Performance Investigation by Optimizing Various Mechanisms for Maximum Kinetic Energy Gain Through Human Powered Flywheel

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Abstract— In the recent past various human powered mechanisms such as brick making mechanism, chaff cutter, soap mixer, flour mill etc are developed. The common system among all these mechanisms is the flywheel motor. Flywheel is used in manually driven machines, mainly as flywheel motor. Flywheel is pedaled to a higher speed to store kinetic energy. This K.E. is drained out in a short period to accomplish a desired process which needs process power beyond human capacities. In this paper we discuses about the working construction and optimizing the performing characteristics of various mechanism (quick return ratio one mechanism and double lever inversion mechanism). The pedal operated flywheel provides a wide aspect of living in a different way. It gives us a way to produce energy by the use of human effort. The following report proposes the use of a pedal operated flywheel to maximize K.E. gain and its optimization. The report firstly defines the problems associated with maximizing the K.E. gain and its use. Subsequent section will compare different types of bicycle mechanism and describe it briefly. The remainder of the report will focus on the optimization of human powered flywheel motor to maximize K.E. gain. To have increased efficiencies, flywheel motors have some special arrangements of inputting power. They are, 1) Quick return ratio one, 2) Elliptical chain wheel, and 3) Double lever inversion. Hence in this paper arrangement and testing values of various mechanisms is presented on flywheel motor.

Key words: Quick Return Ratio One Mechanism, Double Lever Inversion Mechanism, Flywheel Motor and K.E. Gain

I. Introduction

During 1979-99, Modak J.P. developed a human powered brick making manufacturing of bricks (Modak J.P. J.P. 1982, 1994, 1997, 1998) [1]. And since then various processes are energized by the human power such as wood turning, cloth washing, chaff cutter [2], potter's wheel, flour mill etc. All these machines are operated by the human power with one common mechanism among them- The Flywheel Motor. The Machine consists of flywheel motor , driven bicycle mechanism with speed increasing gearing , which drives the shaft of process of process unit through clutch and torque amplification unit (Gupta 1977)[1]. Since ever increasing fuel crises, energy crises, busy schedules of load shading, unemployment justify the need of human powered machines, the constants efforts are being continuously made to optimize the various parameters of these machines so as to provide the ease for the operator and consequently make efficient use of human energy. In an attempt, this paper presents the exhaustive literature survey on the flywheel motor throwing lights on the experimentation done on flywheel motor with double lever inversion for optimizing its performance.

II. Flywheel Motor the Concept

Any machine, to power it by human energy, the maximum power requirement should be 75Watts. Any machine or process requiring more than 75 Watts and if process is intermittent without affecting and product, can also be operated by human energy (Alexandrove 1981)[3]. This is possible with the provision of intermediate energy storing unit which stores the energy of human and supply periodically at required rate to process unit, this is called as "human powered flywheel motor." Modak J.P. and his associates are working on flywheel motor from 1977. A manually driven brick making machine was first of its kind in which manually energized flywheel motor is used for first time [4]. Essentially the flywheel motor consists of flywheel, which is being driven by a human through a simple bicycle mechanism and pair of speed increasing gears [3]. The schematic of flywheel motor is as shown in fig 1.

A rider pedals the mechanism "M" converting the oscillatory motion of thighs into rotational motion of counter shaft "C". This counter shaft "C" connected to flywheel shaft "FS" with speed increasing transmission consisting machine for the of pair of speed gears [4]. Driver pumps the energy in flywheel at energy rate convenient to him [4]. In this way, the muscular energy of human is converted into kinetic energy of flywheel by this man machine and for its efficient use it is necessary to optimize its parameters [4].

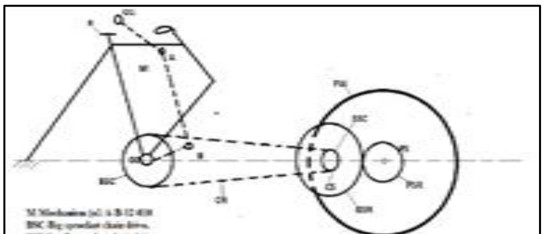

Fig. 1: Schematics of flywheel motor

III. Design Consideration in Flywheel Motor

At the beginning, the flywheel motor was not based on any design data, rather it was built only on the institution of human [4]. Later with the numerous experimentation the design data is made available which is discussed below.

