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Electricity Generation from Speed Breakers: Numerical Analysis of Existing Mechanisms for Bangladesh's Road Condition

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Abstract

With the rapid and geometrical population growth in the country, the demand for electricity along with the demand for transportation are constantly rising. It's necessary to look for an alternative technology to produce electricity that can be supplied to fulfill the rising demand. Due to the rapid increase of different light and heavy vehicles on city streets and highways, an alternative technology using speed breakers to generate electricity may be a viable solution for meeting local demands. It may further be integrated with the national grid. Numerous technologies like rack and pinion mechanism, reciprocating mechanism, and roller mechanism exist and have been implemented previously. The effectiveness of the mechanism and quantity of the energy harnessed largely depends upon different physical variables like traffic density, speed of the vehicles, weight of the vehicles, etc. This paper aims to draw a quantitative comparison of rack and pinion mechanism and roller mechanism in terms of power output and effectiveness considering all related physical parameters like mass of the vehicle, and traffic of a certain area. Both mechanisms exhibit separate advantages and disadvantages over one another. The Computer Aided Drawing (CAD) models of both mechanisms have already been created considering all the constraints. This work aims to show the numerical comparison between these two mechanisms using the detailed mathematical formulation found in the literature. The rack & pinion mechanism can produce 217.78 kWh which is equivalent of 36.04kg of diesel or 44.14kg of petrol combustion. On the other hand, the roller mechanism can produce 2471 kWh which is equivalent of 418.59 kg of diesel or 500.87 kg of petrol combustion. This paper will analyze the viability of the abovementioned technologies and underscore the potential of selecting appropriate energy conversion technology in the road conditions of Bangladesh and the roller mechanism can be more effective in power production and more environment friendly.

Keywords: CAD models, Speed breaker power generation, Rack and pinion mechanism, Roller mechanism, Comparative analysis.

1. Introduction

Energy is responsible for major developments in any country's economy. The energy industry includes the discovery, production, distribution, and sale of energy for multiple power needs including heat, light, propulsion, and whatever else energy may be needed for. The main energy source for the world's energy consumption includes nearly 80% of fossil fuels. These fossil fuels mainly include oil, gas, and coal [1]. But as the population rises, the energy demand also rises. The need for alternative fuels becomes a necessity because of the harmful gasses, those are produced by burning fuel, and other pollutions. These alternative fuels include energy sources like wind, water, solar, geothermal, nuclear power etc. However, these alternatives are not highly capable of minimizing the shortage of electricity generation[2]. So, new alternatives or neglected sources of energy should be worked on. Energy generation from speed breakers can be such an alternative. There already exists some mechanisms that have made it possible to generate electrical power from speed breakers. Such mechanisms are piezoelectric systems, hydraulic

systems, rack & pinion, and roller mechanism. There are also some mechanisms that use vehicle pressure on the speed breaker, which is transformed by a hydraulic press into rotating energy via a rack and pinion[3]. There is a report that shows the possibility of producing 245 watts for 250 kg of load, 441 watts for 300 kg of load, and 147 watts for 150 kg of load in an hour by using a rack and pinion mechanism [4]. Rack & pinion mechanism and roller mechanism are widely studied as they are easy to set up and obtain energy. Our paper focuses on these two mechanisms and their comparison. For the rack & pinion mechanism, reciprocating motion is converted into rotary motion via the rack, pinion, and gears and produces energy [5]. On the other hand, roller mechanism doesn't need to convert motion's nature as it originally produces rotary motion. Bangladesh has a higher population density in comparison to its surrounding territory. As a result, there are a lot of vehicles. Nowadays, it is observed that the intention of using personal and luxurious vehicles has grown up [6]. Because of this, traffic is now a major concern in practically every city. It is feasible to recover a sizable quantity of electricity if these techniques are put into practice. Criteria for calculating energy generation should be set with the traffic condition in mind.

