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Improved Cost-Effective Design of Man-Powered Tricycle/Rickshaw

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Abstract: Paddle rickshaw/tricycle is still used widely in many parts of developing countries for small distance transportation of goods and passengers. The design of the paddle rickshaw is almost same everywhere, with minor variations largely focused on the appearance. The pedal rickshaw used are ergonomically not very efficient. They are mostly pulled by daily wage laborers who have to put large effort in pedaling the rickshaw due to its inefficient design. Subsequently very little research is available on the subject of the effort applied by rickshaw puller with respect to rpm and load of on paddle Rickshaw. In the current case, systematic experimental study has been performed to find out the effort applied by the rickshaw puller at various conditions of speed and load on paddle rickshaw. Based on these results, a two gear mechanism has been designed to reduce the effort of the rickshaw puller to almost 50% in the initial start condition, where maximum effort has to be applied by the puller. The result of this research work can have implication on the society by easing the life of these people.

Key words: Paddle Rickshaw, Two gear system, Bearing, Safe and environmentally friendly.

I. INTRODUCTION

A Paddle Rickshaw, also known as tricycle rickshaw or cycle rickshaw is a human-powered tricycle. It has two to four seats for carrying passengers and some room for leg space or luggage in between the puller and passengers. It mostly comprises of a steel and wooden body/frame. The paddle rickshaw has chain sprocket system with a single set of driving and driven sprocket. The rickshaw is driven by the effort applied by the puller on the paddle. It is widely used in Asia. It is an environmentally friendly and also inexpensive in terms of transport.

About 80 lakhs rickshaws run all over the India in both urban and rural areas therefore rickshaws provide livelihood of eight millions poor rickshaw pullers families in India.

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Paddle Rickshaw is majorly used for travelling through short distances in the form of passenger rickshaw (Fig.1) and loading rickshaw (Fig. 2).

Fig. 1: Passenger Paddle rickshaw

There are many manufacturers in India and abroad, but mostly all the designs of paddle rickshaw are old and same, which are ergonomically very less efficient as far as rickshaw puller is concerned. These designs are not equipped with effective and suitable gear mechanisms, bearing and suspension systems. Also the Rickshaws are not light weight.

If the design of paddle rickshaw can be made such, that it becomes comfortable for both puller and passengers, this can become a very viable option to replace Diesel/CNG Auto Rickshaw, for travelling small distances, within narrow roads and promoting tourism. Thus can add a huge contribution towards green energy [1].

II. DESCRIPTION OF THE PROBLEM

Current designs of paddle rickshaw faces following major problems:

- Absence of Multiple gear shifts to incorporate various loading and speed conditions.
- Inadequate suspension system for both passenger and puller.
- Improper wheel bearings to take various loads.
- Heavy weight of the Paddle Rickshaw.
- Space for luggage and passengers

The main objective is to overcome the major problems without adding much of *extra cost*. Out of the above mentioned issues major focus has been made on the most prominent one, i.e. : providing multiple gear/sprocket system in the paddle rickshaw for various driving conditions [2] (load on rickshaw and its rpm). Here main constraint is to provide a solution that is **durable and cheap**, as the end consumer of these paddle rickshaw cannot afford expensive solutions.

Thorough literature survey has been done related to paddle rickshaw. It is found that imperceptible research is done to find the effort applied by rickshaw puller with respect to rpm of; and load on; paddle Rickshaw to the best of our knowledge.

Previous studies were mainly focused to improve the cycling performance [3] by using various novel crank peal mechanisms [4] or modifying the chain ring shape [5].

So an experimental setup has been designed to find out the actual effort applied by the puller at various loading and rpm conditions. And based on the results obtained a new sprocket-gear is designed to reduce the effort of the puller.

