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Research Paper :

Application of pedal operated flywheel motor as an energy source for fodder chopper

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ABSTRACT

The Pedal Operated Energized Flywheel Motor has been adopted for many design of rural applications in the last two decades, establishing functional feasibility and economic viability of Pedal powered process machines of 3 to 7h.p capacity .In recent past a pedal powered process machines has been developed for wood turning (Modak and Bapat, 1993), washing (Dhakate, 1995), brick making (Modak and Moghe, 1998). The functional feasibility and viability of this application is established in this paper. The paper presents experimental work executed for establishing generalized empirical model for fodder-cutting operation. This also includes design and development of a machine .Estimation of mathematical model and its optimization.

Key words : Pedal operated energized flywheel motor, Spiral jaw clutch, Fodder clutch

The main objective to design and develop a machine, which uses the Pedal, operated energized flywheel motor as an energy source, consisting of a bicycle mechanism, use of non-conventional energy as source. Developing countries like India are facing problems of Power storage due to rapid industrialization. Non availability of power in Interior areas and large scale unemployment of semi-skilled worker. In the context of the present condition in India of Power shortage and exhaustion of coal reserves and unemployment, it is felt that "Pedal Operated Energized Fodder Chopping machine" for cutting fodder is very necessary. This machine is environment friendly *i.e.* non-pollutant. It will bring innovation and mechanization in agricultural engineering. Unskilled women may also get employment. Development of such energy source which has tremendous utility in energizing many rural based process machines in places where reliability of availability of electric energy is much low.

METHODOLOGY

The average work rate of a man working continuously is equivalent to 75W (Alexandrove, 1981). Therefore, only continuous manufacturing process requiring less than 75W can be man powered. Any manufacturing process requiring more than 75W and which can be operated intermittently without affecting end product can also be man powered. Such man powered manufacturing process can be based on the following concept.

In this processes a flywheel is used as a source of power. Manpower is used to energize the flywheel at an energy input rate, which is convenient for a man. After maximum possible energy is stored in flywheel it is supplied through suitable clutch (Gupta, 1997) and gearing system to a shaft, which operates the process unit. The flywheel will decelerate at a rate dependent on load torque. Larger the resisting torque larger will be the deceleration. Thus theoretical a load torque of even infinite magnitude could be overturn by this man-flywheel system. Pedal driven fodder chopper operates on the basis of above principle. If such machine is developed it will be great help to farmers of rural area because it does not need conventional energy. It is environment friendly machine.

Working of machine:

Working of manually energized chaff cutter machine as shown in Fig.1 and 2, the rider inputs mechanical energy during one minute pedaling time. Each rider accelerates the flywheel for about one minute. The flywheel is accelerated to the speed of 600 rpm in minute time. The flywheel size of 1 m rim diameter, 10cm rim width and 2 cm rim thickness such a flywheel when energized to the speed of 600 rpm stores energy. In this machine, first energy is stored in the flywheel by accelerating it to a desired speed by pedal through chain and gear drive. When flywheel attains desired speed, it is connected to the torque amplification gear by engaging a spiral two jaw clutch. The energy then stored in flywheel is supplied at the required rate to shaft of the chaff cutter and cutting of fodder, to obtain small pieces of fodder. A free wheel is used between pedals and the flywheel to prevent the back flow of energy from flywheel to pedals. A special jaw clutch is used in this machine in place of conventional friction clutch. A manually driven type fodder cutter machine is being developed in absence of any design data.