A. Modification in Existing Bicycle Mechanism

Modak J.P (1985) has established the relationship between the useful torques developed at the crank as function of crank position during its revolution [5]. Modak J.P. also observed that out of 360° rotation of pedal crank, only from 30°-115° of crank position from top dead center is useful. The rest of the period of crank position i.e. 0°-30° and 115°-162° is not effectively used and from 162°-360° is completely idle. Even when both the cranks are considered the useful driving angle is found to be 154°.[5]. Consequently for maximum utilization of operators energy Modak J.P. suggested three modified mechanisms namely Quick return ratio one, Double lever inversion and Elliptical sprocket[5].Based on his mathematical modeling he concluded improvement of 17%,38%, and 18% in human energy utilization for Quick return ratio one, Double lever inversion and Elliptical sprocket respectively. This performance of various bicycle drives then was experimentally verified by Modak J.P, Chandurkar K.C. et ,al (1987) and found almost matching with theoretical values[6].

B. Flywheel Speed and Moment Of Inertia

Modak J.P(1987) during the experimentation has ob-served the maximum thigh oscillation for the average person of 165 cm stature from age group 20-22 years is 40. [7]. With the available chain drive for existing 22” bicycle frame the flywheel speed of 240 rpm was fair enough from point of total speed rise from pedals to flywheel shaft [7]. Further with calculation Modak J.P. (1987) has deter-mined the size of flywheel with the objective to store the maximum energy irrespective of speed fluctuations (180-240 rpm)[7]. The Flywheel rim diameter is found to 82 cm which gives the weight of flywheel as 150Kg and 266 Kg for 240 rpm and 180 rpm respectively. Hence Modak J.P. (1987) suggested the flywheel with 150 Kg @240 rpm [7]. Further Modak J.P. (1987) has also found that driving tor-que of pedal is unaffected by increasing flywheel moment of inertia and stores same energy for same frequency of thigh oscillation [7].

C. Gear Ratio

Modak J.P. (1987) suggested the value of gear ratio as 4:1 so as to reduce the effect of jerk induced at process unit shaft as result of energy or momentum exchange during the clutch engagement. If lower value of gear ratio is to be used then flywheel speed should be maintained higher than 240 rpm [7].

1) Quick return ratio-one:

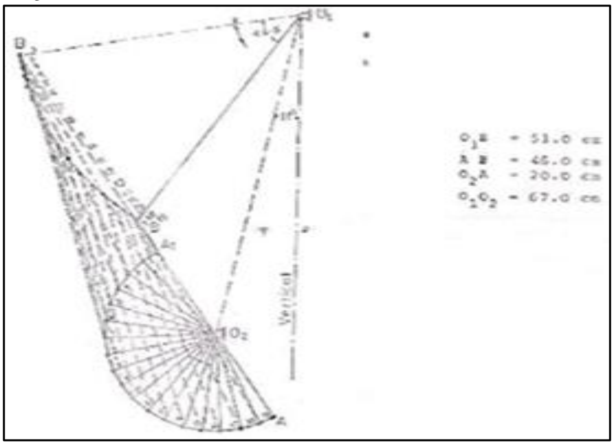

Fig. 2: Modified Mechanism (Quick return ratio-one)

From figure,
O_1B is thigh length,
AB is length,
O_2A is crank length,
O_1O_2 is frame.

It is modified form of mechanism called as Quick Return Ratio One. In the existing mechanism, the ratio of forward travel to return travel is 0.82. In the Quick Return Ratio One, the ratio is one therefore; the second paddle will be immediately ready when the first one goes down.

In this, the thigh oscillation angle, thigh length and the leg length are kept same. In existing mechanism, the crank length is 18.5 cm and in QRR- one it is 20 cm.

Similarly, in existing mechanism the frame length i.e. crank Centre to rider’s hip joint 74 cm and frame inclination to vertical is 20^0. But in QRR-one, the frame length ie. Crank centre to rider’s hip joint 67 cm and frame inclination to vertical is 11^0.