III. EXPERIMENTAL SETUP

The experimental setup included various components listed with description:

1. Pedal Rickshaw

A new paddle rickshaw was procured. This is a loading type which is very common in Ahmedabad. The unit came with all the basic components. (Fig. 2)

Fig 2: Pedal Rickshaw

2. Load cell and Indicator

A single point table top cantilever type load cell (model number 60710) is procured from ADI Artech Transducers Pvt. Ltd. A load cell [7] is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured which is a cantilever beam type. In the experimental setup, a fixture is made so that one end of the load cell is fixed with the pedal of rickshaw. The effort of the puller is applied on the open end of the load cell (fixed with a pad so that puller can place his foot easily on it). The load cell is calibrated using universal testing machine with known amount of load. The error in measurement is less than 0.01% of full scale output. The load cell is connected to the digital indicator that display the load applied in Kg on its screen. The least count of the indicator is 0.001 kg. (Fig. 3)

Fig. 3: Load Cell with fixture and Indicator

3. Rope type dynamometer

Rope type dynamometer is used to provide load on the rear wheels. Rear wheels of the rickshaw are lifted in air and coupled with the dynamometer shaft. The actual loading of the passengers is simulated in the experimental setup by loading the rope dynamometer.(Fig. 4)

Fig.4: Rope type Dynamometer

It was calculated that 1.5 kg of dead weight on dynamometer produces same tractive force/loading torque on rear driving wheels; as a 60kgs of actual passenger does (refer section IV). So for simulation of four passengers, the dynamometer weight was varied as 1.5kg, 3 kg, 4.5 kg and 6 kg.

4. Tachometer

A Lutron Make DT-2235B model contact/surface speed Digital Tachometer is used. It ranges from 0-999 rpm with a least count of 0.1 rpm. It is used for measuring the speed (Rpm) of the wheels by connecting its spindle to the rope type dynamometer.

5. Sprocket

Modified sprocket for initial start condition is fabricated as per the results obtained from the experiments. (Fig. 5)

Fig. 5: Modified Sprocket

IV. CALCULATION FOR SIMULATING ACTUAL PASSENGER LOAD TO THE DYNAMOMETER LOAD

It should be barred in mind that the biological systems are not easy to analyze mechanically as there are various chemical and thermodynamic processes taking place simultaneously [8].

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This has prompted the authors to look for the external work done by calculating the friction between the tire and road based on the no. of passengers i.e. weight load on the tricycle.

The rolling resistance between tire and rough road – 0.008 [6]

- Considering mass of human – 60kg

F = μ * N F = Friction force
= 0.008 * 600
= 4.8 N

T = F * r T = Torque
= 4.8 * 0.365 r = Radius of wheel
= 1.752 N. m

Radius of dynamometer Flywheel = 120 mm
T = F * r
1.752 = F * 0.12
1.752 / 0.12 = F
F = 14.8 N
F~15 N or aprox 1.5 kg mass.

V. EXPERIMENTAL PROCEDURE

The experimental data is generated for the effort applied by the rickshaw puller at various loading conditions [9] and different rpm of the rickshaw. For the same the rear wheels were lifted and connected with the dynamometer. Four loading conditions are considered viz : 60kg, 120kg, 180kg, 240kgs, representing the weight of at most four human beings. These conditions are simulated by applying load on dynamometer as explained earlier (Refer Section III and IV). The puller was seated on the rickshaw and applied effort with his foot on the load cell connected to the rickshaw paddle.

The ride of Rickshaw has been divided into four categories viz (a) Initial Start (0–4 kmph), (b) Slow Riding (4–8 kmph), (c) Average Riding (8-12 kmph), (d) Max speed Riding (12-17 kmph). Maximum speed however for a cyclist for normal riding is determined to be aprox 16 kmph in many texts [6]. The radius of the wheel (including tire) of the Rickshaw is aprox 36.5 cms. So for each category based on speed of rickshaw rpm has been calculated. For initial start condition its 0 – 30 rpm, for slow riding, 30-60 rpm; for average riding 60-90 rpm and for maximum speed its 90-120 rpm approximately.

Experiments were carried out for each loading conditions under above mentioned speed categories. For example: when the dynamometer was loaded with 1.5 kg of dead weight (equivalent to 60 kg of passenger load), the puller applied increasing effort to rotate the rickshaw wheels to four rpm range (ride categories) mentioned above.

Slow motion video was taken for each rpm range, and the maximum effort applied by the puller for a particular riding category at a given loading was noted.

Each experiment was repeated six times to minimize the error. From the data received the maximum effort applied by the puller under each category was noted and average of similar experiment was calculated.