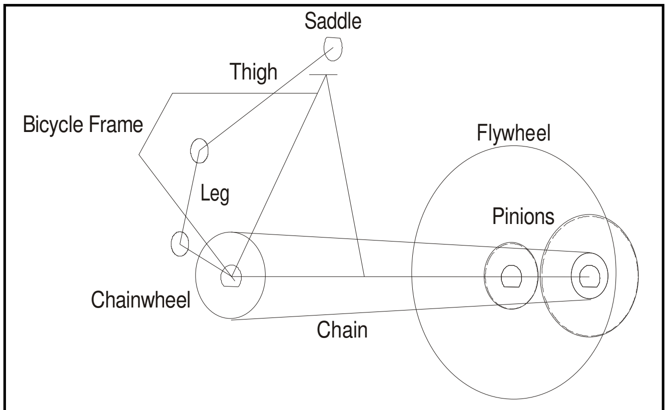

Fig. 1 : Energy unit and the transmission system

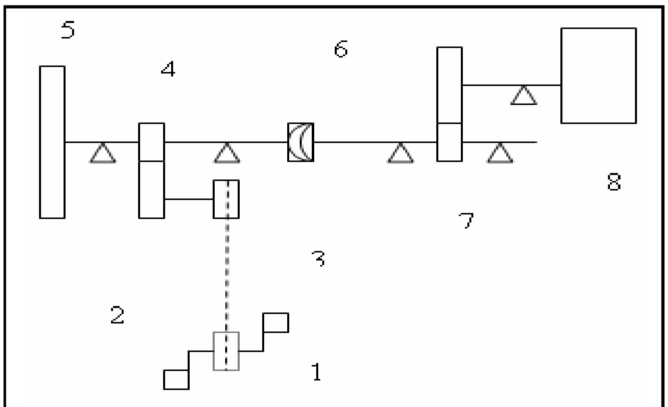

Fig. 2 : Schematics of pedal powered energized fodder chopper [1] Sproket and pedal ,[2] Chain, [3] Freewheel, [4] Speed rise gear , [5] Flywheel ,[6] Spiral Jaw Clutch, [7] Torque rise gear , [8] Process Unit

Design of experimentation :

Generalized experimental models for resistive torque, number of cuts, and Process time are established by adopting methodology of experimentation (Schenck, 2005). It is planned to generate design data by performing extensive experimentation by varying physical quantities encountered in the process of chopping over the widest range. The planning of experimentation is carried out by using the classical plan of experimentation (Schenck, 2005). The response data collected was based on this entire generalized models formed.

The methodology of experimentation is briefly stated as under:

– Identification of all independent, dependent and extraneous variables.

– Reduction of variables through dimensional analysis.

– Determination of Test Envelopes, Test points and Test sequence.

– Design of an experimental setup.

– Execution of experimentation to generate the experimental data.

– Purification of an experimental data.

– Formulation of the mathematical model of the dimensional Equation.

– Artificial Neural Network Simulation.

Dimensional analysis:

The process variables for manually energized fodder chopper were identified and were tabulated in Table 1. Dimensional analysis was carried out to established dimensional equations, exhibiting relationships between dependent π terms and independent π terms using Buckingham π theorem.

M, L and T are the symbols for mass, length and time, respectively.

Dimensional analysis can be used primarily as experimental tool to combine many experimental variables into one. The main purpose of this technique of is making experimentation shorter without the loss of control.

Applying Raleigh's method the dimensional equation for resistive torque, number of cuts, process time are formulated.

Resistive torque:

$Tc = f[(d/D), n, (D^4/gI)E, (W_b/D), (t_b/D), \alpha, (\sqrt{(D/g)}\,\omega), G] \sqrt{(g/D)}\, t_c]$ $(D/gI)\, Te = f[(dW_b\, t_b/D^3), (D^4/gI)E, \alpha, G, n, (\sqrt{(D/g)}\,\omega) \sqrt{(g/D)}\, t_c]$ (1)

Number of cuts :

$C = f[(dW_b\, t_b/D^3), (D^4/gI)E, \alpha, G, n, (\sqrt{(D/g)}\,\omega)] \sqrt{(g/D)}\, t_c]$ $v(D/g)\, Cp = f[(dW_b\, t_b/D^3), (D^4/gI)E, \alpha, G, n, (\sqrt{(D/g)}\,\omega)] \sqrt{(g/D)}t_c]$ (2)

Process time for cutting (t_p) :

$t_p = f[(dW_b\, t_b/D^3), (D^4/gI)E, (\sqrt{(D/g)}\,\omega), G, \alpha, n]$

$v(g/D)\, t_p = f[(dW_b\, t_b/D^3), (D^4/gI)E, (\sqrt{(D/g)}\,\omega), G, \alpha, n] \sqrt{(g/D)}\, t_c]$ (3)

In equations 1, 2and 3, f stands for "function of".