2) Elliptical Sprocket:

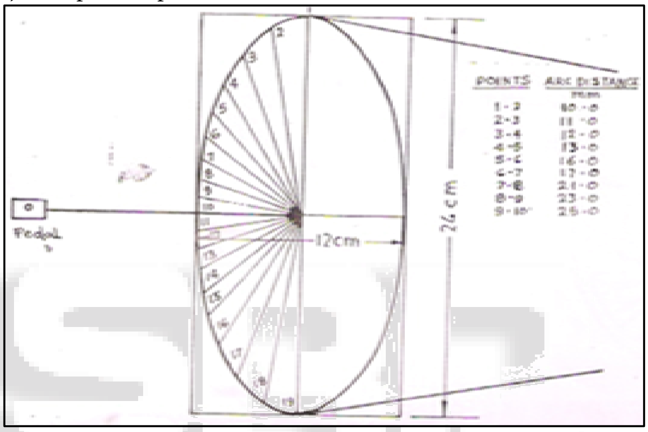

Fig 3: Modified Mechanisms (Elliptical Sprocket)

In modified mechanism, an elliptical sprocket is at the crank and circular sprocket at the wheel. The main objective of using elliptical sprocket to such a drive can be that the chain becomes alternately loose and tight.

From figure, an elliptical sprocket, chosen, the chain becomes loose by 0.8 cm only from its tight condition and sag of only 3 cm is produced by its weight in the span of 49.5 cm. Here an elliptical sprocket of major diameter 24 cm and minor diameter is 12 cm. chosen so as to keep the chain length same.

Assuming that the chain speed is constant, the elliptical sprocket will rotate at a higher speed when the transmission angle is poor and will rotate slow when the transmission angle is good. Thus, giving more time to the mechanism for receiving power input.

IV. THE READINGS AND CALCULATION FOR KINETIC ENERGY DEVELOPED IN TESTS OF ACTUAL SETUP

When the model of human powered flywheel motor with quick return ratio one was fabricated in our lab, we took readings of kinetic energy for 15 seconds, with 3rd and top gear. First we did this for weight wise for eight weight groups between 40-80 kg. Then we did this for age wise for eight age groups between 20-60.

A. Calculations for Kinetic energy stored in flywheel

Assuming the density for the flywheel material as 7874 kg/m^3i.e., for cast iron and weight of arm and hub to be 15% more to be multiplied to moment of inertia of flywheel of rim.

The dimensions of the flywheel are as follows:
Outside diameter of flywheel (Do) = 40cm =400mm
Rim thickness (h) = 0.05 Cm =5mm
Width of the flywheel (b) = 0.6Cm = 60mm
The following figure shows the dimensional details of the flywheel.

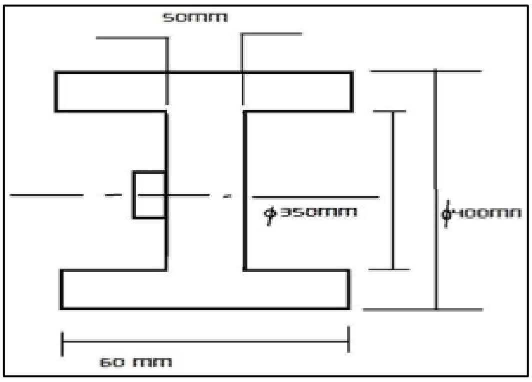

Fig. 4: Dimension of the flywheel

Now the mass of the flywheel is given by,
Mass= volume x density.

Volume of the flywheel is calculated as follows
$Mass = [(\Pi D*Area)] * [Density]$
$Mass = [(\Pi D*(b*t)] * [Density]$
$Mass = [(\Pi*0.4*(0.06*0.005)]*[7874]$
Mass = 2.968 Kg. s
=3Kg (Approx.)

Now Moment of Inertia of Flywheel (Only Rim)
$I = w/g*(k^2)$
$I = 20/9.81* (0.35^2)$
$I = 4.37*10^{-3}\ kg.s.m^2$
Consider Weight of Arm and hub.
$M.\ I.\ Flywheel = 4.37*10^{-3}*1.15$
$= 5.026*10^{-3}\ kg.s.m^2$
Kinetic Energy Stored in Flywheel
$= 1/2 *I* \omega^2$
$= 1/2*I*(2\Pi N/60)^2$
$K.E. = 1/2 *4.37*10^{-3}*(2\Pi/60)^2*N^2$
$K.E. = 2.396*10^{-5}*N^2$ Joules.
Consider RPM = 539 Top Gear,
Kinetic Energy $=2.396*10^{-5}*539^2$
=6.96 Joules.
Consider RPM = 372 Third Gear,
Kinetic Energy $=2.396*10^{-5}*372^2$ Joules.
=3.32 Joules.

