

Experimental investigation of effortless hybrid human powered vehicle: New insights into bicycle

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Abstract

This work is dedicated to possibility of human power vehicle in urban and rural transport systems. Due to the need to look for alternative solution for fossil fuel with conventional drive systems, Human powered vehicle is one of the practical possibilities for sustainable transport systems. It also improves independence from imports oil which is one of the main priorities of countries like India. The vehicle which driven by human power i.e. muscular energy will provide an immediate solution to mechanical challenges and fuel limitations. This Research will deals with developing mechanism of high speed effortless Human Powered Hybrid Vehicle. Hybrid HPV vehicles are powered by peddling and an electric motor, which uses energy stored in the batteries. The kinetic energy will be store in the battery and utilized at the time of needy condition. The main objective behind this research is to build alternative mode of transportation, which would utilize human energy in an efficient way and will also compute with conventional vehicle. The mechanism is used in the HPV which increases input energy like step up transformer and indirectly increases the speed of HPV. The mechanism is attached with a pair of Neodymium magnets (NdFeB) along with slider to transmit motion in forward direction only. Force in the Neodymium magnets is transferred and utilized on the rear wheel which helps to reduce the pedaling force applied by the rider. The motor generator used in HPV performs both the drive and regeneration functions. The developed HPV [Magnet used NdFeB N42 (50 X 15)] can achieve speed of 32 kmph with pedaling rate of 70 rpm, this will provide an alternate for fuel propelled vehicle.

Keywords: Human powered vehicle (HPV), Electric vehicles(EVs), Electric Bicycle(EBs), Effortless bicycle, sustainable mobility; future mobility etc.

1. Introduction

The vehicles which are using traditional fuels such as gasoline and diesel emits harmful pollutant like hydrocarbons (HC), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM) and these are predicted to significantly increase by 2020. In fact, many countries like

United Kingdom, China, France, Germany, India, Ireland, Israel, and Norway, are planning to eventually ban all fossil-fueled vehicles. Lot of research is going on to reduce environmental pollution and another approach to reduce environmental pollution is using electric vehicles (EVs) [1]. Electric bicycle are usually small and can traverse in hilly, rugged, and flat, making them more flexible than other electric vehicles. In most countries Electric bicycles (EBs) does not require insurance, road taxes, or a license to ride. EBs is cheaper, require less maintenance and also improve the health of the rider [1–3].

The purpose of this research is to design assisted mechanism to the bicycle/HPV, which can attain higher speed, compared to conventional bicycles with less pedaling force applied. So to obtain speed of 25 to 30 kmph with minimum efforts of the rider, it can be achieved with the help of various techniques such as by maintaining proper air pressure in tires, replacing broad tires with narrow one, increasing the crank length which would often increase the height of bicycle, varying the gear ratios of sprocket as well as chain ring (front sprocket) with the help of shifting mechanism, by using a flywheel to store the kinetic energy (i.e. flywheel bicycle), or an additional electrical energy can be used to drive motor which will assist the pedaling force (i.e. Electrical Bicycles). Basically the idea is instead of walking for several hours to cover a specified distance, it becomes faster and more efficient on HPV which conserves our precious fossil fuel and it will help to reduce environmental pollution. Reaching speeds of 15 miles or 30 km an hour is achievable by even a beginner. Cycles are being kept aside because of the efforts required to ride it and also because of rider's social economical reputation. Lot of research is being going on to increase the speed of bicycle by keeping its applied force constant. Keeping the input force constant and increasing the speed by using some geared cycle, electric motors or by other means which is achievable up to some extent.

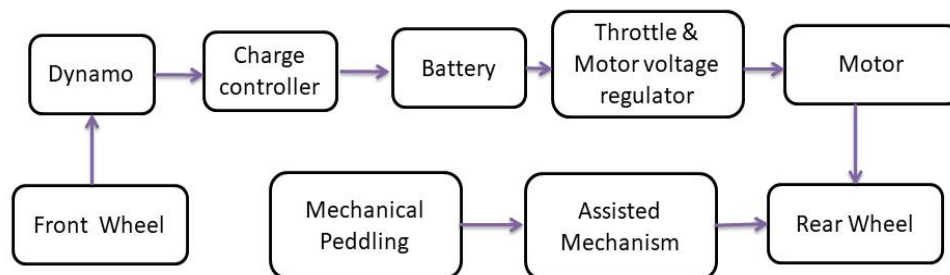


Fig.1. Block diagram of hybrid powered bicycle

The hybrid bicycle uses more than one energy source. It is driven by the motor and muscular power according to the will of driver Shown in fig.1. Dynamo is mounted on front wheel in such way that dynamo shaft is touching the ring of front wheel. As wheel rotates dynamo generates electric power. Then this power is supplied to the battery through charge controller. The function of Charge controller is to adjust the constant voltage and charges the battery. The Permanent magnet dc motor converts electric energy of battery into mechanical energy, which is given to

the rear wheel. Motor Voltage regulator controls the voltage level as per requirement means it indirectly control the speed of EBs. A throttle allows the driver to pedal or enjoy a free ride, it means when the throttle is engaged the motor provides power to the EBs. Assisted mechanism which provides the additional torque on the rear wheel assists the pedaling force applied by the rider. Due to this, driver required less force at the time of peddling, indirectly it helps to increase speed of EBs.[1]

