Formulation of experimental data based model for oil press using human powered flywheel motor as energy source

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Abstract: Human powered oil press extracts oil from oilseeds. The extracted oil can be used for eating purpose or even in laboratories where one can take different tests on the oil. A machine was fabricated which will perform this pressing operation not by electric power but by human power. It is seen that human power is sufficient enough to be converted into work. The evolution of oil press by using human power is a complex phenomenon. There are many factors affecting the performance of oil press. To study man-machine interaction and human fatigue in various agricultural tasks, AICRP on HESA (All India Coordinated Research Project on “Human Engineering and Safety in Agriculture”) (1996) started by Indian Council of Agricultural Research, used experimental approach. As a result of the continuous variation of speed of the process unit input shaft, understanding of the phenomenon of execution of the process cannot be logic based. Hence it is necessary to adopt application of Methodology of Experimentation to such a process for formulating experimental data based model. Hence Theory of Experimentation, provided by H. Schenck Jr. was applied. In this paper, an approximate generalized data based model for such a human powered oil press is developed by varying independent parameters during the experimentation. Subsequently the optimization of the model was established. Thus the results of this experimental research would be useful to farmers or small scale entrepreneurs in the rural area, where there is 10 to 12 hours load sheding of electricity, especially in rural Maharashtra (India). This technology will not only improve the socioeconomic condition of the rural population, but also reduce the gap between supply and demand of edible oils.

Keywords: Human powered flywheel motor, energy, oilseed, oil press, dependent variables, and independent variables

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1 Introduction

Modak and some other engineers developed human powered process machines which energized process units needing 3 to 7 kW and which have intermittent operation.

This machine system comprised of three subsystems; energy unit, mechanical power transmission system and process unit. Energy unit comprised of an arrangement similar to a bicycle, a speed raising gear pair and a flywheel. The flywheel size is 1m diameter, 10 cm width and 2 cm thickness. The flywheel is with 6 armed constructions and each arm is with elliptical cross section. Mechanical transmission comprises of spiral jaw clutch and torque amplification gear pair. The process units used are for brick making, wood turning, Algae formation machine, wood strips cutter and Smiths hammer and electricity generation.

A young operator with a slim stature and 165cm height sped up crusher flywheel to 700 to 800 r/min in a minute. Then pedaling was stopped and clutch was engaged connecting this human powered flywheel through torque amplification gears to a process unit. The stored energy in the flywheel around 28000 joules exhausted within 10 s to 20 s in operating a process unit depending on its process resistance. Recently Modak

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(2001) has proposed the concept which gave an idea about when to use human powered flywheel as an energy source or on load operation of the process unit depending on the operating characteristic of the process unit. In view of this, oil press by using human powered flywheel motor as an energy source was developed. Its approximate generalized experimental data based model was built. This model was evolved applying methodology of experimentation proposed by H. Schanck Jr. (1961).

1.1 Scope of present research

Design data was established for low to medium capacity oil press energized by human powered flywheel motor. With the help of the design data, the specific unit for a low to medium capacity press was designed. The utility of such a press is for a small scale farmer and low profile entrepreneur. Thus, the result of this research is partly useful as an aid to a low/ medium capacity farmer for production of edible oil. The residual cake left after oil extraction can be used as a raw material for livestock feed manufacturing. The machine is also useful for the low-income entrepreneur in the vegetable oil extraction industry. As the work is ultimately useful to the small scale farmer in present context where there are many suicide cases committed by farmers in India. The result of the research would be useful in minimizing the severity of this socio economic problem. Low profile farmers will be benefit from the proposed machine. Other similar systems will be needed by a large number of low profile farmers who may need such oil press but with different capacities remaining within the same concept of human powered oil press in future and can be adopted for various agricultural operations. This will add to enhancement of technology for low profile farmers in view of human powered mechanization of agricultural operation.

2 Theoretical considerations

2.1 Need for formulating generalized experimental data based model

In view of foregoing, it is obvious that people have to decide what the minimum human energy to be supplied to the system for getting appropriate oil seed pressing with minimum load torque. This would be possible if we have a quantitative relationship among various dependent and independent systems. This relationship would be known as the mathematical model of this man-machine system. It is well known that such a model for the man-machine system cannot be formulated by applying logic [14]. The only option with which one is left is to formulate an experimental data based model [14]. Hence, in this investigation it was decided to formulate such an experimental data based (empirical) model. In this approach, all the independent variables were varied over a widest possible range, a response data was collected and an analytical relationship was established. Once such a relationship was established, the technique of optimization could be applied to deduce the values of independent variables at which the necessary responses could be minimized or maximized. In fact, determination of such values of independent variables is always the puzzle for the operator because it is a complex phenomenon of interaction of various independent variables such as geometric parameters of the barrel and screw shaft (base diameter of screw shaft, maximum diameter of screw shaft, length of taper, diameter of barrel, pitch of helix) variable speed of the rotation of shaft, the amount of oil seed taken and the operator. The response variables would be time of pressing, instantaneous torque on the shaft, quantity of oil extracted.