2. Methodology

2.1 Rack & Pinion Mechanism

The methods we are working on initially take diverse approaches. Usually, reciprocating motion is the first action of the rack and pinion system. The speed breaker descends for a predetermined distance when a car crosses it. Along with the speed breaker, the rack also goes downward. This phenomenon causes the pinion to synchronize with the rack and begin to revolve. A gear that is attached to a shaft synchronizes with the pinion. The flywheel and shaft are linked as well [7]. By making some assumptions about the specs and rotation of this setup and its functioning, we may calculate the energy output. It should be noted that the pinion and gear were constructed with a 2:1 tooth-to-gear ratio in mind. Therefore, the flywheel will complete two full rotations with a single full turn.

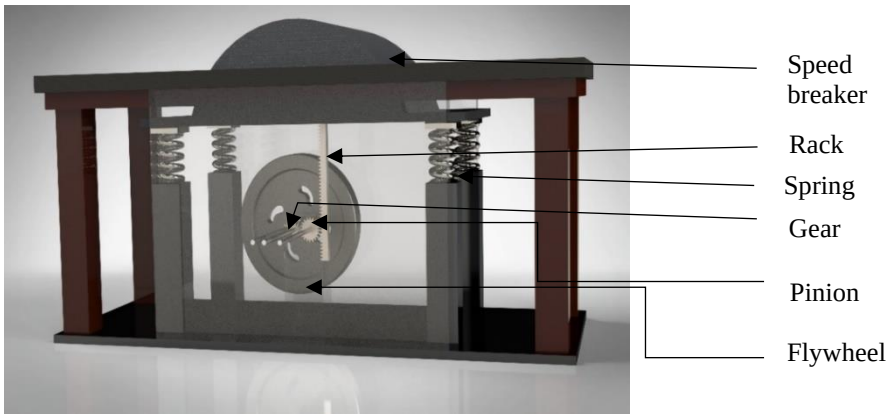


Fig. 1. 3D model of Rack & Pinion mechanism

2.2 Roller Mechanism

Compared to the rack and pinion system, the roller mechanism is more basic. The speed breaker rotates when a vehicle passes over it [8]. The same flywheel that powers the rack and pinion system also generates energy when this rotating motion is employed. To obtain greater spin for the flywheel, however, we set up a few gears. Equal synchronization exists between the roller and the gear attached to the shaft. The second gear and the first gear are synced, and the third gear and the second gear are synchronized. There is a 4:2:1 ratio between the first, second, and third gear teeth. As a result, the first gear will rotate once with a single roller revolution. The third gear completes four rotations, and the second gear completes two, according to the ratio. Via a shaft, the flywheel and third gear are coupled. Ultimately, the flywheel turns four times the roller's rotational speed. Lastly, the energy is calculated using the flywheel.

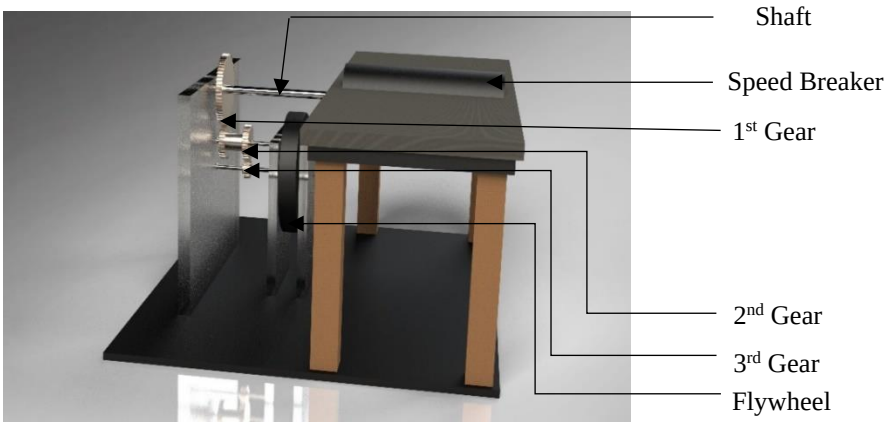


Fig. 2. 3D model of Roller mechanism

2.3 Numerical Investigation of Rack & Pinion Mechanism

2.3.1 Design of springs

Four springs are considered in this mechanism and their material is considered steel. By using the material's modulus of rigidity, assumed values of the parameters are inserted in the equation [9].

$$k = \frac{G \times d^4}{8 \times (D-d)^3 \times n} \quad (1)$$

Where,
Material of the spring = ASTM A228 Steel (Modulus of Rigidity, G=80)
Wire diameter of the spring, d = 8mm
Outer diameter of the spring, D = 60mm
Length of the spring, l = 240mm
Number of the coils, n = 12
Mean coil diameter, D-d = 60 – 8 = 52mm
So, Stiffness of the spring, $k = \frac{80 \times 6^4}{8 \times (52)^3 \times 12}$
= 6.858 N/mm.