2. A short history and development of bicycle

Somchaiwong and Ponglangka [2006] have given the details of the motor and the electronic converter. He designed a regenerative power control for a pure Electric bicycle, which uses a permanent magnet brushless DC motor installed inside the wheel of the electric bicycles. [1]

Osman Isvan (2014) showed a large portion of a cyclist's power is consumed by air drag. In his research Opposing force power meters measure air drag with a wind sensor. In cross winds the bicycle and rider experience a different air drag than that noted by a conventional wind sensor. The main objective of this research is to quantify this error as a function of wind yaw. Additionally, if power is independently measured with a direct force power meter, we estimate the drag area (C_dA) as a function of wind yaw without using a yaw sensor. It worked on using exact equations to estimate air drag from airspeed and wind yaw instead of approximate equations and a conventional wind sensor that responds to the axial component of the airspeed known as inline airspeed. It also describes a novel method for estimating air drag using a conventional wind sensor under naturally-occurring wind conditions, where the missing wind yaw data is inferred from ground speed, heading and the prevailing velocity of wind [9].

According to R. S. Jadoun et al., the flaw in the conventional electric bicycle which was propelled only with the battery power and no human muscular power was assisted with it. The old electric bicycle was having only a single mode of charging, it was just capable to travel 15 km through battery. In this research motor provides torque to the rear wheel and the gear ratio is kept 5:2. This work of EBs is more beneficial in hilly region and confined areas like schools and college campus, zero noise effect, zero pollution and no fuel consumption [10].

The research of Carmelina Abagnale et al. (2015) is about the model for electric motor assisted bicycle. The main objective of study the human power can be modeled separately with motor power and in the last the total power required can also be determined [11].

In 2017 Nguyen Ba Hung et al. showed the effects of input parameters such as rider mass, bicycle mass, wind speed, crank length, wheel diameter, and grade on the dynamics and required power of a power-assisted bicycle, where the electric motor installed on EB. Because the electric motor is used as a power assist, the motor power of a pedelec is usually less than that of a pure electric bicycle (without Peddling force)[8]. The simulations and experimental studies of the operating performance of an EB integrated with a semi-automatic transmission was also done

by Nguyen Ba Hung et al.[7].There has been a lot of research on bicycles in the world and this research provide useful information for designing and developing high performance bicycle[1-11]. Nguyen Be Hung et al. (2020) in his review article explained history, development design research of electric bicycle along with benefits among the electric vehicle [1].