It is well known that mathematical modeling of any man-machine system is possible by applying methodology of experimentation. The same is adopted in the present work.

2.2 Brief description of theory and experimentation application

The approach adopted for formulating generalized experimental model suggested by Hilbert Schenck Jr (1961) was indicated as follows:

1. Identification of independent, dependent and extraneous variables.

2. Reduction of independent variables adopting dimensional analysis

3. Test planning comprising of determination of test envelope, test points, test sequence and experimentation

plan.

4. Physical design of an experimental set-up.
5. Execution of experimentation
6. Purification of experimentation data
7. Formulation of model
8. Model optimization
9. Reliability of the model

The first six steps mentioned above constituted the design of experimentation. The seventh step constituted model formulation while eighth and ninth steps were respectively optimization and reliability of model. Independent, dependent variables were identified and mention in Table 1.

Table 1 Descriptions of dependent and independent variables

Sr. No.	Description of variables	Types of variables	Symbols	Dimensions
1	Base dia. of screw shaft	Independent	d_b	L
2	Max. dia. of screw shaft	Independent	d_m	L
3	Length of taper	Independent	L_t	L
4	Diameter of barrel	Independent	D	L
5	Speed of flywheel	Independent	ω	T^{-1}
6	Pitch of helix	Independent	P	L
7	Input energy to machine	Independent	E	ML^2T^{-2}
8	Acceleration due to gravity	Independent	g	LT^{-2}
9	Gear ratio of torque amplification	Independent	G	$M^0L^0T^0$
10	Crushing strength of material process	Independent	T_c	$ML^{-1}T^{-2}$
11	Average size of oil seed	Independent	S	L
12	Quantity of raw material admitted per cycle pressing	Independent	Q_R	M
13	Instantaneous time	Independent	t	T
14	Crushing strength of material of screw	Independent	T_s	$ML^{-1}T^{-2}$
15	Load torque	Dependent	T_{shaft}	ML^2T^{-2}
16	Quantity of oil extracted (oil yield)	Dependent	Q_o	M
17	Speed of screw shaft during the crushing process	Dependent	ω_r	T^{-1}

2.3 Determination of test points

The spacing of the test points within the test envelop was selected not for getting a symmetrical or a pleasing curve but to have on every part of the experimental curve map the same precision as every other part. Thus, the concept of proper spacing is now replaced by permissible spacing of the test points. Similarly, for all other π terms the test points were decided by permissible spacing rather than by the proper spacing.

2.4 Determination of test sequence

The choice of test sequence was decided by nature of experimentation viz reversible or irreversible. In fact, basically all the tests were irreversible in the sense that no piece of apparatus returns to an identical previous configuration after same use. But if the changes brought by testing were below the level of detection such tests could be assumed as reversible. The independent variables were varied from one extreme to another in a sequential plan or in a perfectly random fashion in a random plan. The sequential plan was essential for irreversible experiment or experiments where randomization was not practicable. In this test, like majority of engineering experiments partial randomized sequence was proposed.

Table 2 List of independent and dependent π Terms

Sr. No.	Description of π terms	Equation of π terms
Independent π Terms		
1	π terms relating to geometric variables of oil seed presser	$(\pi_1)=\frac{\omega^{10}}{g^5}(d_b,d_m,L_t,D,P)$
2	π terms relating to crushing strength of material to be process and material of screw	$\pi_2=\frac{T_c}{T_s}$
3	π terms relating to average size of oil seed	$\pi_3=\frac{\omega^2}{g}S$
4	π terms relating to initial energy given to the flywheel	$\pi_4=\frac{E\omega^2}{g^2}Q_R$
5	π terms relating to instantaneous time	$\pi_5=\omega t$
6	π terms relating to gear ratio	$\pi_6=[G]$
Dependent π Terms		
1	π terms relating to load torque	
2	π terms relating to quantity of oil extracted	$\pi_{02}=\frac{Q_0}{E}\frac{g^2}{\omega^2}$
3	π terms relating to speed of screw shaft during the crushing process	$\frac{\omega_r}{\omega}$

2.5 Experimental plan

Many discrete extraneous variables like different instruments and different geometric variables can be taken care of by the concept of randomized blocks like Latin square or Graeco Latin square, which were among the general family of factorial plans (Logothesis, 1997). For multifactor experiments two types of plans viz. classical plan or full factorial and factorial plan were available. In this experimentation, the classical plan of experimentation was recommended and given in Table 3,