2.3.2 Calculation of Load

The deflection of each spring will be considered 120mm. As four springs are considered, the calculated load should be multiplied by 4. The total load will be the maximum working load of the spring.

$$w = 4 \times k \times d \quad (2)$$

Where,
Stiffness of the spring, k = 6.858 N/mm
Deflection of the spring, d= 120mm

So, Total Load, $w = 4 \times 6.858 \times 120$
= 3292 N.

2.3.3 Calculation of Speed Multiplication

A minimum speed will be assumed in this segment. Speed ratio,

$$\frac{T_2}{T_1} = \frac{N_1}{N_2} \quad (3)$$

Where,
Speed of the gear, N_1= 20 RPM
Number of teeth in gear, T_1= 20

Number of teeth in pinion, T_2= 10
So, Speed of the pinion, $N_2 = 20 \times \frac{20}{10}$
= 40 RPM.

2.3.4 Calculation of Torque and Power
By assuming a perpendicular distance, torque and power will be calculated. The teeth ratio of the pinion and gear will also be considered.

$$T = \frac{w \times s}{(\frac{T_1}{T_2})} \quad (4)$$

Where,
Force = w = 3292N
Perpendicular distance, s = 30mm
So, Calculated T = $\frac{3292 \times 30}{(\frac{20}{10})}$ = 49N-m.

$$P = \frac{2\pi N_2 T}{60} \quad (5)$$

So, Power, P= $\frac{2\pi \times 40 \times 49}{60}$ = 205.25W.

2.3.5 Fuel Analysis
Generally, a Diesel Generator works between 30% to 45% of efficiency and a Petrol Generator does mostly 25% to 30% in terms of size. But here we will assume that a Diesel Generator with 50% of efficiency and a Petrol Generator with 40%, will produce the same amount of energy. From that, we will calculate the fuel consumption to produce that much energy.
Here,
Total power generated = 217.78 kWh.
Specific fuel consumption (in g/kWh or kg/kWh) = SFC
Conversion factor (energy per hour in seconds: 1 hour = 3600 seconds) = 3600s
Efficiency of the generator = η
H_{diesel} = Heating value (calorific value) of diesel, is typically around 42,500 kJ/kg**.**
H_{petrol} = Heating value (calorific value) of petrol (gasoline), typically around 44,400 kJ/kg

$$SFC = \frac{3600}{\eta \times H} \quad (9)$$

$$\text{Fuel Consumption} = SFC \times \text{Total power generated} \quad (10)$$

So, Diesel required = 36.04 kg,
Petrol required = 44.14 kg.

2.4 Numerical Investigation of Roller Mechanism

2.4.1 Force over the speed breaker
The vehicle's weight will be effective in this process [10]. So, the heavier vehicle will be more effective in producing energy.

$$F = (M \times 9.81) \quad (6)$$

Where,
Force over the speed breaker =F
Mass of the vehicle = M.

2.4.2 Calculation of speed multiplication

From equation (3), speed multiplication will be calculated by using gear teeth ratio that is designed in the CAD model.
Speed of the gear, N_1= 20 RPM
Number of teeth in gear, T_1= 60
Number of teeth in 3rd gear, T_3= 15
So, the Speed of the 3rd gear which is directly connected to the flywheel by a shaft, $N_3 = 20 \times \frac{60}{15} = 80$ RPM.