3. Methodology

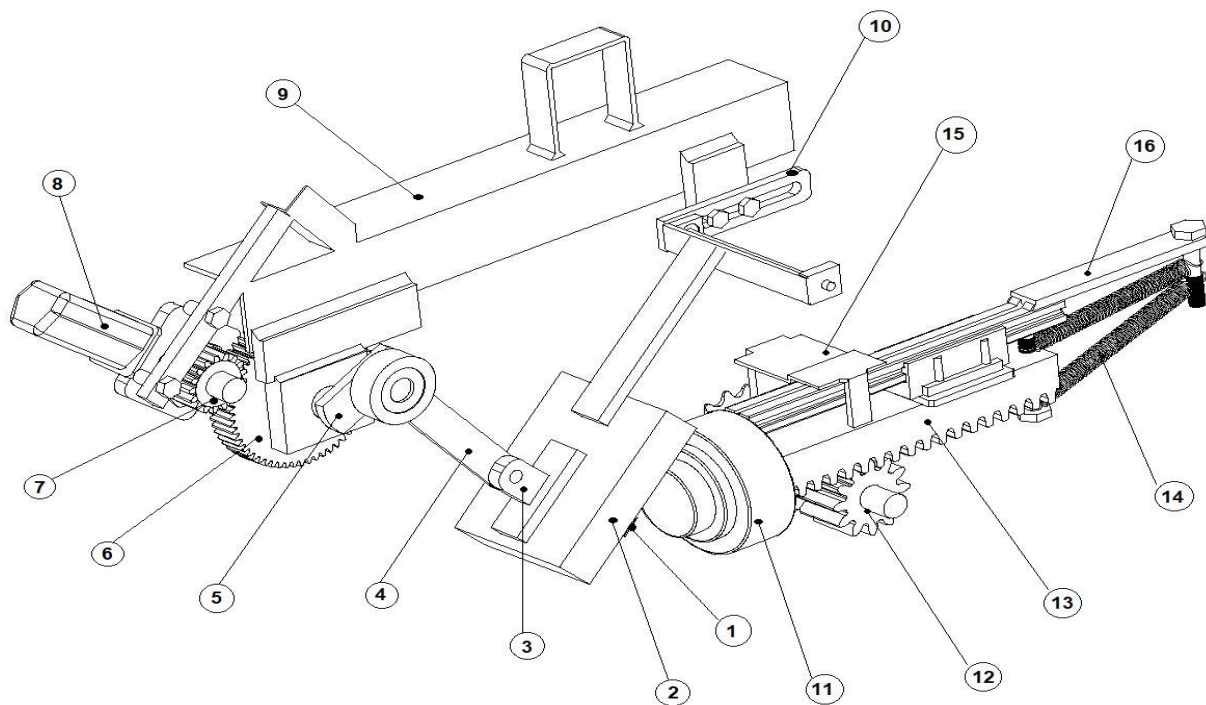


Fig.3. Complete 3D diagram of assisted Mechanism

1. Magnet no. 1
2. Frame holding magnet 1
3. T socket holding the frame
4. Link connecting crank and the socket.
5. Crank
6. Wheel
7. Worm
8. Motor rotating worm
9. Frame connecting the mechanism with the bicycle

10. Link adjusting the distance between two magnet
11. Nonferrous disk holding magnet no. 2
12. Pinion
13. Rack
14. Tension spring
15. Slider Mechanism and supporting element.
16. Link holding the slider and the spring

3.1 Selection of magnet done on the following condition.

- a) Selection Based on Magnet Environment
- b) Selection Based on Thermal Properties
- c) Selection Based on Required Properties
- d) Selection of Magnet Material

As per working environment and objective of the research, Neodymium magnet is suitable for assisted mechanism. Neodymium magnet is also known as NdFeB, NIB or Neo Magnet, these are the strongest and most controversial magnets. Neo Magnet a permanent magnet made from an alloy of neodymium, iron and boron to form the Nd₂Fe₁₄B tetragonal crystalline structure [12].

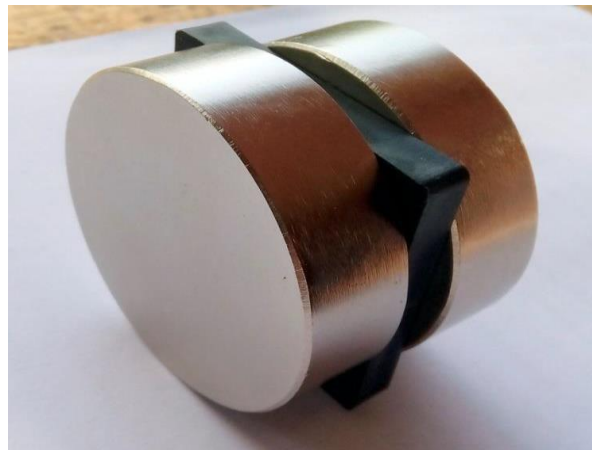


Fig.3.1. Neodymium Magnet N42 (50mm x 15m) (Ref: Curtesy Texpert Pvt. Ltd. Chennai)

The mechanism is designed theoretically and it's actual (theoretical) and allowable strengths are compared for design safety. As per the designed dimensions, all parts of assisted mechanism are

prepared in Catia software. After completion of modeling by using save as option, model is saved in the “iges” file format for the analysis and it is done in the Ansys “Workbench 16.0”. After visualization it is found that the mesh pattern is uniform over the entire object, there is no failure of elements in quality criteria of meshing. Maximum deformation which is far below the measurable value hence no visible deflection found in the any part of assisted Mechanism.



Fig.3.1(a). Assisted mechanism installed to bicycle.

Magnets are having the property to attract or repel when they come in contact with each other. This property of magnet can be utilized in human power vehicles (HPV) where cyclically human input is provided. This human power is coupled with a mechanism which uses magnets pull force and provides relative torque on the rear wheel. One magnet is attached with an oscillating arm and other is fitted on one side of the rack. When the oscillating arm oscillates it pulls the rack attached with magnet and this forward stroke of rack rotates the pinion which is then through a free wheel clutch coupled with the rear wheel shown in fig 3.1(a). Springs are provided on the other side of rack so that in the forward stroke it comes under tension force which is then relieved at extreme point. In the backward stroke motion to the wheel is prevented by the free wheel clutch, its function is to only transfer the forward stroke. This addition torque on the rear wheel assist the pedaling force applied by the rider and makes the ride and the bike an effortless bicycle.

