ISSN: 0974-5823 Vol. 7 No. 4 April, 2022

International Journal of Mechanical Engineering

Formulation of Mathematical Model using Dimensional Analysis Approach for Tandum Drive Human Powered Flywheel Motor (HPFM)

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Abstract

The development in existing bicycles with some modification in cranking system, speed increasing gear pair and flywheel to store the pedaling energy form the novel system known as HPFM. This HPFM has wide applications. Leg muscles are stronger than arm muscles and hence bicycle drive mechanisms are generally preferred. The energy of the human leg powered bicycle is converted into electricity. This centerare used to operate mechanical systems. [1]. Idea developed by Modak et al. [2, 3] known as Human Powered Flywheel Motor (HPFM). The present work deals to establish precise dimensionless equations for four parameters i.e. Human Energy , Effectivenness of mechanism, Gear ratio, and mass moment of inertia of flywheel using the Buckingham pi-theorem technique for tandum drive human powered motor(HPFM). The independent and dependent variables have been identified to form the experimental data-basedmodel equations for the above-mentioned response variables. These equations will further help to understand the phenomenon of tandum drive HPFM in the rural sector and they will also help in developing the capacity of the machine according to the various requirements.

Keywords: Human Power, Pedal Power, Flywheel Motor, Novel Gearbox, Mathematical Modeling, Buckingham's π theorem, HPFM.

1. Introduction

Formulation of mathematical model using dimensional equation is the planning process of a research study to accomplish specific objectives, and it is used to develop an experimental data based model for a tandom drive human driven flywheel motor. In order to meet the research objectives clearly and quickly with the relevant sort of data and adequate sample size, proper experiment planning is essential. The performance of tandum drive HPFM is influenced by a number of factors.

1.1. Experimental Setup

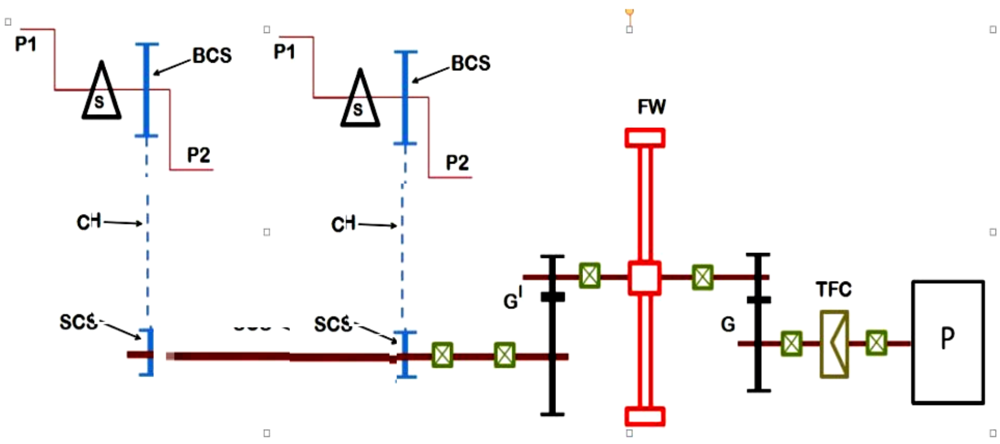

Fig 1: HPFM Tandum Drive [3]

S = Seat,P1, P2 = Pedals, BCS = Big Chain Sprocket, SCS = Small Chain Sprocket,CH = Bicycle Chain Drive, GI = Speed increasing gear pair, FW = Flywheel, TFC/SJC = Torsionally Flexible Clutch / Spiral Jaw Clutch,P = Process Unit, G = Torque Amplification Gear pair

This novel machine system comprises of three subsystem viz

(1) Energy unit

(2) Transmission

(3) Process machine.

The Schematics of the system is shown in Fig 1. Energy unit: This comprises a bicycle like pedaling system, speed increasing gear pair G' and flywheel FW. Transmission comprises TFC (the torsionally flexible Clutch) and the torque amplification gear pair G and (3) the process unit.

Working:

Step 1: A young boy (20-25 years), slim stature, middle height peddles the bicycle like system for 1 minute and speeds up the flywheel FW to the speed of 500-1000 rpm. The FW is 0.8m Rim diameter X 10cm rim width X 2cm rim thickness, The energy stored in the flywheel is 3500-4000kgf-m.

Step 2: Upon FW reaching the rated speed TFC is engaged and the energy stored in the FW is made available to the process unit P. The energy stored in the FW is exhausted in 5 to 15 seconds depending on the process unit.