Table 4 and Table 5. Here, the capital alphabet represents shaft with different geometric variables, numbers represents the gear ratio and the small alphabets represent input energy given to the flywheel

Oil seed presser shafts:- A, B, C, D, E, F, G, H, I

Input Energy given to the machine: -400(a), 500(b), 600(c)

Gear Ratio:- 1:2(2), 1:3(3), 1:4(4), 1:5(5), 1:6(6)

Table 3 Variation of geometric variables keeping other parameters constant

No.	For variation of geometric variables keeping other parameter constant								
→1	Aa2	Ba2	Ca2	Da2	Ea2	Fa2	Ga2	Ha2	Ia2
→2	Aa3	Ba3	Ca3	Da3	Ea3	Fa3	Ga3	Ha3	Ia3
→3	Aa4	Ba4	Ca4	Da4	Ea4	Fa4	Ga4	Ha4	Ia4
4	Aa5	Ba5	Ca5	Da5	Ea5	Fa5	Ga5	Ha5	Ia5
5	Aa6	Ba6	Ca6	Da6	Ea6	Fa6	Ga6	Ha6	Ia6
6	Ab2	Bb2	Cb2	Db2	Eb2	Fb2	Gb2	Hb2	Ib2
7	Ab3	Bb3	Cb3	Db3	Eb3	Fb3	Gb3	Hb3	Ib3
8	Ab4	Bb4	Cb4	Db4	Eb4	Fb4	Gb4	Hb4	Ib4
9	Ab5	Bb5	Cb5	Db5	Eb5	Fb5	Gb5	Hb5	Ib5
10	Ab6	Bb6	Cb6	Db6	Eb6	Fb6	Gb6	Hb6	Ib6
11	Ac2	Bc2	Cc2	Dc2	Ec2	Fc2	Gc2	Hc2	Ic2
12	Ac3	Bc3	Cc3	Dc3	Ec3	Fc3	Gc3	Hc3	Ic3
13	Ac4	Bc4	Cc4	Dc4	Ec4	Fc4	Gc4	Hc4	Ic4
14	Ac5	Bc5	Cc5	Dc5	Ec5	Fc5	Gc5	Hc5	Ic5
15	Ac6	Bc6	Cc6	Dc6	Ec6	Fc6	Gc6	Hc6	Ic6

Table 4 Variation of input energy keeping other parameters constant

No.	For variation of input energy keeping other parameter constant								
↓1	aA2	aB2	aC2	aD2	aE2	aF2	aG2	aH2	aI2
2	bA2	bB2	bC2	bD2	bE2	bF2	bG2	bH2	bI2
3	cA2	cB2	cC2	cD2	cE2	cF2	cG2	cH2	cI2
4	aA3	aB3	aC3	aD3	aE3	aF3	aG3	aH3	aI3
5	bA3	bB3	bC3	bD3	bE3	bF3	bG3	bH3	bI3
6	cA3	cB3	cC3	cD3	cE3	cF3	cG3	cH3	cI3
7	aA4	aB4	aC4	aD4	aE4	aF4	aG4	aH4	aI4
8	bA4	bB4	bC4	bD4	bE4	bF4	bG4	bH4	bI4
9	cA4	cB4	cC4	cD4	cE4	cF4	cG4	cH4	cI4
10	aA5	aB5	aC5	aD5	aE5	aF5	aG5	aH5	aI5
11	bA5	bB5	bC5	bD5	bE5	bF5	bG5	bH5	bI5
12	cA5	cB5	cC5	cD5	cE5	cF5	cG5	cH5	cI5
13	aA6	aB6	aC6	aD6	aE6	aF6	aG6	aH6	aI6
14	bA6	bB6	bC6	bD6	bE6	bF6	bG6	bH6	bI6
15	cA6	cB6	cC6	cD6	cE6	cF6	cG6	cH6	cI6