4. Results and discussion

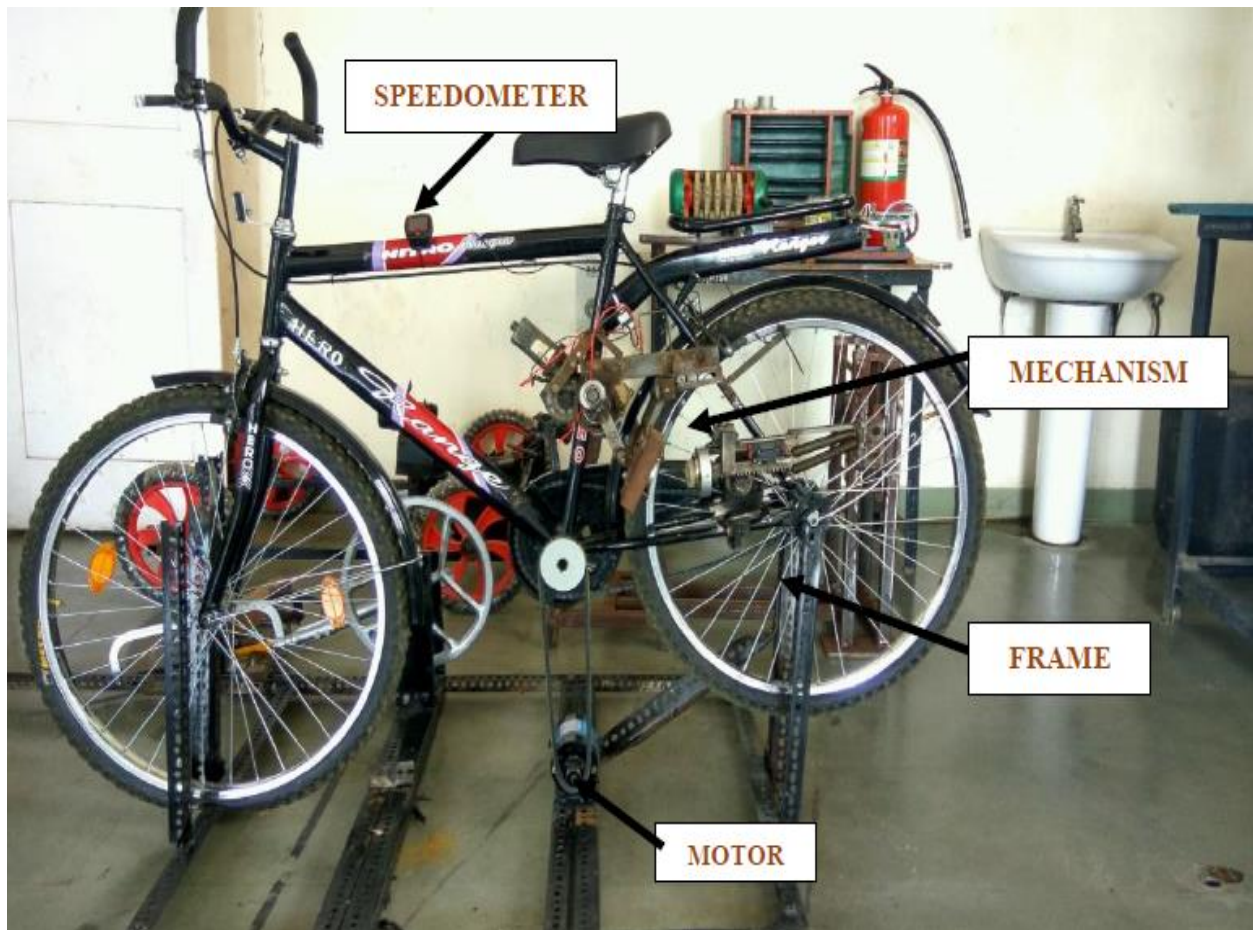


Fig.4. Experimental Setup

The experimental setup is prepared for the developed bicycle. The frame is fabricated in such a way that the bicycle is lifted half meters so that the wheels can rotate freely. Then the pedal shaft is attached with the pulley and then with a belt is coupled with the motor fitted on the frame.

This is done to provide a measurable input to the wheel, as it is complicated to measure the force applied by the rider and also it varies with rider to rider. The supply is provided to the motors both oscillator motor and the pedal motor. Speedometer is also attached to measure the speed of bicycle, the digital dial directly shows the speed in km/hr. and the input is a magnetic sensor which senses the number of revolutions of the rear wheel shown in fig.4. Mechanism is provided with a switch to activate or deactivate it, so that the effectiveness or suitability of the mechanism can be check. The Table 4 shows the speed when the mechanism is switched OFF and when the mechanism is switched ON. It is observed in the table that pedaling rate increases with the speed of the bicycle.

