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Bicycle Equipped with Slotted Lever Quick Return Mechanism

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Abstract

The low-impact nature of cycling does not exclude cyclists from musculoskeletal problems that arise due to prolonged and incorrect postural adaptations combined with repetitive limb movements. Hence efforts are made to reduce the musculoskeletal problems by replacing the conventional chain and sprocket mechanism of the bicycle with a slotted lever quick return mechanism (SLQRM), which eliminates the 360° crank and ankle rotation by allowing nearly vertical up and down motion of the legs, which reduces the flexion at the knees. The reduced knee flexion is thus expected to reduce the risk of pain at the knee's patellofemoral joint (PFJ), sciatic nerve blockage, and knee swelling. This mechanism is more efficient than the conventional chain and sprocket mechanism because the levers are longer than cranks and pedals move up and down, so the rider puts less effort into generating more torque. Additionally, the gravity force is useful for riders to help move down the lever crank. Preliminary analysis of various assemblies with a load of 100 kg on a single pedal shows that the maximum stress of 220 MPa and the maximum strain of 0.000842 were developed at the gear and curved strip assembly; the maximum displacement of 3.22 mm and minimum FOS of 1.95 were seen at the gear and pedal crank arm assembly, which are considered satisfactory.

Keywords: *Knee Flexion, Musculoskeletal, PFJ, Sciatic Nerve, SLQRM.*

1.0 Introduction

Among various physical activities, cycling is considered to have less impact on the rider. Although most cyclists are required to have endurance in this sport, it does not protect them from musculoskeletal problems in the lower body parts. Apart from the injuries sustained by the rider as a result of a fall from the bike, one of the primary causes of the development of lower limb and lower body problems in recent times has been identified as prolonged and incorrect riding posture with limb movement for an extended period of time. It can be concluded that between 23% and 33% of cyclists have suffered from knee pain caused by cycling at one point or another, based on research carried out by Benjamin Clarsen, Tron Krosshaug, and Roald Bahr in 2010. They say that most of the cycling-related knee pain comes from "overdoing it," i.e. riding for a longer duration and/or harder than the body is conditioned to will strain the body's connective tissues, which causes inflammation and pain in the knee[1].

This research aims to present one of the most effective solutions to the musculoskeletal problems that are caused by the current mechanism used in the bicycle. In an innovative approach, efforts are made to reduce the impact on lower body parts by replacing the conventional chain and sprocket mechanism with the slotted lever quick return mechanism.

2.0 Literature Review

2.1 Pain at the PFJ

In recent times, the problems related to the PFJ have been so common due to cycling because of which, this problem is

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known as 'biker's knee' and also 'cyclist's knee'. A large reaction force is developed at the surface of PFJ and in addition to it, significant by the amount of knee flexion produced by the rider during the beginning of the down stroke is considered a primary reason for the predominance of problems at PFJ[2].

2.2 Blockage of Sciatic Nerve

According to the research carried out by Cheryl A. et al., Cavanagh P. R. et al. Al. and Houtz et al., the smallest hip flexion recorded was between 28° and 30°, while instead of continuing to flex past 90° the hip begins to internally rotate and abduct during cycling[3-5]. From the results of Magnetic Resonance Imaging (MRI) conducted on ten volunteers by Colin Scott Moore et al. al., it can be concluded that the sciatic nerve gets blocked when the hip begins to rotate internally. Prior to the MRI, markers were placed on the surface where a needle would have been inserted for an anterior approach to the sciatic nerve. Next, three scans were then performed: one with both legs in the neutral position, the other two with maximal bilateral internal rotation at the hip; and maximal bilateral external rotation at the hip. The number of times the needle path passed through the femoral neurovascular bundle also fell from 55% in external rotation to 15% in internal rotation, which shows that internal rotation of the thighs leads to static nerve blockages[6].

2.3 Region of Maximum Knee Flexion

The research carried out by Houtz and Fischer shows that maximum dorsiflexion will occur along with maximum knee flexion between 337° and 23° of crank position[3,5]. From Figure 1, it can be seen that the region of maximum dorsiflexion and maximum knee flexion is further divided into three regions for better understanding. The red coloured region indicates the region of highest knee flexion, the orange coloured region indicates the region of moderate knee flexion, and the yellow coloured region indicates the region of comparatively less knee flexion.