VI. ANALYSIS OF RESULTS

The data is tabulated in table 6.1 that represents maximum effort of the puller under various loading conditions for each riding category. For each loading (viz 1.5, 3, 4.5 and 6 kg) and riding category (viz 0-30, 30-60, 60-90, 90-120 rpm) an average maximum value of effort has been measured and tabulated. Each cell represent the average of maximum value of effort applied by puller (in kg) under particular rpm range and loading condition. Example for loading condition of 1.5 kg dynamometer weight (equivalent to 60 kg passenger load) and 0-30 rpm ride category, the average of maximum effort of all six experiment is 7.98 kg.

Table 6.1 Maximum Human effort with Load and Speed

LOAD (KG)	SPEED (RPM)/ RIDE CATEGORY			
	0-30	**30-60**	**60-90**	**90-120**
1.5	7.98	9.95	11.51	10.31
3	7.89	9.18	11.50	9.74
4.5	22.00	14.96	18.96	19.17
6	23.18	16.90	14.53	14.14

The sprocket design has to be done to minimize the maximum effort applied by the puller. Hence the data for maximum effort for each loading condition and speed range has been tabulated above.

With the help of the experimental results, graphs are made and trend can be seen between the paddler effort and speed of rickshaw at different loading conditions.

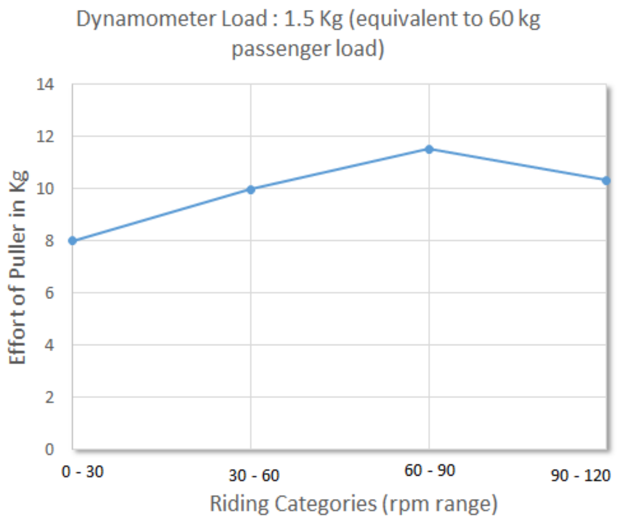

Fig 6: Paddler Effort with Dynamometer Load 1.5 kg

Fig. 6 shows human effort for dynamometer load of 1.5kg, (equivalent to one passenger weight ie 60 kgs), and riding category rpm range (0-120). It can be seen from the graph that the effort applied by the puller ranges from 7.98 to 11.5 kgs during its operation which is within the paddler comfort.

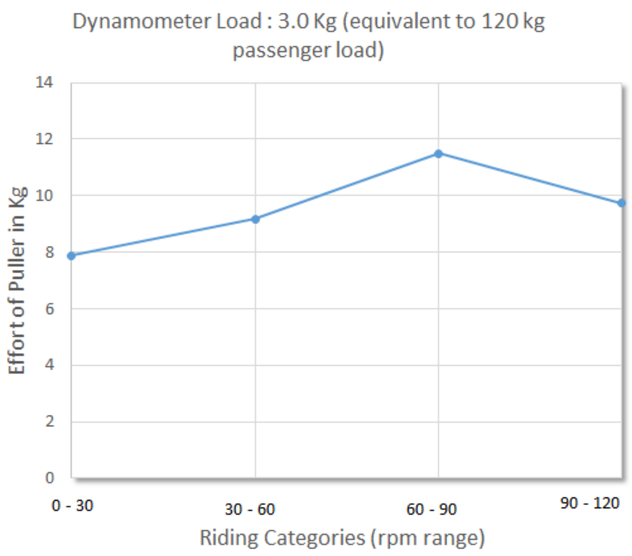

Fig. 7: Paddler Effort with Dynamometer Load 3 kg

Fig. 7 shows human effort for dynamometer loading of 3kg (equivalent to two passenger weight ie 120 kgs) and riding category rpm range (0-120). Here also the variation of effort of paddler with rpm is almost same as in previous figure 6. The effort applied is within the comfort range of puller.