Formulation of experimental data based models:

A probable exact mathematical form for the dimensional equations could be represented by solving

Table 1 : The process variables, their symbols and dimensions

Sr. No.	Description	Types of variable	Symbol	Dimensions
1.	Tip diameter of blade	Independent	D	L
2.	Hub diameter	Independent	d	L
3.	Acceleration due to gravity	Independent	g	LT^{-2}
4.	No. of blades	Independent	n	-
5.	Young modulus of elasticity of cutting blade	Independent	E	$ML^{-2}L^{-1}$
6.	Width of cutting blade	Independent	W_b	L
7.	Thickness of cutting blade	Independent	t_b	L
8.	Cutting blade angle	Independent	α	-
9.	Equivalent moment of inertia of flywheel	Independent	I	ML^2
10.	Angular velocity of flywheel	Independent	ω	T^{-1}
11.	Gear ratio	Independent	G	-
12.	Sp time instant during cutting operation	Independent	t_c	T
13.	Kinetic Energy of flywheel	Independent	e	ML^2T^{-2}
14.	Instantaneous torque on cutting blade	Dependent	Tc	ML^2T^{-2}
15.	No. of cuts during cutting	Dependent	Cp	-
16.	Process time for cutting chaff	Dependent	t_p	T

this problem by curve fitting technique [Spiegel,1998].

An approximate generalized experimental data based model for the pedal operated energized fodder cutting machine system had been established for responses of the system such as Instantaneous Resistive Torque (p_{D1}), Number of Cuts (p_{D2}) and Process Time (p_{D3}).

Model for dependent term Instantaneous Resistive torque: π_{D1}

The models are :

$$\frac{D}{gI}T_c = 1.645 \times 10^3 (\pi_1)^{3.8074} (\pi_2)^{0.5141} (\pi_3)^{-0.4521} (\pi_4)^{1.686} (p_5)^{2.3237} (\pi_6)^{0.8162} (\pi_7)^{-0.4189} (\pi_8)^{-0.3840} \quad (4)$$

Model for dependent term number of cut (C)π_{D2} :

$$\pi_{D2} = 0.6449 (\pi_1)^{-0.0001} (\pi_2)^{-0.0146} (\pi_3)^{0.3471} (\pi_4)^{-1.0151} (\pi_5)^{0.2781} (\pi_6)^{0.1233} (\pi_7)^{0.9701} (\pi_8)^{0.4773} \quad (5)$$

Model for the dependent term process time, π_{D3}:

$$\pi_{D3} = 43.43 (\pi_1)^{0.0001} (\pi_2)^{-0.1753} (\pi_3)^{-0.0012} (\pi_4)^{-0.0001} (\pi_5)^{-0.0505} (\pi_6)^{-0.2508} (\pi_7)^{1.0008} (\pi_8)^{-0.0004} \quad (6)$$

respectively.

Computation of the predicted values by (A.N.N):

One of the main issues in research is prediction of future results. The experimental data based modeling was achieved through mathematical models for the three dependent pi terms Instantaneous Resistive Torque (π_{D1}), Number of Cuts (π_{D2}) and Process Time (π_{D3}). In such complex phenomenon involving non-linear systems it was planned to develop artificial neural network (ANN). The output of this network was evaluated by comparing it with observed data and the data calculated from the mathematical models. For development of ANN the designer had to recognize the inherent patterns. Once accomplished, training the network was mostly a fine-tuning process. An ANN consisted of three layers of nodes the input layer, the hidden layer or layers (representing the synapses) and the output layer. Nodes were used to represent the brains neurons and these layers were connected to each other in layers of processing. The specific mapping performed by ANN depended on its architecture and values of synaptic weights between the neurons. ANN, as such was highly distributed representation and transformation, that was operated in parallel and had distributed control through many highly interconnected nodes. ANN was developed utilizing this black box concepts. Just as human brain learn with repetition of similar stimuli, an ANN trains itself within historical pair of input and output data usually operating without a prior theory that guided or restricted a relationship between the inputs and outputs. The ultimate accuracy of the predicted output, rather than the description of the specific path(s) or relationship(s) between the input and output, was the goal of the model. The input data passed through the nodes of the hidden layer(s) to the output layer, a non linear transfer function assigned weights to the information as it passed through the hidden layer nodes; mimicking the transformation of information as it passes through the brains synapses. The role of ANN model was to develop a response by assigning the weights in such a way that it represented the true relationship that really existed between the input as and output. During training, the ANN effectively interpolated a function between the input and output neurons. ANN did not build an explicit description of the function. The prototypical use of ANN is in structural pattern recognition. In such a task, a collection of features was presented to the ANN and it was able to categorize the input feature pattern as belonging to one or more classes. In such cases the network was presented with all relevant information simultaneously.