2.4.3 Calculation of Torque and Power

The same deflection value will be used to calculate torque. Then, with the help of torque and 3rd gear's speed, power will be calculated.

$$T = \frac{F \times d}{\frac{T_1}{T_2}} \quad (7)$$

$$P = \frac{2\pi N_3 T}{60} \quad (8)$$

Where,
Deflection, d =120mm
Torque, $T = \frac{(M \times 9.81) \times 120 \times 10^{-3}}{\frac{60}{15}} = (M \times 0.2943)$ N-m
So, Power, $P = \frac{2\pi \times 80 \times (M \times 0.2943)}{60} = (2.456 \times M)$ W.

2.4.4 Fuel Analysis

The same process is followed here to calculate fuel consumption as it was done before in rack & pinion mechanism. But the total generated power will be 2471 kWh in this method. So, Diesel required 418.59 kg and petrol required 500.87 kg.

3. Results

Vehicle composition of the traffic stream of Dhaka's specific area (from Bijoy Sarani to Satrasta) is used to calculate the average value of power production of an hour [9].

3.1 Rack & Pinion Mechanism

The calculation has been done for a spring load of 335.6kg. So, the functioning maximum mass is 335.6kg. The amount of mass that crosses that maximum mass won't be counted because of the spring and the barrier to protect the spring and the setup. Most of the vehicles that are counted here are above the maximum mass except motorbikes and NMVs (Non-Motorized Vehicles). So, we have assumed two motorbikes and three NMVs (Non-Motorized Vehicles) will produce the calculated amount. **Table 1** represents power produced using rack and pinion mechanism for various types of vehicles. It is observed that as the volume of motorbikes are significantly higher than other types of transports, it has produced maximum power followed by the power produced by passenger cars.

Table 1. Power production specifically within an hour using Rack & Pinion mechanism

Vehicle	Volume	Energy production for a single vehicle (watt)	Total (watt)
Bus	6	205.25	1231.5
Passenger Car	241	205.5	49465.5
Utility Vehicle	16	205.5	3284
Microbus Jeep	38	205.5	7809
NMV	374	68.5	25619
CNG	381	205.5	78295.5
Motorbike	507	102.75	52094.25

Total Production = 269036.75Wh = 217.78 kWh.

3.2 Roller Mechanism

According to the equation, derived before, power generation will be depended on the mass of the vehicle here. The average mass of the vehicles will be counted to calculate power. **Table 2** represents power produced using roller mechanism for various types of vehicles. A similar pattern has been observed with respect to the rack and pinion mechanism.

Table 2. Power production specifically within an hour using Roller Mechanism

Vehicle	Average Mass (M) in kg	Volume (n)	Power = $\frac{2\pi N_3 T}{60}$ = (2.456 × M × n) watt
Bus	13,000	6	191568
Passenger Car	1500	241	887844
Utility Vehicle	2250	16	88416
Microbus Jeep	3500	38	326648
NMV	110	374	101039
CNG	750	381	701802
Motorbike	140	507	174326.88

Total Production = 2,471,643.88Wh ≈ 2471 kWh.

3.3 Environmental Effect Analysis

If we use fuel to generate power, there will be some effect on the environment. The amount of different harmful gasses, that emits during combustion, is huge. By considering an average value of emissions, the amount of toxic gases and particulate matter has been calculated and represented in **Table 3** for both mechanisms. It can be clearly seen that to produce the same amount of energy yielded using rack and pinion mechanism, 36.04 kg diesel and 44.14 kg petrol need to be burned, respectively. On the other hand, since the amount of energy produced using roller mechanism is much higher than rack and pinion, so the savings of fuel and associated environmental benefits.

Table 3. Harmful gas emissions for the combustion of fuel to produce energy

Fuel	Mechanism	Calculated Amount (kg)	Carbon Dioxide (CO_2) (kg)	Carbon Monoxide (CO) (kg)	Nitrogen Oxides (NOx) (kg)	Particulate Matter (PM) (kg)
Diesel	Rack & Pinion	36.04 kg	96.59	4.505	3.604	1.0812
	Roller	418.59 kg	1121.82	52.32	41.859	12.5577
Petrol	Rack & Pinion	44.14 kg	101.96	9.93	1.766	0.353
	Roller	500.87 kg	1157	112.7	20.035	4