Table 5 Variation of gear ratio keeping other parameters constant

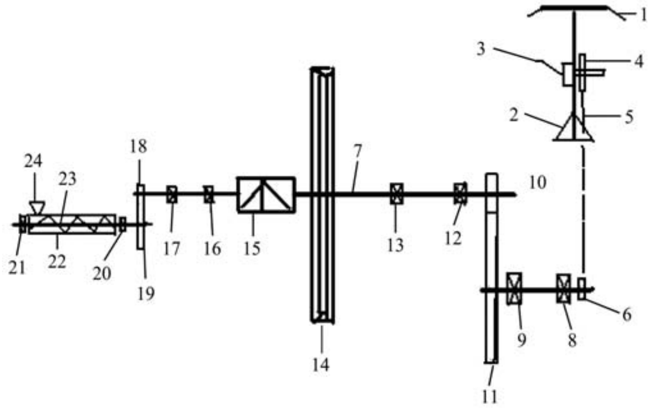
No.	For variation of gear ratio keeping other parameter constant								
↓1	2Aa	2Ba	2Ca	2Da	2Ea	2Fa	2Ga	2Ha	2Ia
2	3Aa	3Ba	3Ca	3Da	3Ea	3Fa	3Ga	3Ha	3Ia
3	4Aa	4Ba	4Ca	4Da	4Ea	4Fa	4Ga	4Ha	4Ia
4	5Aa	5Ba	5Ca	5Da	5Ea	5Fa	5Ga	5Ha	5Ia
5	6Aa	6Ba	6Ca	6Da	6Ea	6Fa	6Ga	6Ha	6Ia
6	2Ab	2Bb	2Cb	2Db	2Eb	2Fb	2Gb	2Hb	2Ib
7	3Ab	3Bb	3Cb	3Db	3Eb	3Fb	3Gb	3Hb	3Ib
8	4Ab	4Bb	4Cb	4Db	4Eb	4Fb	4Gb	4Hb	4Ib
9	5Ab	5Bb	5Cb	5Db	5Eb	5Fb	5Gb	5Hb	5Ib
10	6Ab	6Bb	6Cb	6Db	6Eb	6Fb	6Gb	6Hb	6Ib
11	2Ac	2Bc	2Cc	2Dc	2Ec	2Fc	2Gc	2Hc	2Ic
12	3Ac	3Bc	3Cc	3Dc	3Ec	3Fc	3Gc	3Hc	3Ic
13	4Ac	4Bc	4Cc	4Dc	4Ec	4Fc	4Gc	4Hc	4Ic
14	5Ac	5Bc	5Cc	5Dc	5Ec	5Fc	5Gc	5Hc	5Ic
15	6Ac	6Bc	6Cc	6Dc	6Ec	6Fc	6Gc	6Hc	6Ic

3 Materials and methods

3.1 Physical design of an experimental setup

It is necessary to evolve physical design of an experimental set up having provision of setting test points, adjusting test sequence, executing proposed experimental plan, provision for necessary instrumentation for noting down the responses and independent variables. From these provisions one can reduce the dependent and independent π-terms of the dimensional equation. The experimental set up was designed considering various physical aspects of its elements. For example if it involves a gear, then it has to be designed applying the procedure of the gear design. In this experimentation there was a scope for design as far as oil press is concerned more with the strength considerations. Actually, the oil press was designed from the consideration of the dimensions having influence on user's fatigue from ergonomic considerations. The other dimensions of the oil press were designed by using previous mechanical design experience and practice. Schematic arrangement of the machine was shown in Figure 1.

Experimental set up can be designed for the above stated criteria so that the general ranges can be set properly within the test envelope proposed in the experimental plan. The procedure of design of experimental set up however cannot be totally followed in the field experimentation. This is so because in the field experimentation, we are carrying out the experimentation using the available ranges of the various independent variables to assess the value of the dependent variable.



1. Handle 2. Seat for driver 3. Paddles 4. Sprocket wheel 5. Roller chain 6. Free wheel with smaller sprocket 7. Flywheel shaft 8. Bearing 9. Bearing 10. Gear 11. Pinion 12. Bearing 13. Bearing 14. Flywheel 15. Spiral clutch 16. Bearing 17. Bearing 18. Pinion 19. Gear 20. Bearing 21. Bearing 22. Barrel of oil seed presser 23. Wire wound presser shaft 24. Hopper

Figure 1 Schematic arrangement of the machine

3.2 Test Procedure

The experiment was conducted in 45 d. The oil press parameters selected as per the design of experimentation plan mentioned. Average size of oil seeds (peanuts) was measured. These oil seeds were poured through the hopper into oil press. The (human) input energy was given to the flywheel to reach its required speed. As the required speed was obtained the clutch was engaged to communicate from the shaft of the flywheel to the shaft of the process unit. As soon as the energy was transferred, the shaft of the oil press rotated and oil seed got pressed in between the tapered portion of the press shaft and inner surface of the barrel of the oil press. During this process the input and output speed, instantaneous speed and time for flywheel shaft and press shaft was measured and recorded through the computer. Recorded data was converted into the graph which helped to get instantaneous torque on the press shaft.

Figure 2 Oil press during the testing procedure

3.3 Analysis of the experimental data

During the experiment, 405 graphs were obtained, where different speeds and gear pairs were used. The numbers of observations in the tables were computed from the above graphs. Sample of the graph was shown below.