1.2. Operation Principle of Setup

1.3.

In the entire work done so far only one peddler is tried. As the system is introducing a new employment guarantee scheme with energy application or new process unit, it is worthwhile trying more than one peddler either two (i.e. tandum drive)schematically as shown in Fig.1 or three or even four. This innovation of the Energy unit may store more than 3000-4000 kgf-m energy in the flywheel[1,2,3,4,6,12,16 to 25,26 to 40].

Fig 2: Experimental Setup-HPFM Tandum Drive

This enhancement of stored energy in the flywheel during the same peddling time i.e.60 seconds or 1 minute may prove to be worth for energizing other process units manufacturing other rural/village/interior based products/processes which are otherwise beingenergized by other conventional prime movers either electric Motor /Engine/Air motors etc. in the h.p.range 8 to 24 hp.

- To enhance the power range of so far developed HPFM energized process Machines[1-40]*
- To establish an expression for ωT.
- To establish an expression for maximum stored energy in the flywheel.
- To establish an expression for maximum efficiency of the system

2. Mathematical Model

1.4. Dimensional Analysis

Dimensional analysis is a useful mathematics tool for reducing variables by creating non-dimensional sets of variables known as pi (π) terms. The number of independent terms in an experiment is reduced when the dimensional equation for a phenomenon is deduced.The intended model is the exact mathematical form of this dimensional problem. As a result, this dimensional analysis method allows for more systematic experimental planning and the presenting of results in a more informative and simple manner.

1.5. Variables Identification

The term "variables" is used in a broad sense to refer to any physical quantity that changes. It is an independent variable if physical quantities may be modified independently of other physical quantities. The term "dependent" or "responsive variable" refers to a physical quantity that changes in reaction to the modification of one or more independent factors.An extraneous variable is a physical quantity that impacts our test and changes in a random and uncontrolled manner.The different dependent or response variables, independent variables, and extraneous variables affecting the phenomena are determined based on the functioning condition of the tandum drive HPFM.

In addition, data purification is carried out to reduce the effect of extraneous variables on the phenomena in order to avoid their unfavourable impact.

Table 1 shows Tandum Drive HPFM Various Dependent and Independent Variables

Variables	**Unit**	**MLT**
ω Angular velocity of the flywheel in rad/sec reached after time interval T seconds	rad /s	T^{-1}
G = Gear Ratio	---	$M^0L^0T^0$
I Mass moment of inertia of the flywheel	Kg-m2	ML^2
R Input energy by the rider,	Kgf-m	ML^2T^{-2}
T peddling time, in seconds	Seconds	T
EM effectiveness of the mechanism, M	--	$M^0L^0T^0$
Acceleration due to gravity ,g	m/s2	LT^{-2}

1.6. Buckingham's π - Theorem is used to reduce Pi terms.

The pi (π) terms for all dependent/response and independent factors impacting the phenomenon of tandem drive human powered flywheel motor are formed using Buckingham's π - Theorem approach.

.The dimensional equation would be obtained as under.

ω = f [I, R, T, g, G,EM] Eq. (1)

R=R1+R2,

R1: Energy Input by One Rider.

R2:Energy Input By Other Rider.

2. Formations of pi (π) Terms for All Dependent and Independent Variables

Buckingham's p Theorem method is applied to execute the dimensionless analysis for tandum drive HPFM machine system [19–46]. Table 1 above presents the various identified independent and dependent variables. In total, seven variables have been identified [24–49]. The Angular velocity of the flywheel is the dependent variables of the tandum drive HPFM. The dimensionless equation for these mentioned dependent variables have to be formed using Buckingham's π Theorem approach which is as follows:-

Total no. of independent variables = n = 7

Total no. of repeating variables = m = 4

Total no. of pi terms = n – m = 7-4 = 3

3. Formation of Pi-Terms for Independent Variables

Buckingham's p Theorem approach employed here uses basic physical quantities of Mass as {M} in kilogram as {Kg}, Length {L}in meter as {m} and, Time {T} in seconds as{S} to represent all the independent and dependent variables. All the equations formed below have been formulated on this principle

3.1 First π term

$$\pi 1 = (I)^{x_1} (R)^{Y_1} (T)^{Z_1} \quad \text{Eq. (2)}$$

$$[M^0L^0T^0] = \left[ML^2\right]^{X_1} [ML^2T^2]^{Y_1} [T]^{Z_1}$$

The obtained values for x1, y1 and z1 are quantified by equating the powers of Mass, Length & Time on both sides as represented below:

The values of X_1, Y_1 and Z_1 are quantified by equating the powers of M, L & T on both sides as given below:

For 'M'M $\rightarrow 0 = X_1 + Y_1$

For 'L' L $\rightarrow 0 = 2X_1 + 2Y_1$

For 'T' T $\rightarrow 0 = 2Y_1 + Z_1$

The results obtained for the indices X_1, Y_1 and Z_1 are subs. in Eq. (2) of π **1** term, The final Eq. will be:

$$\pi 1 = \left[\frac{I}{R^2T}\right]$$

3.2 Second π term

$$\pi 2 = (EM)^{x_1} \quad \text{Eq.(3)}$$

$$[M^0L^0T^0] = \left[M^0L^0T^0\right]^{X_1}$$

The obtained values for x1, y1 and z1 are quantified by equating the powers of Mass, Length & Time on both sides as represented below:

The values of X_1, Y_1 and Z_1 are quantified by equating the powers of M, L & T on both sides as given below:

For 'M' M $\rightarrow$ 0 = X_1

The results obtained for the indices X_1, Y_1 and Z_1 are subs. in Eq. (3) of π 2term, The final Eq. will be:

$$\pi 2 = [EM]$$

3.3 Third π term

$$\pi 3 = (GR)^{x_1} \qquad \text{Eq. (4)}$$

$$[M^0 L^0 T^0] = [M^0 L^0 T^0]^{X_1}$$

The obtained values for x1, y1 and z1 are quantified by equating the powers of Mass, Length & Time on both sides as represented below:

The values of X_1, Y_1 and Z_1 are quantified by equating the powers of M, L & T on both sides as given below:

For 'M' M $\rightarrow$ 0 = X_1

The results obtained for the indices X_1, Y_1 and Z_1 are subs. in Eq. (4) of π 3term, The final Eq. will be:

$$\pi 3 = [G]$$

3.4 Formation of pi (π) terms for dependent variables

Similarly, the dimensional analysis for dependent variables is performed by applying again the Buckingham's π - Theorem.

$$\pi 0 = (\omega)^{X_{d1}} (T)^{Y_{d1}} \qquad \text{Eq. (5)}$$

$$[M^0 L^0 T^0] = [T^{-1}]^{X_{d1}} [T]^{Y_{d1}}$$

The obtained values for x1, y1 and z1 are quantified by equating the powers of Mass, Length & Time on both sides as represented below:

The values of X_{d1}, Y_{d1} are quantified by equating the powers of M, L & T on both sides as given below:

For 'T' T $\rightarrow$ 0 = - $X_{d1} + Y_{d1}$

The results obtained for the indices X_1, Y_1 and Z_1 are subs. in Eq. (5) of π 0term, The final Eq. will be:

$$\pi 0 = [\omega T]$$

Hence Eq.1 can be rewrite as

$$\omega T = f\left[\left(\frac{I}{R^2 T}\right), (EM), (G)\right] \qquad \text{Eq.(6)}$$

In general it can be stated as under

$$\pi(0) = f[(\pi 1), (\pi 2), (\pi 3)] \qquad \text{Eq.(7)}$$

In equation (7),

$$\pi 1 = \left[\frac{I}{R^2 T}\right], \pi 2 = [EM], \pi 3 = [G] \text{ and } \pi 0 = [\omega T]$$

where ω Angular velocity of the flywheel in rad/sec reached after time interval T seconds

The exponential form of dimensional from eq 1. $\omega T = k\left[\left(\frac{I}{R^2 T}\right)^a, (EM)^b, (G)^c\right]$ Eq.(8)

Where K stands for a curve-fitting constant, and a, b, c stand for constant exponent.. The effects for these factors are found by means of multiple regression analysis and a suitable computer platform

Hence, by applying Buckingham's π Theorem method the selected independent and dependent variables have been converted into dimensionless equations which after experimentation values will be further deduced into a regression model and will help in understanding the tandum drive HPFM for developing its capacity for various requirements.

4. Results and Discussion

Thus, the dimensional equations are established in a reduced or compact mode in order to shorten the time required for the entire experimental procedure by generating optimal data.Experimental data will be collected in order to develop a mathematical model.Experiments with a predetermined test envelope, test points, and experimentation plan will be used to generate the experimental data.Regression analysis will be used to formulate the mathematical model's indices. Sensitivity analysis, determination of limiting values, optimization, reliability, and AI techniques will be used to construct an ANN model and reduce inaccuracy between experimental and mathematical data .

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