Similarly the kinetic energy stored for each case is calculated.

1) Weight Wise:

Sr. no.	Wt. of riders in kg	Cycling time in sec	Elliptical Sprocket				Quick Return Ratio			
			Load 12 kg speed of flywheel in RPM		Load 20 kg speed of flywheel in RPM		Load 12 kg speed of flywheel in RPM		Load 20 kg speed of flywheel in RPM	
			Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear
1.	40-45	15	418	345	518	396	432	314	539	372
2.	45-50	15	448	416	598	410	534	357	673	421
3.	50-55	15	452	428	572	460	520	340	649	424
4.	55-60	15	450	407	540	430	443	347	560	419

Table 1: Comparison of RPM between elliptical sprocket & quick return ratio for weight (Quick Return Ratio)

2) Age Wise:

Sr. no.	Age of riders in year	Cycling time in sec	Elliptical Sprocket				Quick Return Ratio			
			Load 12 kg speed of flywheel in RPM		Load 20 kg speed of flywheel in RPM		Load 12 kg speed of flywheel in RPM		Load 20 kg speed of flywheel in RPM	
			Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear
1.	20-25	15	470	370	510	427	558	445	562	516
2.	25-30	15	524	361	506	419	480	305	482	372
3.	30-35	15	549	402	535	380	510	315	524	367
4.	40-45	15	474	378	482	371	545	347	538	395

Table 2: Comparison of RPM between elliptical sprocket & quick return ratio for age (Quick Return Ratio)

3) Weight Wise:

Sr. no.	Wt. of riders in kg	Cycling time in sec	Elliptical Sprocket				Quick Return Ratio			
			Kinetic Energy gain in joule		Kinetic Energy gain in joule		Kinetic Energy gain in joule		Kinetic Energy gain in joule	
			Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear
1.	40-45	15	4.19	2.85	6.43	3.76	4.47	2.36	6.96	3.32
2.	45-50	15	4.81	4.15	8.37	4.03	6.83	3.05	10.85	4.25
3.	50-55	15	4.89	4.39	7.84	5.07	6.48	2.77	10.10	4.31
4.	55-60	15	4.85	3.97	6.99	4.43	4.70	2.88	7.51	4.21

Table 3: Comparison of K.E between Elliptical Sprocket & Quick Return Ratio for weight (Elliptical Sprocket)

4) Age Wise:

Sr. no.	Age of riders in year	Cycling time in sec	Elliptical Sprocket				Quick Return Ratio			
			Kinetic Energy gain in joule		Kinetic Energy gain in joule		Kinetic Energy gain in joule		Kinetic Energy gain in joule	
			Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear	Top Gear	3rd Gear
1.	20-25	15	5.29	3.28	6.23	4.37	7.46	4.74	7.57	6.38
2.	25-30	15	6.58	3.12	6.13	4.21	5.52	2.23	5.57	3.32
3.	30-35	15	7.22	3.87	6.86	3.46	6.23	2.38	6.58	3.23
4.	40-45	15	5.38	3.42	5.57	3.30	7.12	2.88	6.94	3.74

Table 4: Comparison of K.E between Elliptical Sprocket & Quick Return Ratio for age (Elliptical Sprocket)

V. Conclusion

1) Due to ever increasing energy crises the use of human energized machines are increasing day by day.
2) The numbers of advantages are associated with this such as unavailability of power specially in rural side of India, less skilled operators, unemployment, bicycle exercising etc. Hence human power machines seem to have great future ahead.
3) In this paper the human powered flywheel motor with Quick return ratio as well as elliptical sprocket mechanism is proposed as well as the readings of kinetic energy developed for limited period, weight wise and age wise, are tabulated.
4) In this paper the human powered flywheel motor with Quick return ratio for weight wise maximum K.E. is 12.15 & age wise maximum K.E. is 7.57 and elliptical sprocket for weight wise maximum K.E. is 8.45 & age wise maximum K.E. is 7.22.
5) Quick return ratio one is always more than the elliptical sprocket.

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