Table 4. Evaluate suitability of the mechanism

Without Mechanism		With Mechanism	
Pedaling Rate (RPM)	Speed (kmph)	Pedaling Rate (RPM)	Speed (kmph)
30	12	30	14
40	14	40	18
50	17	50	23
60	22	60	27
70	26	70	32

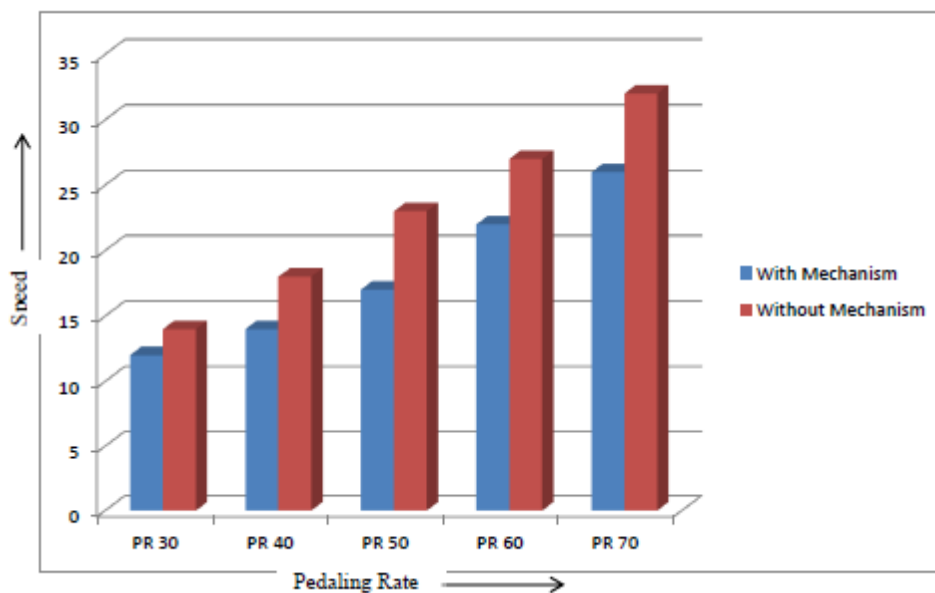


Fig. 4 (a) Pedaling Rate Vs Speed

It can be observed that when we engage the mechanism there is a proportional increase in the speed. On X-axis pedaling rate is shown, this is divided into five levels depending on the standard pedaling rate, a rider can achieve for that specific gear ratio (44:18) of front and rear sprocket and On Y-axis speed achieved in km/hr. is shown, above graph fig.4 (a) is plotted from the table of with or without assisted mechanism system. There is substantial increase in the speed with engaging the mechanism, as we goes on increasing the pedaling rate the higher the speed of the bike.

4.1 Taguchi Design

An experimental design methodology that allows choosing a product or process that performs more consistently in the operating environment. It identifies controllable factors (control factors) that minimize the effect of the noise factors. During experimentation, manipulation of noise

factors to force variability to occur and then find optimal control factor that make the process or product robust.

4.2 Design of Experiment

There are two basic important aspects of concern in scientific experimentation these are the design of the experiment and the statistical analysis of the data. Knowledge of the factors that influence the output is required for successful experimentation. Design of experiments helps to determine the factors, which are important for explaining a process variation. DOE also helps to understand influential factors interact with the system. In the present study, Taguchi technique is used for studying the influence of input parameters on the output. Taguchi has tabulated 25 basic orthogonal arrays that are known as standard orthogonal arrays. Each orthogonal array uses a notation that indicates its number of rows and columns, as well as the number of levels in each column. In this Taguchi method, L5 orthogonal arrays is used, with nine rows (corresponding to the number of runs), two parameters or factors and five levels considered as experimental conditions. We have selected the two factors i.e. pedaling rate and the magnetic distance and total number of runs for different pedaling rate and at distance magnetic distance is decided based on the orthogonal arrays used in Taguchi method. So the total numbers of runs are given below:

Table 4.2 Selecting Factors and Levels

Factor	Type	Levels	Values
Pedaling Rate	Fixed	5	30, 40, 50, 60, 70
Magnet Distance	Fixed	5	9, 12, 15, 18, 21

Table 4.2(a) Design of Experiments (DOE)

Trail No.	Pedaling Rate (RPM)	Magnet Distance (mm)	Speed (kmph)
1.	30	9	12
2.	30	12	11
3.	30	15	10.5
4.	30	18	9
5.	30	21	8
6.	40	9	14
7.	40	12	13
8.	40	15	12
9.	40	18	12
10.	40	21	11