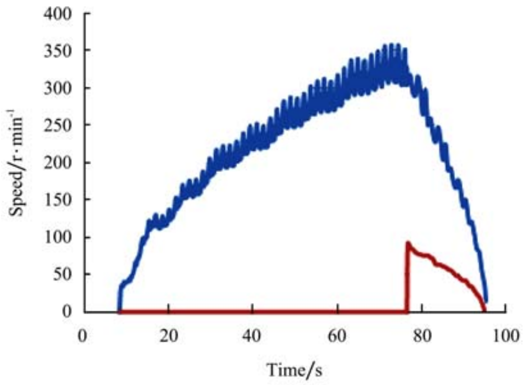


Figure 3 Curves of speed and time (shaft of H, Gear Ratio of 1:3, and speed of 300 r/min)

3.4 Development of experimental data based model

Six independent π terms (π_1, π_2, π_3, π_4, π_5 and π_6) and two dependent π terms (π_{01} and π_{02}) were identified in the design of experimentation. These π terms were available for the model formulation. Dependent π terms were assumed to be the function of the available independent π terms.

3.4.1 Development of model for dependent π terms (π_{01} and π_{02})

For the dependent π term (π_{01}),

$$\pi_{01} = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6) \quad (1)$$

A probable exact mathematical form for this phenomenon could be represented by

$$\pi_{01} = K_1 (\pi_1)^{a_1} (\pi_2)^{b_1} (\pi_3)^{c_1} (\pi_4)^{d_1} (\pi_5)^{e_1} (\pi_6)^{f_1} \quad (2)$$

$$\pi_{02} = K_2 (\pi_1)^{a_2} (\pi_2)^{b_2} (\pi_3)^{c_2} (\pi_4)^{d_2} (\pi_5)^{e_2} (\pi_6)^{f_2} \quad (3)$$

There were seven unknown terms in the Equation (2), including curve fitting constant K_1 and indices a_1, b_1, c_1, d_1, e_1 and f_1. To get these values of unknowns we need minimum seven sets of values of π_1, π_2, π_3, π_4, π_5 and

π_6.and π_{01} as per the experimental plan in design of experimentation we have 405 sets. If any arbitrary one set from this table is selected and the values of unknowns K_1, a_1, b_1, c_1, d_1, e_1 and f_1 were computed, then it may not result in one unique solution representing a best- fit unique curve for the remaining set of the values.

To be very specific we can find out ${}^{n}c_{r}$ combinations of r sets taken together out of the available n sets of the readings. The value of ${}^{n}c_{r}$ in this case will be ${}^{405}c_{7}$ solving these many sets and finding their solutions will be Herculean task. Hence, it was decided to solve this problem by curve fitting technique (Spiegel 1980). To follow this method it is necessary to have the equations in the form as shown below,

$$Z = a + bx + cy + dz \tag{4}$$

The Equation (2) can be brought in the form of Equation (4) by taking the log of both the sides. By taking the log of both the sides of equation one gets,

$$\lg \pi_{01} = \lg K_1 + a_1 \lg\pi_1 + b_1 \lg\pi_2 + c_1\lg\pi_3 + d_1\lg\pi_4 + e_1\lg\pi_5 + f_1 \lg\pi_6 \tag{5}$$

Let $\lg \pi_{01} = Z_1$, $\lg K_1 = k_1$, $\lg\pi_1 = A$, $\lg\pi_2 = B$, $\lg\pi_3 = C$, $\lg\pi_4 = D$, $\lg\pi_5 = E$, $\lg\pi_6 = F$

Then the Equation (5) can be written as

$$Z_1 = k_1 + a_1A + b_1B + c_1C + d_1D + e_1E + f_1F \tag{6}$$

Equation (6) was a regression equation of Z_1 on A, B, C, D, E and F. In an n-dimensional co-ordinate system this represents a regression hyper-plane. To determine the regression hyper-plane a_1, b_1, c_1, d_1, e_1 and f_1.are determined in Equation (6) so that

$$\Sigma Z_1 = n\, k_1' + A + b_1\Sigma B + c_1\Sigma C + d_1\Sigma D + e_1\Sigma E + f_1\Sigma F$$

$$\Sigma Z_1A = k_1'\Sigma A + a_1\Sigma A A + b_1\Sigma BA + c_1 \Sigma CA + d_1\Sigma DA + e_1\Sigma EA + f_1 \Sigma FA$$

$$\Sigma Z_1B = k_1' \Sigma B + a_1\Sigma A B + b_1\Sigma BB + c_1\Sigma CB + d_1\Sigma DB + e_1\Sigma E B + f_1 \Sigma FB$$