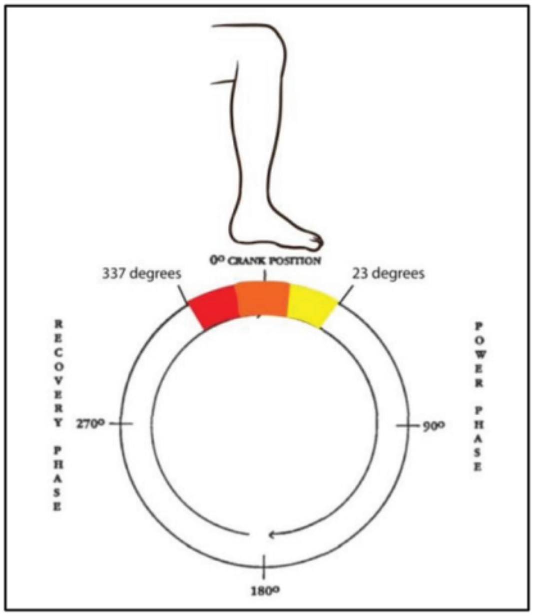

Figure 1: Region of maximum knee flexion

2.4 Pulling up Force during Cycling

As opposed to the results obtained from the studies designed to determine forces during the recovery phase while cycling, most of the time cyclists report exertion of pulling up force during the recovery phase. However, only a few cases of cyclists exerting a pulling up force were observed in a study of steady-state riders and recreational riders which was of small magnitude and lasted for a short duration[2]. Increased force results in an increase in the pressure on the patella and soft tissues surrounding it or incorrect tracking of the patella also lead to compression of the patella at the PFJ[7].

2.5 Knee Swelling

Excessive bending or twisting of the knees is considered the most obvious cause of inflammation or swelling of the knee, which results in the release of excess synovial fluid and accumulates in the knee more than the desired quantity, which is 7.0 mL. Because of this, one might not be able to bend or straighten the leg completely. According to the results from the research by Bini R. R. et al., 283 professional and amateur cyclists who were cross-cultured people were gathered. The overall commonness of knee pain was found to be 25.8%. While popping contributes 6.7% and swelling of the knee contributes 5.0%, the next two most common symptoms with regard to the knee joint[8].

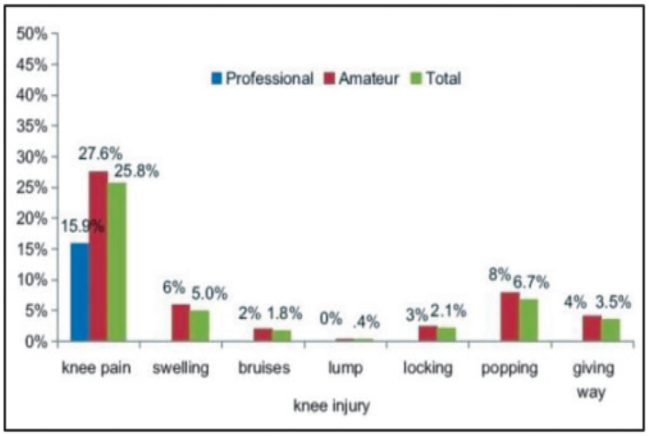

Figure 2: Graph of various knee injuries vs percentage of affected riders from different categories

3.0 Objectives

The following list of five study objectives was created based on the literature review:

a. Reduce knee flexion to reduce pain in the patellofemoral joint caused by the development of large reaction forces at the joint.
b. To reduce or eliminate the hip flexion that occurs between 270° and 360° of crank rotation so as to reduce the chances of sciatic nerve blockage.
c. Create the mechanism with the knee restricted from entering the region of maximum knee flexion,337°-0° degrees.
d. To eliminate the upward (pulling up) force that riders exert and, hence, reduce pressure and compression at the patella.
e. Reduction of excessive bending of the knees in order to avoid the problem of knee swelling.

4.0 Methodology

The approach to this research is multidisciplinary, which involves the basic concepts of biomechanics of musculoskeletal problems that are caused at the lower body parts of a human being due to various postural adaptions. Along with the knowledge about the various positions that are potentially dangerous to different parts of the lower body during cycling in a normal bicycle. Most importantly the concept of basic mechanisms and their inversions. Lastly, appropriate knowledge of any 3D modelling software to prepare a conceptual model and analyze it for various factors like stress, strain etc., is required. As an outcome of this research, the proposed solution for the mentioned musculoskeletal problems caused due to the current chain and sprocket mechanism used in the bicycle is the bicycle equipped with slotted lever quick return mechanism.

In most of the research with respect to designing and manufacturing of a product, material selection is the first step. For a product design, the goal is to reduce the cost of material by meeting product performance goals. Systematic selection of the best material for a given application begins with properties and costs of candidate materials. Steps followed in this process are:

a. Identify the design requirements.
b. Identify the materials selection criteria.
c. Identify candidate materials.
d. Evaluate candidate materials.
e. Select materials.