11.	50	9	18
12.	50	12	17
13.	50	15	16
14.	50	18	15
15.	50	21	13
16.	60	9	24
17.	60	12	23
18.	60	15	21
19.	60	18	19
20.	60	21	16
21.	70	9	31
22.	70	12	29
23.	70	15	25
24.	70	18	23
25.	70	21	19

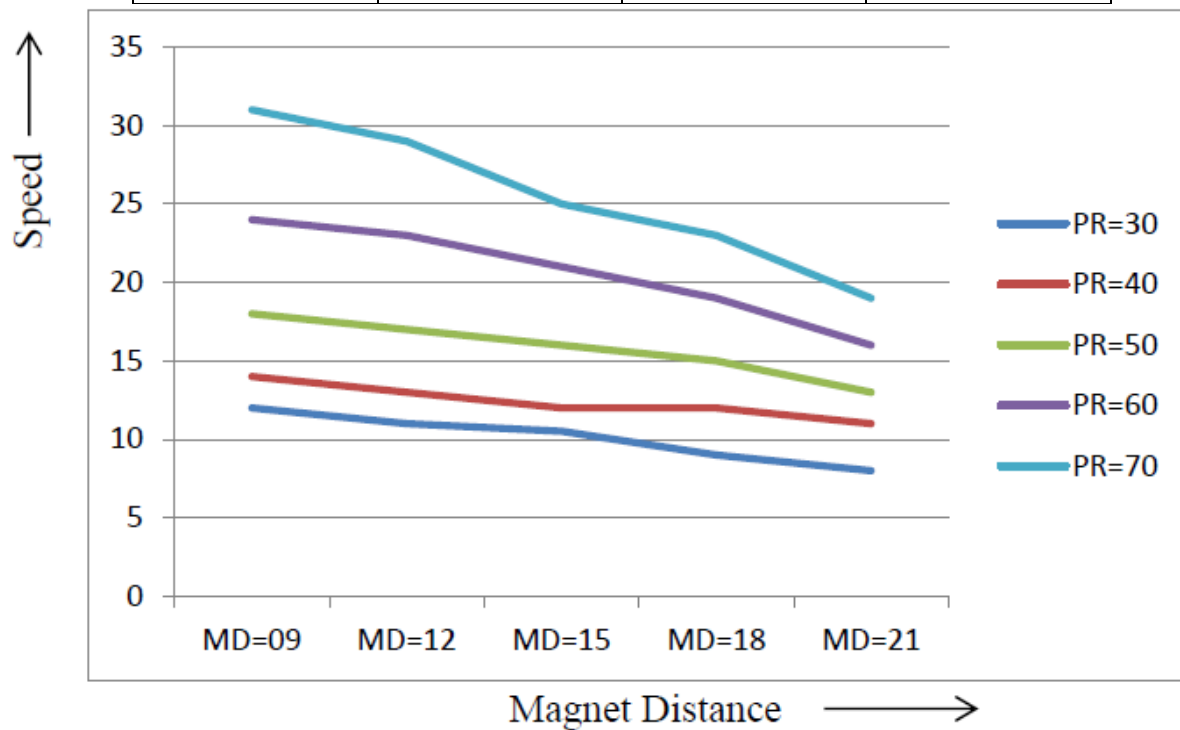


Fig. 4.2 Speed Vs Magnetic Distance

The above graph is plotted from Table 4.2 in that the pedaling rate and the magnet distance is varied and the response that we get is the speed. The trials are decided from the Minitab software on the basis of the maximum pedaling rate achieved from the coupled motor and the maximum distance between the magnets can be maintained. So total five times five equals 25 trials are

conducted with pedaling rate 30, 40, 50, 60, 70 rpm for different magnet distance of 09, 12, 15, 18, 21 mm.

4.3 Analysis of the S/N ratio

Table 4.3 Response Table for Signal to Noise Ratios

Level	Pedaling Rate	Magnet Distance
1	21.40	27.20
2	23.31	25.82
3	24.37	24.79
4	26.33	23.58
5	28.15	22.17
Delta	6.75	5.04
Rank	1	2