$$\Sigma Z_1C = k_1'\Sigma C + a_1\Sigma AC + b_1\Sigma BC + c_1\Sigma CC + d_1\Sigma DC + e_1\Sigma EC + f_1\Sigma FC$$

$$\Sigma Z_1D = k_1'\Sigma D + a_1\Sigma AD + b_1\Sigma BD + c_1\Sigma CD + d_1\Sigma DD + e_1\Sigma ED + f_1\Sigma FD$$

$$\Sigma Z_1E = k_1'\Sigma E + a_1\Sigma A E + b_1\Sigma BE + c_1\Sigma CE + d_1\Sigma DE + e_1\Sigma EE + f_1\Sigma FE$$

$$\Sigma Z_1F = k_1'\Sigma F + a_1\Sigma AF + b_1\Sigma BF + c_1\Sigma CF + d_1\Sigma DF + e_1\Sigma EF + f_1\Sigma FF \tag{7}$$

where, n is the number of runs or the number of sets of the values.

These equations were called normal equations corresponding to the Equation (5) and were obtained as per the definition. In the above sets of equation the values of the multipliers of k_1', a_1, b_1, c_1, d_1, e_1 and f_1 were substituted to compute the values of the unknowns (k_1', a_1, b_1, c_1, d_1, e_1 and f_1) the values of the terms on L.H.S. and the multipliers of k_1', a_1, b_1, c_1, d_1, e_1 and f_1 in the sets of Equation (7) were calculated. After substituting these values in the Equation (7) we will get seven equations that were to be solved simultaneously to get the values of k_1', a_1, b_1, c_1, d_1, e_1 and f_1.

Therefore, a probable exact mathematical form for this load torque could be

$$\pi_{01} = (\pi_1)^{0.8187} (\pi_2)^{0.0511} (\pi_3)^{-1.7050} (\pi_4)^{-1.7799} (\pi_5)^{0.1025} (\pi_6)^{1.7301} \tag{8}$$

This method is repeated to develop the model for π_{02} and hence

The quantity of oil extracted could be

$$\pi_{02} = (\pi_1)^{-4.9564} (\pi_2)^{0.8586} (\pi_3)^{14.9973} (\pi_4)^{6.2841} (\pi_5)^{-4.3832} (\pi_6)^{2.9355} \tag{9}$$

3.5 Model analysis

3.5.1 Analysis of the model for dependent π term $\pi_{01,}$ for instantaneous load torque

The model for dependent π term $\pi_{01,}$ was given below

$$\pi_{01} = (\pi_1)^{0.8187} (\pi_2)^{0.0511} (\pi_3)^{-1.7050} (\pi_4)^{-1.7799} (\pi_5)^{0.1025} (\pi_6)^{1.7301} \tag{10}$$

The deduced equation for this π term was given by

$$\pi_{01} = \frac{Tshaft}{E} \tag{11}$$

It can be seen from the Equation (10) and Figure 4 influence of indices of independent π terms on response variable that this was a model of π term containing load torque as a response variable. The following primary conclusions appear to be justified by the above model.

1) The absolute index of π_6 was the highest i.e. 1.7301. Thus π_6 the term related to the gear ratio was the most influencing π term in the model. The value of this index was positive indicating that π_{01} increases as this π term increases or otherwise.

2) The absolute index of π_4 was the lowest i.e. -1.7799. Thus π_4 the term related to initial energy given to the flywheel was the least influencing π term in the model.

The value of this index was negative indicating that π_{01} increases as this π term decreases or otherwise but has the least influence on the dependent π term.

3) The sequence of direct influence of other π term present in this model was π_1, π_2, π_3, π_5 having absolute indices of 0.8187, 0.0511, -1.7050 and 0.1025 respectively. Out of these indices three were positive indicating π_1, π_2, π_5 increases as these π terms increase or otherwise. Whereas the index of π_3 was negative indicating that π_{01} was reducing as π_3 increases or otherwise.

4) The curve fitting constant is 1. This curve fitting constant represents collective effect of certain immeasurable parameters which have influence on the dependent π term.

3.5.2 Analysis of the model for dependent π term π_{02}, for quantity of oil extracted.

The model for dependent π term π_{02}, was given below

$$\pi_{02} = 1(\pi_1)^{-4.9564} (\pi_2)^{0.8586} (\pi_3)^{14.9973} (\pi_4)^{6.2841} (\pi_5)^{-4.3832} (\pi_6)^{2.9355} \quad (12)$$

The deduced equation for this π term was given by

$$\pi_{02} = \frac{Qo}{E} \frac{g_2}{\omega_2} \quad (13)$$

It can be seen from the Equation (13) and Figure 5, influences of indices of independent π terms on response variable, that this was a model of π term containing quantity of oil extracted as a response variable. The following primary conclusions appeared to be justified from the above model.