Density, yield strength, shear modulus, cost and availability of materials were the major factors taken into consideration while choosing the materials for each part of the bicycle.

After designing each of the 30 parts in the bicycle, the final concept which is the outcome of this research is illustrated using the Figures 3 and 4.

The entire design of the bicycle consists of 30 different parts used in different numbers. The list of components of the design with the respective materials used is tabulated in the Table 1.

Parts such as the left and right rear frames, which are huge compared to the other components of the bicycle, are made of 7075-T6 aluminum, whose ultimate strength and yield strengths are 525 MPa and 455 MPa, respectively, in order to make sure there is a proper balance between the load bearing capacity and the weight of the overall bicycle. The AISI 1045 Steel (Cold Drawn), whose ultimate strength and yield strengths are 625 MPa and 530 MPa respectively, with a 12% elongation at break, is used for components which bear moderate load in the bicycle, such as the centre shaft, gear pin, etc., Greater load bearing parts such as pedal crank arm, curved strip, slotted strip, and seat post are made of AISI 4130 Steel (Normalized at 870°C) whose ultimate strength and yield strengths are 670 MPa and 435 MPa with a 25.5% elongation at break. Lastly, common and minute components such as

Figure 3: Bicycle Equipped with Slotted Lever Quick Return mechanism

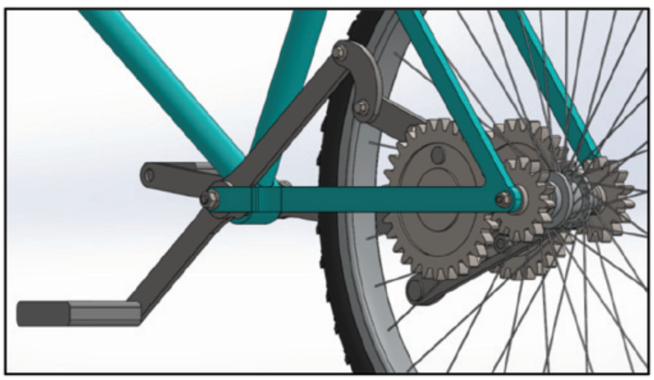

Figure 4: Magnified view of the mechanism in the Bicycle Equipped with Slotted Lever Quick Return mechanism

Table 1: List of parts with their material, weight, and quantity

	Parts	Material	Weight (gm)	QTY
1	Center Shaft	AISI 1045 Steel, cold drawn	595.39	1
2	Rear Frame Left	7075-T6 (SN)	819.68	1
3	Rear Frame Right	7075-T6 (SN)	819.68	1
4	Rear Axle (M10)	Alloy Steel	161.33	1
5	Rear Wheel	6061-T6 (SS)	7965.75	1
6	Washer(Rear Wheel)	AISI 1045 Steel, cold drawn	22.55	4
7	Spur Gear 15T	7075-T6 (SN)	178	2
8	Spur Gear 30T	7075-T6 (SN)	628.9	2
9	Pedal Crank Arm	AISI 4130 Steel, normalized at 870º C	2390.69	2
10	Pedal	2024-T4	392.40	2
11	Curved Strip	AISI 4130 Steel, normalized at 870º C	250.47	2
12	Pin (Curved Strip)	AISI 1045 Steel, cold drawn	42.19	4
13	Gear Pin	AISI 1045 Steel, cold drawn	18.90	2
14	Gear Pin Bush	AISI 1045 Steel, cold drawn	23.38	2
15	M10-1.5 Nut	2024-T4	2.67	7
16	M10-1.5-70-30S Bolt	2024-T4	17.88	1
17	M8-1.25-20-20S Bolt (Gear Pin)	2024-T4	5.05	2
18	M8-1.25-12-12S Bolt (Curved Strip)	2024-T4	4.17	4
19	M10-1.5-1616S Bolt (Rear Frame)	2024-T4	7.84	2
20	M8-1.25-38-19P-25S Bolt (Pedal Crank Arm)	AISI 1045 Steel, cold drawn	22.17	2
21	Slotted Strip	AISI 4130 Steel, normalized at 870º C	1315.36	2
22	Main Frame	7075-T6 (SS)	3071.21	1
23	Fork	AISI 1045 Steel, cold drawn	1262.11	1
24	Front Axle (M10)	Alloy Steel	158.20	1
25	Front Wheel	6061-T6 (SS)	8010.19	1
26	Washer (Front Wheel)	AISI 1045 Steel, cold drawn	25.89	2
27	Handle	6061-T6 (SS)	532.31	1
28	Seatpost	AISI 4130 Steel, normalized at 870º C	470.38	1
29	Bike Seat	2024-T4	784.89	1
30	Washer (Frame)	2024-T4	2.16	2

bolts, nuts, and washers are made using 2024-T4 aluminium, whose ultimate strength and yield strength are 469 MPa and 324 MPa respectively.