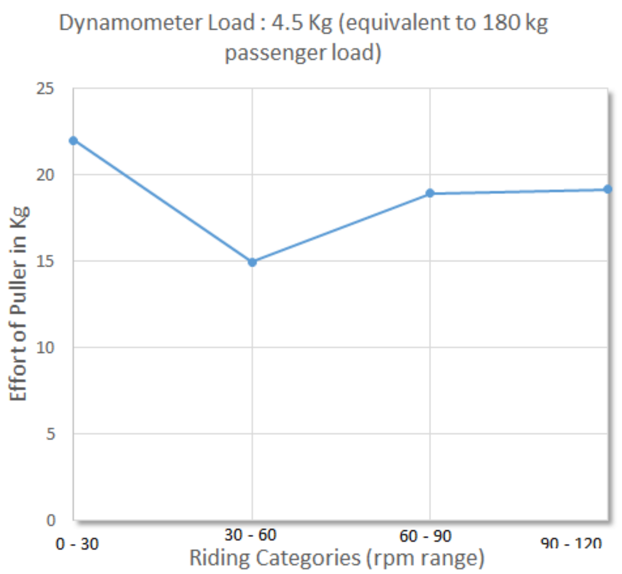

Fig. 8: Paddler Effort with Dynamometer Load 4.5 kg

Fig. 8 shows human effort with dynamometer load of 4.5 kg (equivalent to three passenger weight ie 180 kgs) and riding category rpm range (0-120). *Generally in normal operation of paddle rickshaw this condition prevails (weight that paddler has to pull is mostly (120-180 kgs)*. Here it can be seen that the initial effort to pull rickshaw is quite high (22kgs) which is beyond the comfortable range of applying effort of a human being [10]. *During the rickshaw pulling, a puller has to stop very often and paddle the rickshaw from zero rpm (initial start). So the condition of excessive paddler effort during initial start occurs very frequently and lead to the major cause of fatigue of rickshaw puller*.

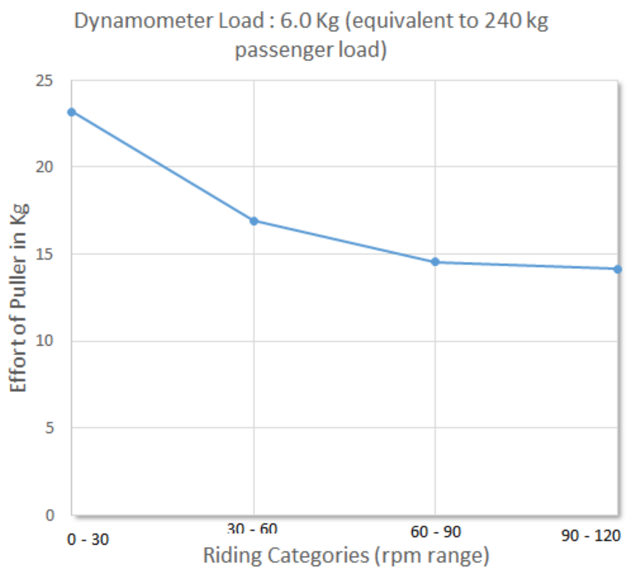

Fig. 9: Human Effort with Dynamometer Load 6.0 kg

Fig. 9 shows human effort with dynamometer load of 6kg (equivalent to four passenger weight ie 240 kgs) and riding category rpm range (0-120). Like the previous graph, it can be seen that initial effort required by the puller is too high.

Based on the above results, it is decided to *put another set of gear/ sprocket for initial start condition of rickshaw*, termed as *low gear*. This gear would be fabricated to reduce the puller's effort in the initial start condition. The puller can then shift to normal high gear while normal riding condition (riding category b, c and d), as for these conditions the effort is well within the range of comfort of puller.

VII. DESIGN OF SPROCKET FOR LOW EFFORT DURING INITIAL START CONDITION

It can be seen from the previous results that the initial effort for the puller was 22 kg, which is beyond the comfort of a puller. So it is decided to reduce this effort to as low as 15 kg for initial start condition to keep it within comfortable limits of puller. Hence the design has been made taking the actual higher load (22kgs) and desired reduced load (15kgs) into consideration. The smaller sprocket diameter at the rear wheels is kept same while the front bigger sprocket (attached to pedals) diameter is changed based on the required effort. Also in both the cases it is considered that the torque produced at the rear wheel remains the same.

