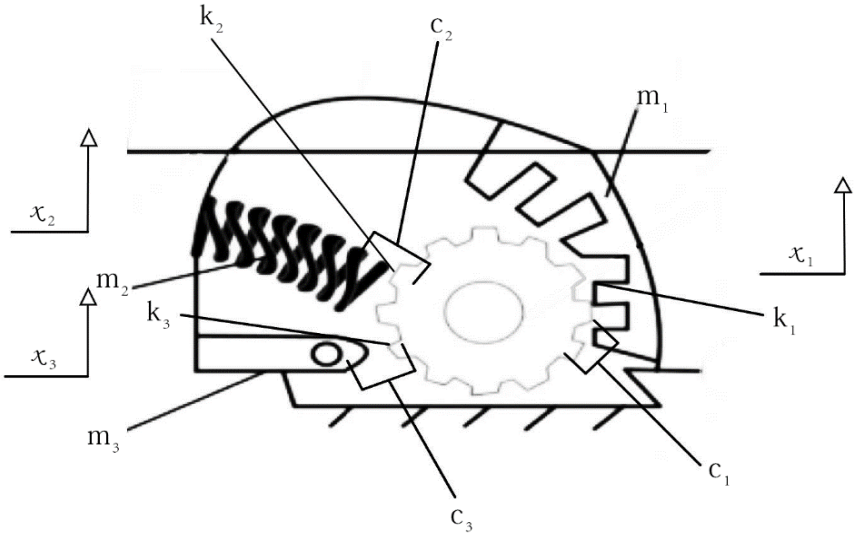

Figure 7. Schematic diagram of the mathematical model of the speed bump device

When analysed in summary, we can see that the speed and weight of the vehicle directly affect the forces generated by the vehicle on the speed bump. In contrast, the effect of the speed bump on the brakes is much smaller than the pressure loss, the check valve activation pressure, and the total system pressure. This is consistent with the small mass of fluid injected in the reservoir compared to the mass of the transducer and its negligible volume compared to the total volume of the reservoir. Therefore, after sizing the hydraulic cylinder, the main factors affecting the force acting on the speed bump during the filling process come from the current system pressure and the damping of the hydraulic cylinder. And since it is not possible to change the damping of the hydraulic cylinder, the force exerted by the vehicle on the speed bump depends mainly on the different models of vehicles, the different speeds of vehicles, the pressure change of the hydraulic system, and the hardness of the return spring.

4.3. Equipment Speed Control Characteristics

Compared with the existing traditional speed bumps, its speed control performance and outstanding characteristics are:

(1) The equipment has the applicability of speed control for traffic on different road sections.

(2) The equipment has the adjustability of speed control of traffic in different time periods; (2) The equipment has the adjustability of speed control of traffic in different time periods.

(3) The equipment reducer plate angle adjustable and achieve power generation and energy storage.

(4) The equipment can be combined with the existing traffic speed measurement system.

4.4. Energy conversion mechanism design

4.4.1. Mechanism design

The use of 3D MAX and Solidworks three-dimensional technology to model the system, and converted to CAD drawings in order to facilitate the expression of structural relationships.

4.4.2. Energy conversion principle

The energy conversion mechanism is the core of the effective operation of the entire equipment, the overall structure of the form of three-dimensional digital modelling design method, the specific principles are summarized as follows:

(1) Segmented reducer plate optimization design in the way of force and power transfer

(2) Segmented reduction plate meets the angle adjustable to achieve the deceleration function

(3) Continuous and reliable power generation and power storage

5. Experimental test and result analysis

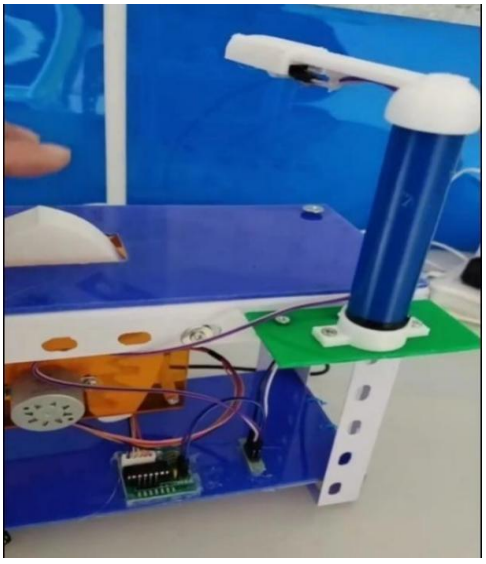

Figure 8. The physical model is shown on the right

As shown in Figure 8 of the physical model above, the top white part is the lamp, which simulates a street light on the road. Pressing the white part below the light can simulate the effect of generating electricity when a car passes over a speed bump, at which time the light will emit green light. Below this is the black USB port, our physical model will generate current by pressing the white module, so that the light will emit green light, below this USB port can be used to store electricity. Next to the stepper motor drive module is, the expansion board is mainly extended positive and negative poles. The motor is connected, the gear is connected, the speed reducer part.

(1) The deceleration warning light will not glow without pressing.

(2) Now we can see that the deceleration warning light emits green light when we press the speed bump part. In other words, pressing the speed bump section generates electricity.

6. Conclusion

This innovative design solves the problems of traditional speed bumps through a combination of speed bump power generation, modular design and energy recovery. The new speed bump adjusts the cushioning strength in real time and is equipped with a power generation facility that converts the force exerted by the vehicle into electricity and stores it in the battery. At night, LED deceleration warning lights provide alerts through the power generation facility to ensure driving safety. The speed bumps have a sunken design to reduce vehicle bumps and at the same time power the street lights. It generates 30KJ of power per pass, and if 30,000 vehicles pass through each day, it can recover 5,000 watts of power per hour, reducing energy loss compared to traditional energy transmission methods. The modular design reduces the price of the system and can be applied to traditional speed bumps, reducing the cost recovery cycle to about one year and expanding the range of applications. This innovative design has achieved satisfactory results in terms of background and significance, design scheme, system control, mathematical modelling and experimental testing, providing strong support for the promotion of sustainable development of road transport.

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