5.0 Results and Discussion

The design of this concept was analyzed by grouping certain components together based on the amount of their interaction considering the situation during the real time usage. The entire design is divided into 3 groups, namely:

I. Gear and pedal crank arm assembly
II. Gear and curved strip assembly
III. Gear and pinion assembly

Each of these assemblies were analyzed separately for

a. Maximum and minimum displacements due to applied load
b. Maximum and minimum stress developed due to applied load
c. Maximum and minimum strain developed due to applied load
d. Values of the factor of safety for the applied load

The equilibrium of forces approach will be used to examine

Table 2: Results of analysis of various sub-assemblies

Assembly	I	II	III
Max. Stress (MPa)	235	220	49.1
Max. Strain	7.29e-4	8.42e-4	4.67e-4
Max. Displacement (mm)	3.22	0.307	0.0796
Max. FOS	7.07e+10	1.00e+16	3.87e+6
Min. FOS	1.95	2.414	10.3

the bicycle's design in order to determine the least amount of force necessary to propel the vehicle ahead.

The following findings were obtained with 100 kg of load applied to a single pedal.

5.1 Analysis on Assembly of Gear and Pedal Crank Arm

- The analysis was conducted for an applied force of 100 kg at the point where the rider applies the force initially, i.e., on the pedal of the bicycle. Generally, the load is distributed on both the pedals of the bicycle. Here we have considered the load of 100 kgf on a single pedal as a factor of safety.
- A maximum stress of 235 MPa was developed in the assembly, which is less than the yield strength of the material assumed.
- A maximum strain of 0.000729 was developed in the assembly.