F_i= effort with normal gear-sprocket (22 kgs)
F_f= effort with modified gear-sprocket (15 kgs)
T_{1i} = Torque with normal sprocket at front.
T_{1f} = Torque with modified sprocket at front.
T_2= Torque produced at the rear (kept same for normal and modified sprocket during initial start condition)
L= length of pedal rod.
D_1= Diameter of Front sprocket (which is to be designed based on reduced effort)
D_2= Diameter of Rear Sprocket (kept same)

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Initial Torque for high effort

$T_{1i} = F_i * L$
$= 22*177$
$= 3894*10$
$= 38940$ N. mm
$= 38.940$ N. m

Final Torque for low effort

$T_{1f} = F_f*L$
$= 15*177$
$= 2655*10$
$= 26550$ N. mm
$= 26.55$ N. m

$T_1 / T_2 = D_1 / D_2$
$T_2 = (D_2 * T_1) / D_1$
$= (95 * 38.94) / 198$
$= 18.68$ N. m
$T_1 / T_2 = D_1 / D_2$
$26.55/18.68 = D_1 / 95$
$D_1 = 135.00$ mm

So a new front sprocket has been fabricated with diameter equal to 135 mm as shown in Fig.5. The rear sprocket diameter is kept same. **With new set of gears, the whole experiment is repeated again only for the initial start condition ie 0-30 rpm.**

VIII. Analysis of Results Using Low Gear Sprocket

Experiments were carried again for initial start condition ie, rpm range of 0-30 at different loading conditions. The results obtained by using *low gear sprocket* for initial start condition has been compared with that of normal gear sprocket. The comparison is shown in Table 8.1. Each cell in the table represent the value of average of maximum effort applied by rickshaw puller at initial start condition (0 – 30 rpm) for various loads.

Table 8.1 Comparison of maximum effort values between regular sprocket and modified low gear sprocket.

LOAD (KG)	SPEED (RPM) 0 – 30 Regular Sprocket	SPEED (RPM) 0 - 30 Modified Sprocket	Percentage Reduction in Effort of puller, due to application of modified sprocket
1.5	7.98	8.82	- 10.52
3	7.89	8.48	- 7.47
4.5	22.00	9.86	55.18
6	23.18	12.26	47.11

The results are displayed in graphs clearly showing the reduction in effort of puller during initial start.

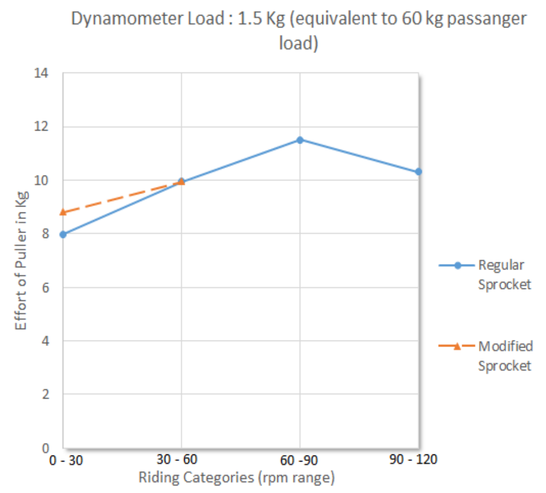

Fig. 10: Paddler Effort using modified sprocket (Dynamo. Load 1.5 kg)

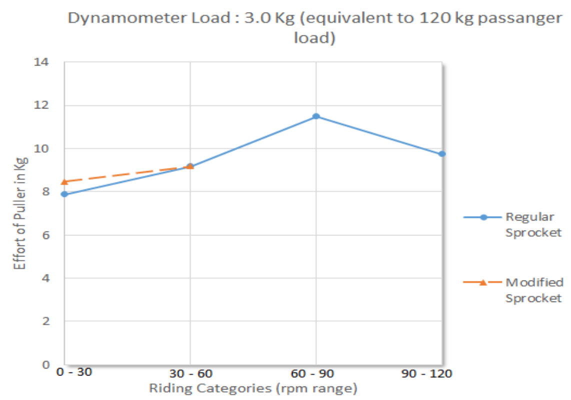

Fig. 11: Paddler Effort using modified sprocket (Dynamo. Load 3.0 kg)