3.4 Generated power comparison

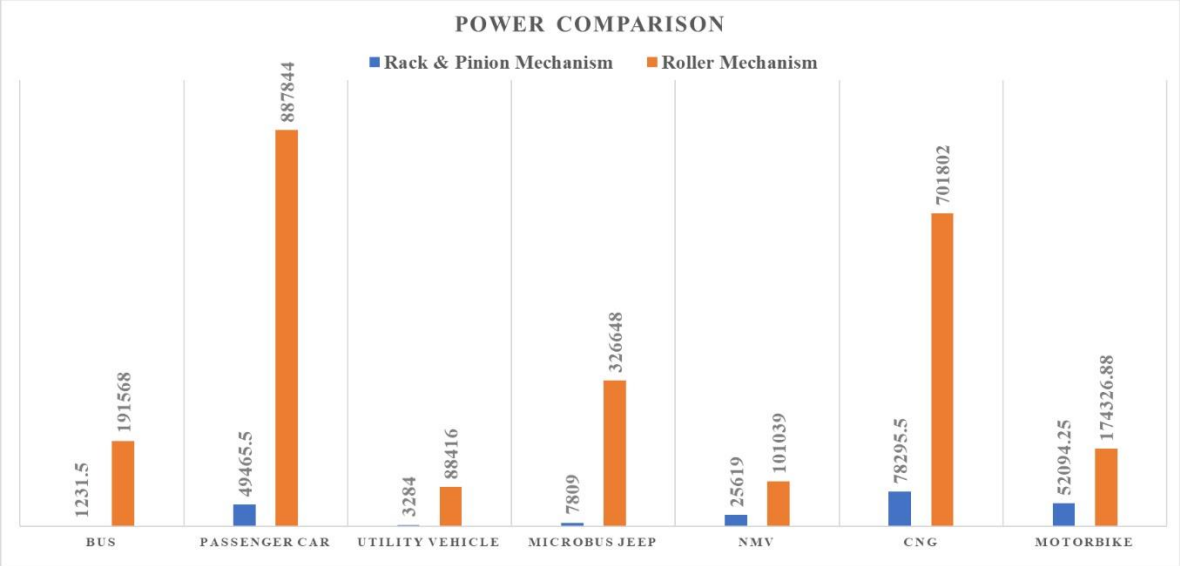


Fig. 3. Comparison of generated power (in Watt) for each vehicle between two methods

The **Fig. 3** shows a huge difference in power generation. The roller mechanism can produce a huge amount of power than rack & pinion mechanism. There isn't any common ratio between them because both of the mechanism is calculated by considering different parameters and limiters like mass.
The calculated amount of fuel, that should be used to produce the same amount of energy in our mechanism, can cause massive pollution. We assumed an average value of generally acknowledged gasses' production due to the combustion of those fuels. The number we get is huge by number compared to those two mechanisms.

4. Conclusion

The calculated power is huge by number. The factors that caused the reduction in production and increase the friction, were neglected during the calculation. So, the result will be different, power generation will be reduced greatly. The previous research on these two methods showed that the roller mechanism can produce more power in the long term. Yet we calculated and found the great difference between them and roller mechanism is more effective. Through further research and calculation, it can be implemented in the future. On the other hand, these methods do not cause much harm to the environment with respect to the conventional way, that we use to produce energy. However, more research is required to overcome the barriers. It will be a great initiative if it becomes implementable. Cause energy demand in Bangladesh is increasing rapidly. These methods can fill up energy demand even if the amount is so low.
The production of the power will be low in numbers if we consider the factors of friction. However, if we still manage to obtain 1% to 10%, it will impact our power industry. In this paper, we tried to compare mathematically which method is more efficient. Yet there are many things to consider to make it implementable. Many things can be improved to increase efficiency. In the rack & pinion mechanism, the pinion and gear revolve clockwise and counterclockwise when the rack gets up and down. By some specific mechanism, it can be rotated in a single direction and increase efficiency. The measurement of the parts of roller mechanism, can be more accurate to upgrade the model. Gear transmission can be improved by reconsidering details. The paper aimed to make a mathematical comparison between these two mechanisms of different segment. After the result and all other discussions, the difference is observed mostly.

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