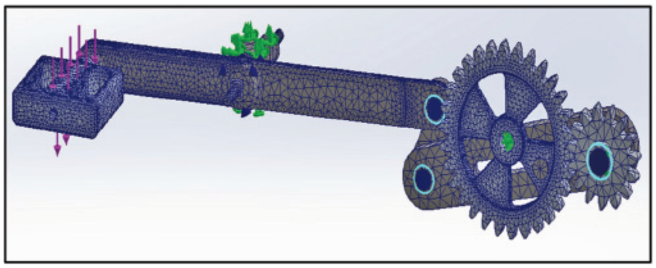

Figure 5: Assembly after application of load and meshing

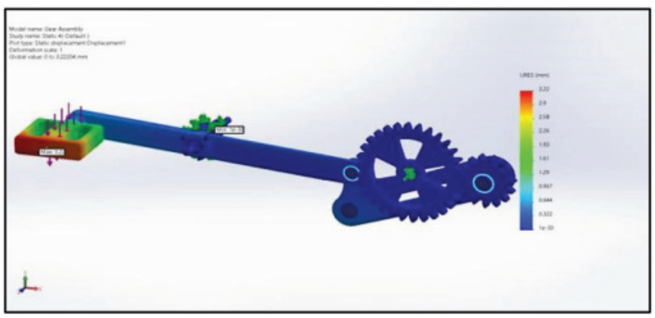

Figure 6: Displacements for the applied load

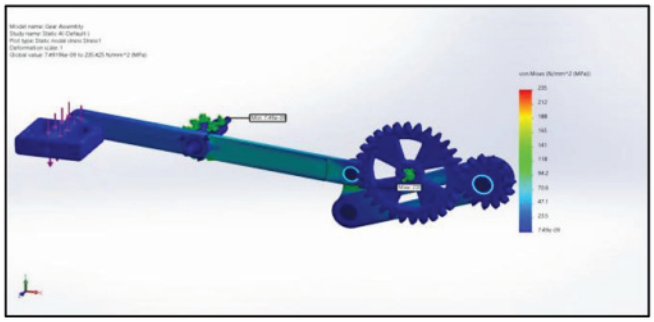

Figure 7: Stresses developed for the applied load

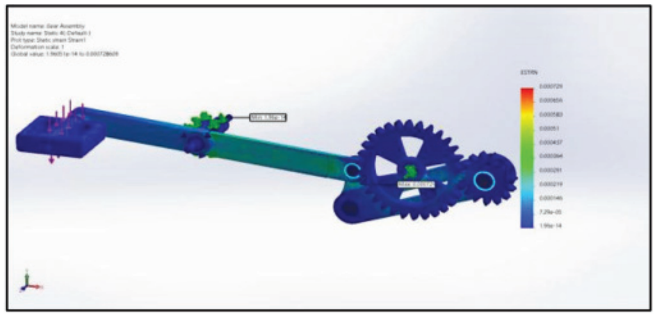

Figure 8: Strain developed for the applied load

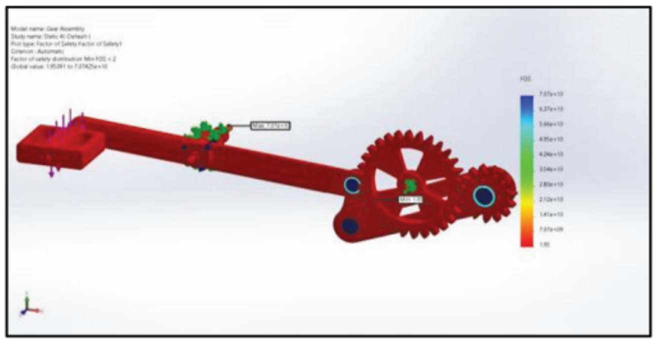

Figure 9: Factor of Safety values for the applied load

- A maximum displacement of 3.22 mm was seen in the assembly.
- The minimum factor of safety was found to be 1.95, which lies in the range of 1.5-2.0.

5.2 Analysis on Assembly of Gear and Curved Strip

- The analysis was conducted for an applied load of 100 kgf at the connecting point between the crank and the slotted strip i.e., on the small hole of the curved strip through which the load is transferred from the pedal to slotted strip.

- A maximum stress of 220 MPa was developed in the assembly, which is less than the yield strength of the material assumed.
- A maximum strain of 0.000842 was developed in the assembly.
- A maximum displacement of 0.307 mm was seen in the assembly.
- The minimum factor of safety was found to be 2.414, which is greater than the range of 1.5-2.0.