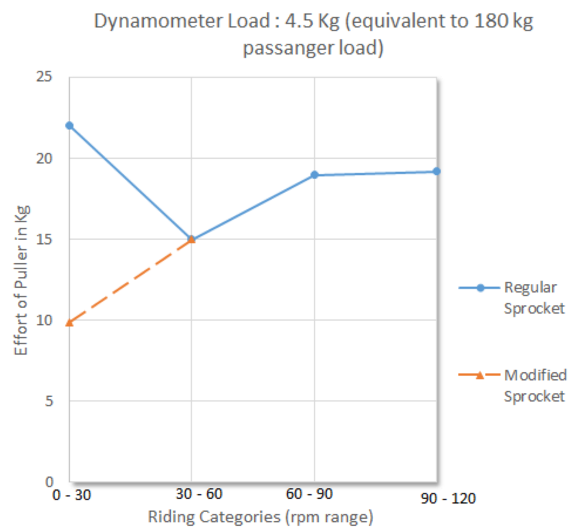

Fig. 12: Paddler Effort using modified sprocket (Dynamo. Load 4.5 kg)

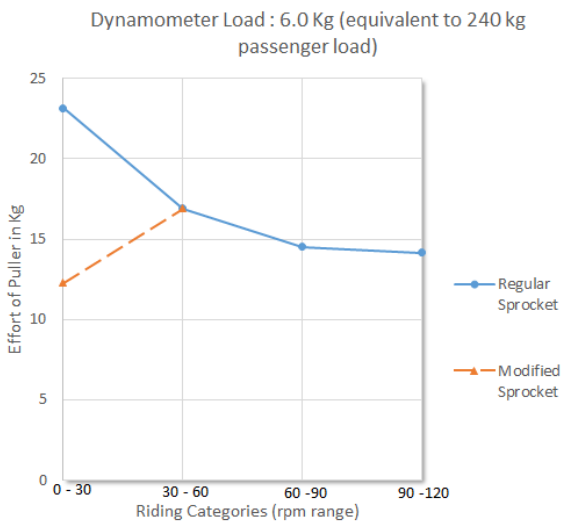

Fig. 13: Paddler Effort using modified sprocket (Dynamo. Load 1.5 kg)

The charts using modified low gear sprocket system in the initial start conditions are shown (Fig. 10-13). It can be inferred from the results that for loading condition of 1.5 and 3 kg the effort applied is almost same. It can be observed that there is a significant reduction in the efforts applied by the rickshaw puller for 4.5 kg dynamometer loading (55.18 % reduction in effort) and 6 kg dynamometer loading (47.11 % reduction).

The overall cost for a new sprocket design is only INR 300/- (Three hundred) and the reduction is effort is substantial.

IX. CONCLUSION

The present study uses a systematic approach by first generating the experimental results of actual effort applied by the rickshaw puller at different loading and speed conditions which has never been done before to the best of my knowledge.

After that proper design of a low gear sprocket has been done to reduce the effort at initial start condition. The results are satisfactory with the maximum reduction in puller's effort as 55.18%.

Hence it is proposed that two gears shall be used in the paddle rickshaw. Low gear sprocket for initial start condition (0 – 30 rpm) and high gear for rest four riding stages/categories. For two gear system we have selected the Sprocket Diameter.

For riding condition b,c and d (refer section V) ; D_1 = 198 mm, D_2 = 94 mm

For initial start category (a); D_1 = 135 mm, D_2 = 94 mm (refer section VII)

The cost of dual gear system will cost around 300 rupees which is quite nominal. Hence the present study can be termed fruitful in solving the major problem of rickshaw pullers without addition of much extra cost.

This mechanism is incorporated in rickshaw will reduce the pullers fatigue to a large extent, and thereby promoting more use of paddle rickshaw adding huge contribution to green energy.

Future work requires a durable, less complicated, cheap and innovative sprocket shifting mechanism which can be added in paddle Rickshaw.

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