.Table 4.3 (a) Response Table for SN ratio and Mean

Trail No.	Pedaling Rate (RPM)	Magnet Distance (mm)	Speed (kmph)	SNRA	MEAN
1.	30	9	12	24.0824	16.0
2.	30	12	11	22.9226	14.0
3.	30	15	10.5	21.9382	12.5
4.	30	18	9	20.0000	10.0
5.	30	21	8	18.0618	8.0
6.	40	9	14	26.0206	20.0
7.	40	12	13	24.6090	17.0
8.	40	15	12	23.5218	15.0
9.	40	18	12	21.5836	12.0
10.	40	21	11	20.8279	11.0
11.	50	9	18	26.8485	22.0
12.	50	12	17	25.1055	18.0
13.	50	15	16	24.0824	16.0
14.	50	18	15	23.5218	15.0
15.	50	21	13	22.2789	13.0
16.	60	9	24	28.2995	26.0
17.	60	12	23	27.2346	23.0
18.	60	15	21	26.4444	21.0
19.	60	18	19	25.5751	19.0
20.	60	21	16	24.0824	16.0

21.	70	9	31	30.7564	34.5
22.	70	12	29	29.2480	29.0
23.	70	15	25	27.9588	25.0
24.	70	18	23	27.2346	23.0
25.	70	21	19	25.5751	19.0

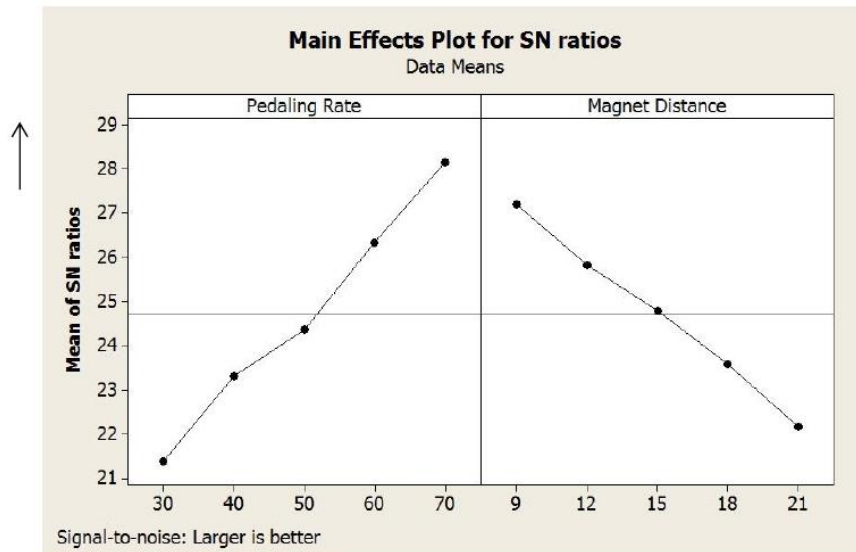


Fig. 4.3 Main Effects Plot for SN ratios

Plot of SN ratio shows that both pedaling rate and the magnet distance is directly proportional to the speed i.e. pedaling rate increases with the increase in speed and magnet distance increases with the decrease in speed, so both the pedaling rate and the magnet distance are inversely proportional to each other but directly proportional with speed. As desired speed should be larger so the SN plot selected for larger is better, it indicates that the reading above the horizontal line in the graph is best suitable for the mechanism.

4.4 Mean of Means

Table 4.4 Response Table for Means

Level	Pedaling Rate	Magnet Distance
1	12.10	23.70
2	15.00	20.20
3	16.80	17.90
4	21.00	15.80
5	26.10	13.40
Delta	14.00	10.30
Rank	1	2