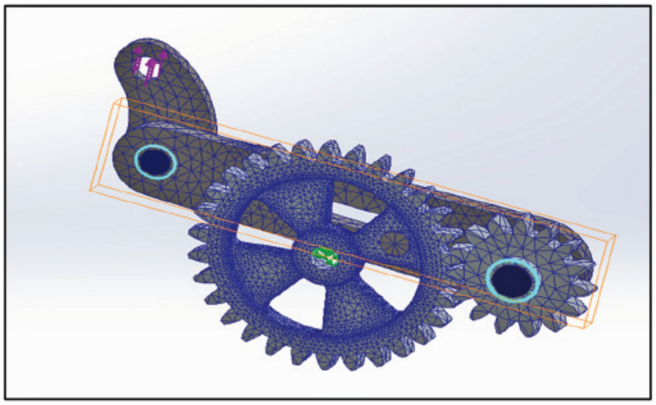

Figure 10: Assembly after application of load and meshing

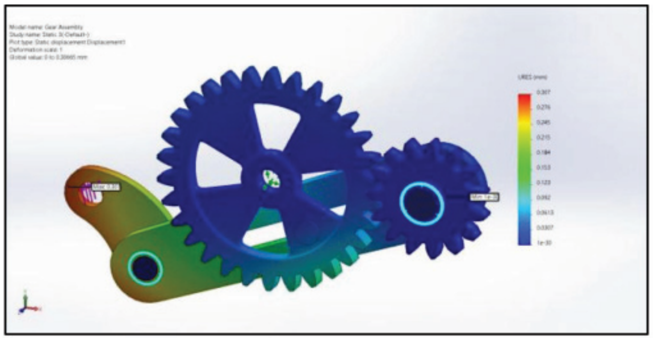

Figure 11: Displacements for the applied load

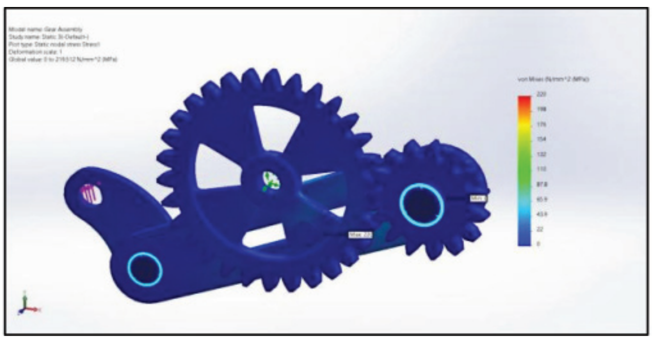

Figure 12: Stresses developed for the applied load

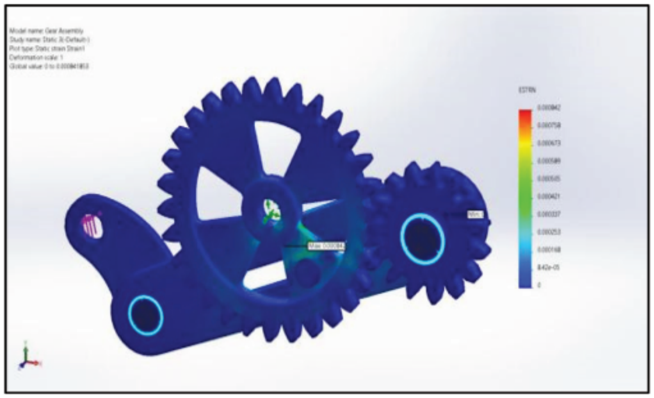

Figure 13: Strain developed for the applied load

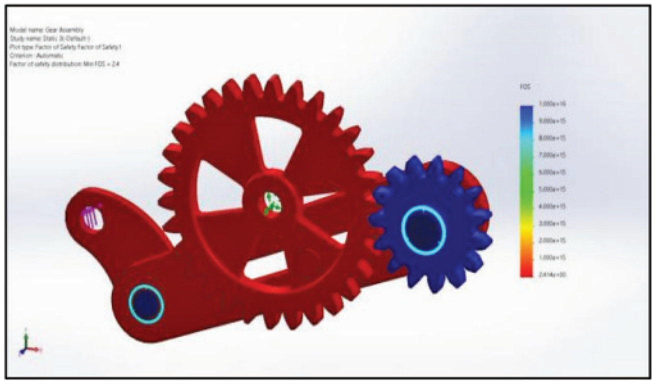

Figure 14: Factor of Safety values for the applied load

5.3 Analysis on Assembly of Gear and Pinion

- The analysis was conducted for a load of 100 kgf applied at the connecting point between the slotted strip and the gear i.e., on the gear pin where the load from the pedal to gear is transferred.

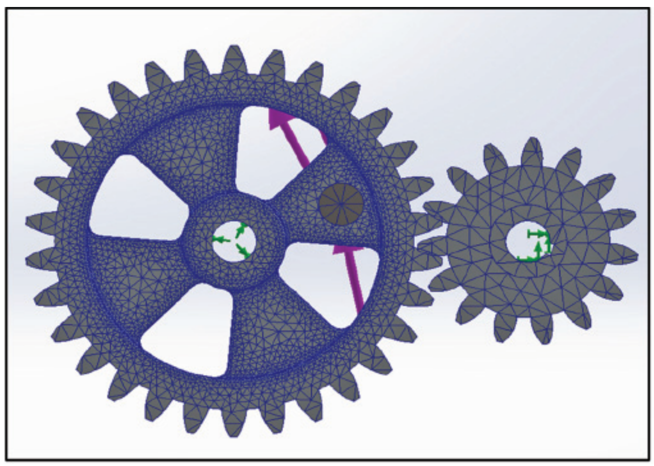

Figure 15: Assembly after application of load and meshing

- A maximum stress of 49.1 MPa was developed in the assembly, which is less than the yield strength of the material assumed.
- A maximum strain of 0.000467 was developed in the assembly.
- A maximum displacement of 0.0796 mm was seen in the assembly.
- A minimum factor of safety was found to be 10.3, which is great than the range of 1.5-2.0