A procedure for model formulation in ANN:

Different software / tools were developed to construct ANN. MATLAB being internationally accepted tool; had been selected for developing ANN for the complex phenomenon. The various steps followed in developing the algorithm to form ANN are as under

– The observed data from the experimentation was separated into two parts *viz.* input data or the data of independent pi terms and the output data or the data of dependent pi terms. The input data and output data were stored in test.txt and target.txt files, respectively.

– The input and output data was then read by the using the DLMREAD function.

– In preprocessing step the input and output data was normalized.

– Through principle component analysis the normalized data was uncorrelated. This was achieved by using prepca function. The input and output data is then categorized in three categories *viz.,* testing, validation and training. The common practice was to select initial 75% data for testing, last 75% data for validation and middle overlapping 50% data for training. This was achieved by developing a proper code.

– The data was then stored in structures for testing validation and training.

– Looking at the pattern of the data feed-forward back-propagation type neural network was chosen.

– This network was then trained using the training data. The computation errors in the actual and target data were computed. Then, the network was simulated as shown in Fig. 3, 4 and 5. The error in the target (T) and the actual data (A) are represented in graphical form.

– The uncorrelated output data was again transformed onto the original form by using posted function.

– The regression analysis and the representation was

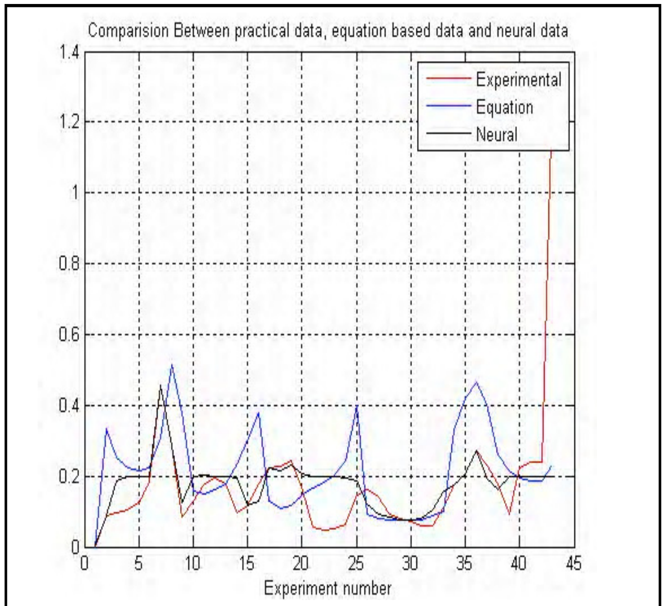

Fig. 3 : Comparison of experimental and computed data by A.N.N (π_{D1})

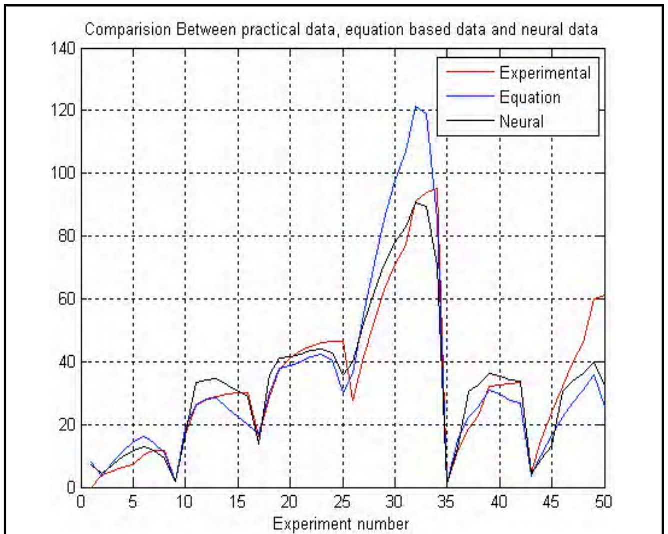

Fig. 4 : Comparison of experimental and computed data by A.N.N (π_{D2})