1) The absolute index of π_3 was the highest i.e. 14.9973 . Thus π_3 the term related to the average size of oil seed was the most influencing π term in the model. The value of this index was positive indicating π_{02} increases as this π term increases or otherwise.

2) The absolute index of π_1 was the lowest i.e. -4.9564. Thus π_1 the term related to the geometric variables of crushing shaft was the least influencing π term in the model. The value of this index was negative indicating that π_{02} increases as this π term decreases or otherwise but has the least influence on the dependent π term.

3) The sequence of direct influence of other π term present in this model was π_2, π_4, π_5, π_6 having absolute indices of 0.8586, 6.2841, -4.3832 and 2.9355 respectively. Out of these indices three were positive indicating that π_2, π_4, π_6 increases as these π terms increase or otherwise. Whereas the index of π_5 was negative indicating that π_{02} was increases as π_5 decreases or otherwise.

4) The curve fitting constant is 1. This curve fitting constant represents collective effect of certain immeasurable parameters which have influence on the dependent π term.

These models were developed from the sample of 405 sets of independent π terms. Most of the values of variables were kept unchanged during experimentation. Thus, the real behavior of the formulated models was not clear from the available set of data. The objective of present study was to formulate the model for quantitative analysis of model of Load Torque and Quantity of oil extracts during experimentation. The models formulated were useful for almost all oilseed presser setup and the observed data range only, as per the suggested criteria.

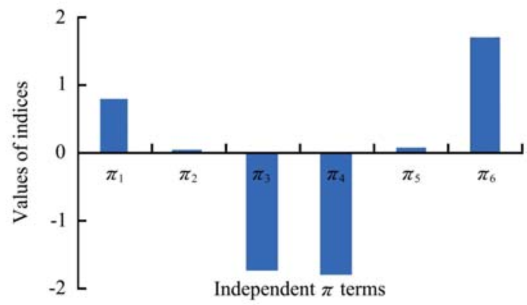


Figure 4 Influence of π terms for (π_{01}) load torque

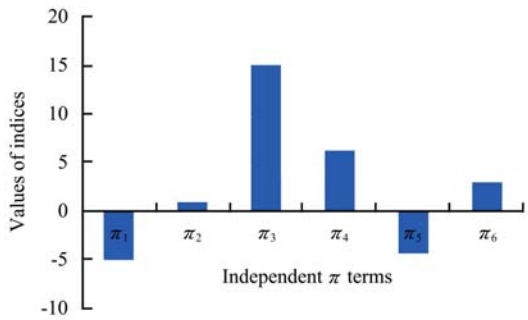


Figure 5 Influence of π terms for (π_{02}) quantity of oil extracted

3.6 Sensitivity analysis

The influence of the independent π terms was studied by analyzing the indices of the various π terms in the models. Through the technique of sensitivity analysis the change in the value of a dependent π terms caused due to an introduced change in the value of individual π term was evaluated. In this case of change of ±10% was introduced in the individual independent π term independently (one at a time). Thus, total range of the introduced change ±10%. The effect of this introduced change on the change in the value of the dependent π term was evaluated. The average values of the change in the dependent π terms due to the introduced change of ±10% in each independent π term. This is defined as sensitivity.

The average value of the change in the dependent π term due to these introduced changes in the independent π terms as shown in the Table 6. These values are plotted on the Figure 6 and Figure 7. The sensitivity as evaluated is represented and discussed below.

Table 6 Sensitivity analysis

Dependent π terms/ indpendent π terms	π_1	π_2	π_3	π_4	π_5	π_6
Load torque	0.00640119	0.00648338	0.006636701	0.0066478	0.00642789	0.0067414
Quantity of oil extracted	9.65916E-08	8.36E-08	1.83E-07	9.77E-08	9.39E-08	1.10E-07