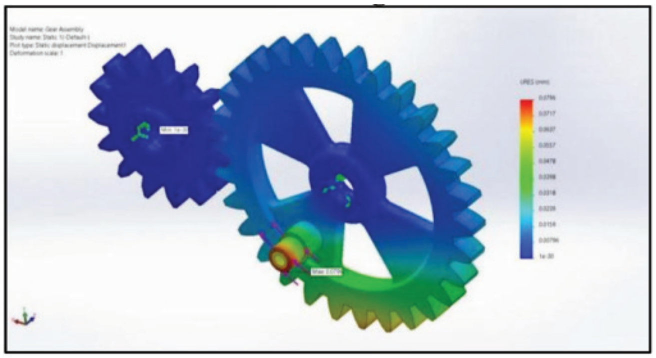

Figure 16: Displacements for the applied load

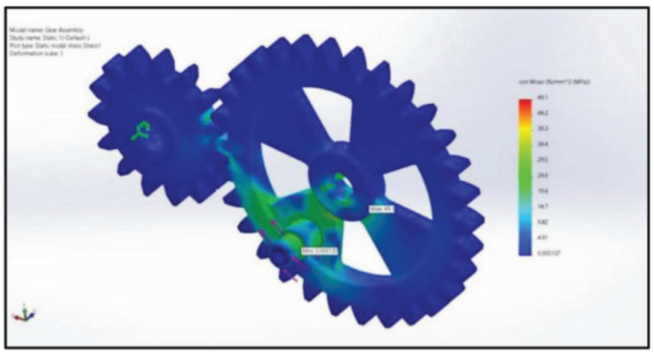

Figure 17: Stresses developed for the applied load

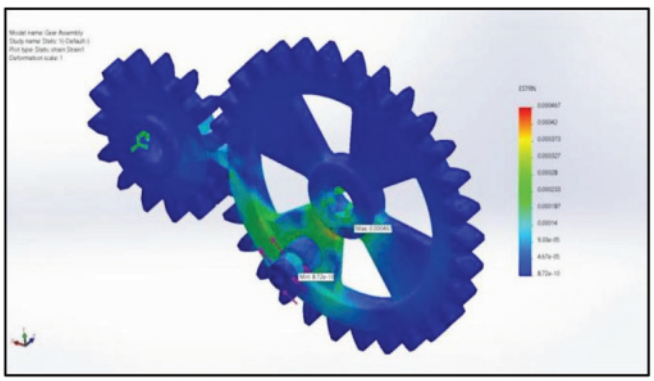

Figure 18: Strain developed for the applied load

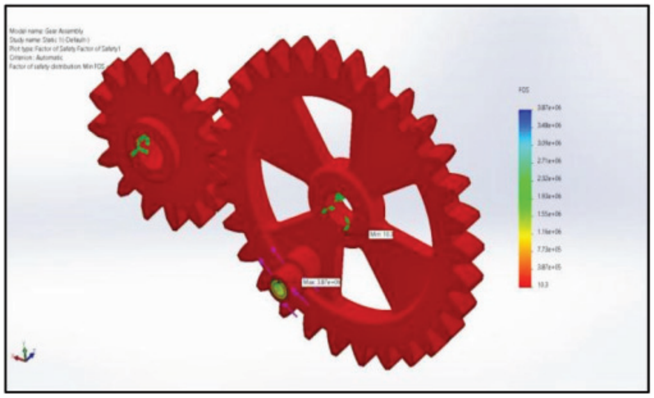

Figure 19: Factor of Safety values for the applied load

5.4 Preliminary Force Analysis

While cycling, the rolling resistance will be estimated by solving the force equilibrium on a moving bicycle. The rolling resistance can be found by solving the force equilibrium:

$$F_p = F_r + F_g + F_a + F_i + F_f + F_b \quad \text{... (1)}$$

Where, F_p = Propulsion force, F_g = Gravity force, F_a = Air drag force, F_i = Inertia force, F_r = Rolling resistance force, F_f = Internal friction forces, F_b = Braking force.

Figure 20 illustrates the force equilibrium in Eq.1. As the test bicycle in this study was brand new and had high-quality wheels, the internal friction from the wheel bearings was neglected. The propulsion force measurement was located directly between the rear wheel sprockets and the hub of the rear wheel. The measurement was therefore unaffected by internal friction, and the internal friction force from the drive train was neglected. Measurements were only included while the pedaling cadence (rounds per minute, RPM) was above zero. It was assumed that braking occurs mainly while the pedaling cadence is equal to zero, and hence the force from braking resistance was neglected. The rolling resistance was therefore estimated using the following simplified force equilibrium:

$F_r = F_p$ “ $(F_g + F_a + F_i)$ ... (2)

Minimum force required to run the bicycle is, $(F_g+F_a+F_i)$N

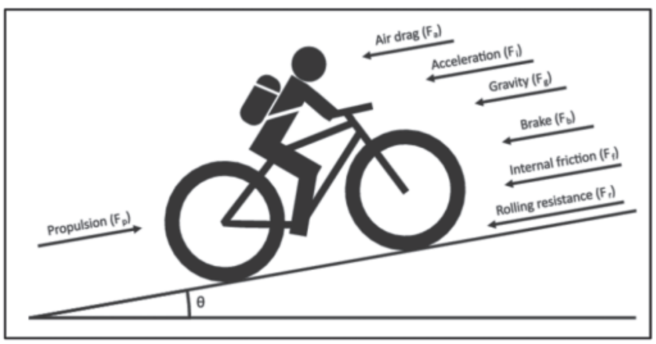

Figure 20: Forces acting on a bicycle during cycling

i.e. rider needs to exert the force of ($F_g + F_a + F_i$) N just to move the vehicle forward.

Resistive force due to gravity is given by

$F_g = M \times g \times \sin(\theta)$ [12] ... (3)

where, M =combined mass of bicycle and rider, g = acceleration due to gravity, θ = slope angle. Considering the situation of starting to move the bicycle on a flat surface, θ = 0, therefore, $F_g = 0$.