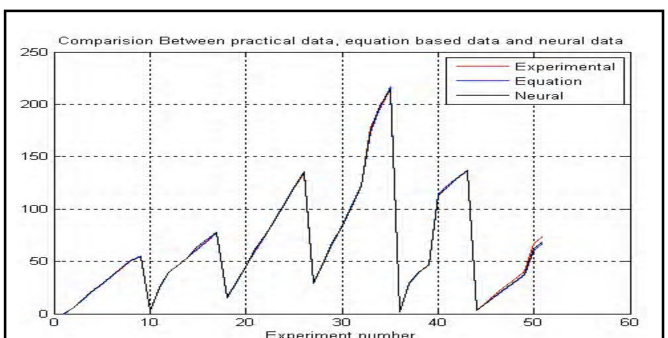

Fig. 5 : Comparison of experimental and computed data by A.N.N (π_{D3})

done through the standard functions.

The values of regression coefficient and the equation of regression lines are represented on the three different graphs (Fig. 5, 6 and 7)

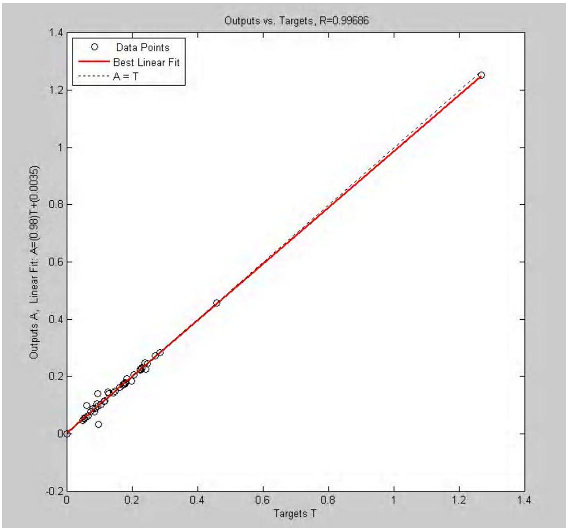

Fig. 6 : Comparison of experimental and computed data by A.N.N (π_{D1})

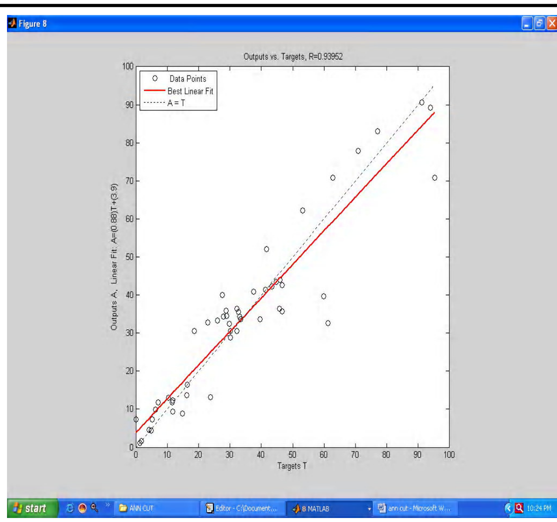

Fig. 7 : Comparison of experimental and computed data by A.N.N (π_{D2})

The values of regression coefficient and the equation of regression lines are represented by Fig. 6, 7 and 8 for the three dependent pi terms *viz.,* Instantaneous Resistive Torque (π_{D1}), Number of Cuts (π_{D2}) and Process Time (π_{D3}).