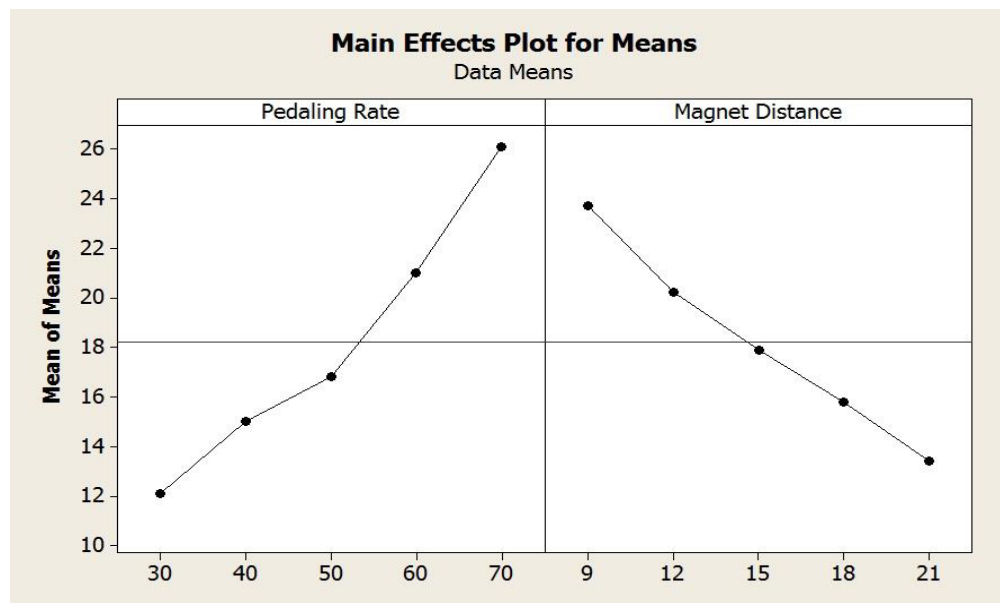


Fig. 4.4 Main Effects Plot for Means

Above plot of means shows that both pedaling rate and the magnet distance is directly proportional to the speed i.e. pedaling rate increases with the increase in speed and magnet distance increases with the decrease in speed, so both the pedaling rate and the magnet distance are inversely proportional to each other but directly proportional with speed. As desired speed should be larger so the SN plot selected for larger is better, it indicates that the reading above the horizontal line in the graph is best suitable for the mechanism.

4.5 Analysis of Variance (ANOVA)

ANOVA is a standard statistical technique determines the variability (variance) of the data. This technique helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors which provide a measure of confidence.

ANOVA Terms

- a) **Degree of Freedom**
- b) **Sum of Squares(SS)**
- c) variance ratio /F statistic
- d) **P-Value**
- e) **R-squared**

By Minitab software, the ANOVA results are shown in Table no. 4.5

Table 4.5 Analysis of Variance for Speed

Source	DF	SS	MS	F	P	Percentage Contribution (%)
Pedaling Rate	4	598.30	149.57	101.84	0.000	65.45%
Magnet Distance	4	315.70	78.92	53.74	0.000	34.54%
Error	16	23.50	1.47			
Total	24	937.50		155.58	0.000	100%

S = 1.21192 R-Sq = 97.49% R-Sq(adj) = 96.24%

In general, the higher the R-squared, the better the model fits given data.

4.6 Regression Analysis

Here for **Regression Analysis** Minitab software is used for analysis. The regression equation is

$$\text{Speed} = 13.7 + 0.340 (\text{PR}) - 0.833 (\text{MD})$$

where,

PR = Pedaling Rate

MD = Magnet Distance (distance between two magnets)

4.6.1 Validation of Regression Equation

If we want to achieve speed of 25 km/hr. at 70 pedaling rate what should be the distance between two magnets?

So, from regression analysis, we have

$$\text{Speed} = 13.7 + 0.340 (\text{PR}) - 0.833 (\text{MD})$$

$$25 = 13.7 + 0.340 \times 70 - 0.833 \times \text{MD}$$

$$\text{Therefore, } 0.833(\text{MD}) = 25 - 20.4$$

$$\text{MD} = 15.006 \text{ mm}$$

If we want to achieve speed of 30 km/hr. at 15mm distance between two magnates, what is the required pedaling rate then?

So, from regression analysis, we have

$$\text{Speed} = 13.7 + 0.340 (\text{PR}) - 0.833 (\text{MD})$$

$$30 = 13.7 + 0.340 (\text{PR}) - 0.833 \times 15$$

$$0.34 (\text{PR}) = 30 - 13.7 + 12.495$$

$$\text{PR} = 84.69 \text{ rpm}$$

Table 4.6.1 Validation of Regression Equation

Sr. No.	Experimentation		Experimental Value	Regression Equation (kmph)	% Error
	Pedaling Rate (RPM)	Magnet Distance (mm)			
1.	30	09	14	16.403	-14.64
2.	40	12	18	17.304	4.022
3.	50	15	23	18.205	26.34
4.	60	18	27	19.106	41.31
5.	70	21	32	20.007	59.94

5. Conclusion

The use of Neodymium magnets is possible for transferring its pull force with the aid of mechanism. Neodymium magnets are the strongest permanent magnets available in that grade N42 is having good Intrinsic Coercive Force (Hci). The mechanism is designed theoretically and it's actual (theoretical) and allowable strengths are compared for design safety. The design of all parts (worm gear, input shaft, crank, connecting rod, oscillator arm, rack and pinion, output shaft and free wheel clutch) is safe. Stress and Deformation of the designed parts are analyzed in workbench 16.0 Pull force in magnets is transmitted to the rear wheel of the bicycle. Higher the pedaling rate higher will be the speed and larger the distance between magnets lower the speed. Percentage contribution of factor pedaling rate and magnetic distance is 50% each. Regression equation is drawn from it speed can be calculated for variables of pedaling rate and magnet distance. The bicycle attains maximum speed of 32kmph at 70 rpm of pedal and as we goes on increasing the pedaling rate the effectiveness of the mechanism also increases. Pedaling rate increases with the increase in speed of the bicycle but magnetic distance increases with decrease

in the speed of the bicycle. So the pedaling rate and the distance between two magnets are inversely proportional.

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