Inertial force due to acceleration is given by,

$F_i = (m + (l_{fw} + l_{wr}/2)) \times a$ [12] ... (4)

where, m = combined mass of bicycle and rider, l_{fw}= mass moment of inertia of front wheel, l_{wr} = mass moment of inertia of rear wheel, a = acceleration of the bicycle. While starting to ride a bicycle, a = 0, therefore, Fi = 0.

Resistive force due to drag is given by,

$F_a = 0.5 \times C_d A \times \tau \times v^2$ [12] ... (5)

where, C_d = drag coefficient, τ = density of air, V = velocity of air, A = frontal area.

Resistive force due to drag can be calculated,

$C_d = 0.6$, V = 16.7 m/s[13], $C_d A = 0.26\ m^2$ [14], τ = 1.181 Kg/m^3 [13]. Substituting all the values in Eqn. (5), we get:

$F_a = 0.5 \times 0.26 \times 1.181 \times 16.72^2$

$F_a = 42.92$ N

Force Fa acts opposite to the direction of motion of the bicycle, to overcome this force, the bicycle should move forward with a force of 42.92 Newton. Hence, the reaction force exerted by road on tire must be 42.92 N i.e Fr = 42.92 N.

Now, to find out the minimum force required to move the bicycle forward, we consider the following pedal crank diagram for the proposed bicycle.

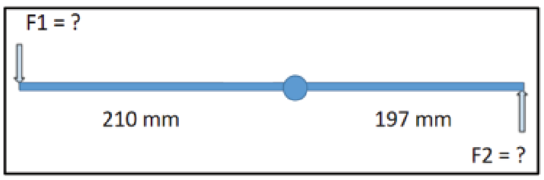

Figure 21: Pedal crank diagram for the proposed bicycle

Let us consider the force exerted by rear wheel on road as equal and opposite to F_r i.e. F_p = 42.92 N which is also the tangential force Ft. Thus, Torque

T_p = Fi x Radius of rear wheel (in mm) ... (6)

$T_p = 42.92 \times 635 = 27254.2$ Nmm.

Assuming no losses in the linkages, same force F2 acts as a tangential force on the gear. Due to meshing between gear and pinion, the same tangential force is transmitted to pinion. Let F3 be the tangential force on pinion, thus

F2 = F3 = T_p/Radius of Pinion ... (7)

F2 = F3 = 27254.2/31.8 = 715.33 N

We know that, T = F2 × l2 (197) ... (8)

i.e. T = 140920.66 Nmm. Now, we also know that

T = F1 × l1 (210) ... (9)

Thus, F1 = 671 N = 68.47 kg of force has to be exerted on the pedal of this bicycle with this dimensions in order to move the cycle forward.

6.0 Conclusions

- The proposed bicycle equipped with SLQRM makes sure that the knee does not enter into the region of highest knee flexion as seen in Section 2.3 of the literature survey. This causes a reduction in knee flexion.
- Knee flexion is not eliminated but is reduced to a great extent, which will prevent the cyclist from experiencing musculoskeletal problems. With the reduction in knee flexion, the development of large reaction forces at the PFJ is reduced, which solves the problems at the PFJ and also reduces the problem of knee swelling, as seen in sections 2.1 and 2.5 of the literature survey, respectively. Additionally, patients who are already experiencing knee swelling can ride this bicycle as it involves less knee flexion.
- Due to the quick-return mechanism used in the bicycle, there is no chance for hip flexion to occur as it occurs between 270° and 360° of crank motion as seen in section 2.2 of the literature survey, which is totally eliminated here. Because of the elimination of the crank motion in the above-mentioned range, internal rotation of the thigh is reduced, and hence the chances of sciatic nerve blockage are also reduced.
- The pedals are alternatively positioned and interconnected through gears; hence, the other pedal automatically comes up when one is pushed down, which eliminates the pulling up force required to be exerted by the cyclists, as seen in section 2.4 of the literature survey.
- The bicycle equipped with SLQRM is a possible exercise for patients suffering from initial stages of osteoporosis. "Osteoporosis is a disease characterised by low bone mass and microarchitectural deterioration of bone tissue, leading to enhanced bone fragility and a consequent increase in fracture risk," as defined by the Consensus Development Conference[9]. Osteoporosis is a major public health problem. When there is low bone mass (osteopenia or osteoporosis), exercise remains integral to fracture prevention but is often avoided for fear of causing a fracture[10]. Since this bicycle involves comparatively less bending of the knees, patients suffering from grade 1 and 2 osteoporosis at the knee can ride this bicycle to improve their condition.

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