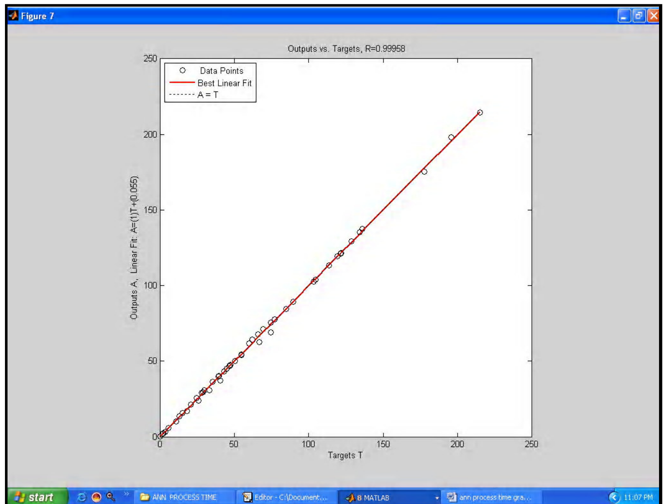

Fig. 8 : Comparison of experimental and computed data by A.N.N (π_{D3})

Table 2 : Comparison between observed and computed values of dependent Pi term

Dependent Pi terms	π_{D_1}	π_{D2}	π_{D3}
Experimental	0.1773	33.588	63.276
A.N.N	0.1866	32.965	63.337
Empirical	0.2155	34.069	63.042
Standard error of estimation	0.026	3.39	0.639

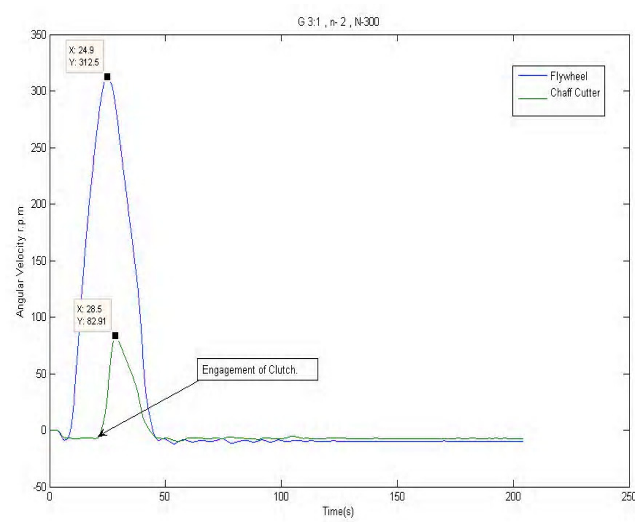

Fig. 9 : Speed plot of flywheel and cutter for independent variable G -3:1,n-2,N-300

RESULTS AND DISCUSSION

Empirical models to predict the performance of the Pedal Operated Energized fodder cutting machine to cut fodder was established and optimum values of various parameters were arrived on the basis of experiments involve in the Pedal Operated energized fodder cutting system.

A new theory of cutting the fodder from the Pedal Operated energized fodder cutting machine was proposed. This hypothesis states that on engagement of the clutch, the speed of flywheel suddenly falls indicating energy loss. A part of this energy loss was subjected to decline because of the load torque acting on the blades due to persistent presence of cutting action.

It was further hypothesized that the cutting time was function of available energy for cutting, resisting torque and average angular speed of the fodder chopper shaft, the proposed fly wheel motor could be used as an energy source for process unit that was operated with its input element in a transient state of motion.

This flywheel motor was applied to brick making, low head water pumping and wood turning. The performance was found to be functionally satisfactory and economically viable. The flywheel motor could be used as an energy source for process unit that need have continuous operation and had an upper limit of about 3 hp.

The mathematical models and an ANN developed phenomenon, truly represented the degree of interaction of various independent variables that's made possible approach adopted in this investigation.

The standard error estimated of the predicted / computed values of the dependent variable wafound to be very low. This gave authenticity to the developed mathematical models and an ANN.

The trends for the behavior of the models demonstrated by graphical analysis, sensitivity analysis were found complementary to each other. These trends were found to be truly justified through some possible physics of phenomenon.

Innovation in the machine would bring mechanization in Agricultural Engineering. The rural population including unemployed and unskilled women in addition to male and may also get employment. Development of such energy sources which had tremendous utility in energizing many rural based process machines in places where availability of electric energy is very low.

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