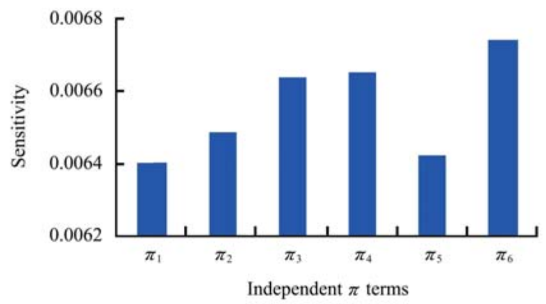


Figure 6 Sensitivity of independent π terms for π_{01}

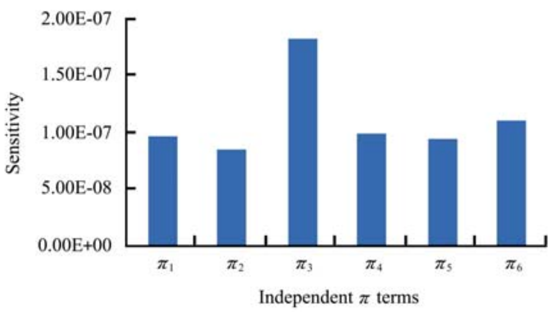


Figure 7 Sensitivity of independent π terms for π_{02}

3.6.1 Effect of introduced change on the dependent π term on π_{01}

When a total range of the change of ±10% in the value of independent π term π_6, is introduced a change of about 43.159% occurs in the value of π_{01} (computed from the model). The change brought in the value of π_{01} because of change in the values of other independent π term π_2 is only 0.5125%. Similarly, the change of about 0.9566%, 8.185%, 17.33% and 18.11% takes place because of change in the values of π_5, π_1, π_3 and π_4 respectively. Thus total range of change introduced brought about average change of 0.5125% and 43.159%.

It can be seen from Figure 6 that the highest change takes place because of the π term π_6 of 0.0095405 with respect to π_{01}, whereas the least change takes place due to the π term π_4 of 0.00547131 with respect to π_{01}. π_1, π_2, π_5 and π_3 have moderate effect on π_{01} of 0.007011247, 0.00659602, 0.006494 and 0.00551229 respectively with respect to π_{01}. Thus π_6 was the most sensitive π term and π_4 was the least sensitive π term. The sequence of the various π terms in the descending order of sensitivity was π_6, π_1, π_2, π_5, π_3 and π_4.

3.6.2 Effect of introduced change on the dependent π term on π_{02}

When a total range of the change of ±10%in the value of independent π term π_3, is introduced a change of about 91.89% occurs in the value of π_{02} (computed from the model). The change brought in the value of π_{02} because of change in the values of other independent π term π_1 is only 8.58%. Similarly, the change of about 53.105%, 65.17%, 46.42% and 69.58% took place because of change in the values of π_2, π_4, π_5 and π_6 respectively. Thus total range of change introduced resulted to average change of 8.58% and 91.89%.

It can be seen from Figure 7 that the highest change takes place because of the π term π_3 of 3.49E-07 with respect to π_{02}, whereas the least change takes place due to the π term π_1 of 5.22E-08 with respect to π_{02}. π_2, π_4, π_5 and π_6 have moderate effect on π_{02} of 9.08E-08, 1.52E-07, 5.51E-08 and 1.95E-07 respectively with respect to π_{02}. Thus π_3 was the most sensitive π term and π_1 was the least sensitive π term. The sequence of the various π terms in the descending order of sensitivity was π_3, π_6, π_4, π_2, π_5 and π_1.

4 Result and discussion

4.1 Justification of the behavior of the models

The influence analysis as well as the sensitivity analysis has demonstrated certain trend in the behavior of the models . This trend has to be justified through some physics of the phenomenon. This is attempted as described below.

It has been observed from the above work that trend of influence of indices (or of the sensitivity) of the independent π terms for the models of dependent π terms on π_{01} and π_{02}, is as discussed below.

4.1.1 Behavior of the model for load torque

As demonstrated by influence analysis and sensitivity analysis π_6 was the most influencing term in this model. 2D graphical analysis also showed that the effect of π_6 on load torque was significant, π_6 was the term related to gear ratio. The second and third influencing terms found to be π_1 and π_5 respectively. They were related to geometrical variables of oil seed presser and instantaneous time respectively. This showed that behavior of model for load torque was mostly depending on gear ratio, geometric variables of oil seed presser and instantaneous time. As per the influence analysis, sensitivity analysis and graphical analysis, other terms viz. π_2, π_3 and π_4 have least effect on load torque.

4.1.2 Behavior of the model for quantity of extracted oil

As demonstrated by influence analysis and sensitivity analysis π_3 was the most influencing term in this model. 2D graphical analysis also showed that the effect of π_3 on quantity of oil extracts was significant, π_3 was the term related to average size of oil seed. The second and third influencing terms found to be π_6 and π_4 respectively. They are related to gear ratio and energy input given to the machine respectively. This showed that behavior of model for quantity of oil extracts was mostly dependent on average size of oil seed, Gear ratio and energy input given to the machine. As per the influence analysis, sensitivity analysis and graphical analysis, other terms viz. π_2, π_5 and π_1 have least effect on load torque.

4.2 Optimization of model

The models have been developed for the investigation of Instantaneous load toque and quantity of oil extracted. The ultimate objective of this work was not merely developing the models but to find out the best set of variable values, which will result in either maximization or minimization of the objective functions. In the two different models were formed corresponding to load toque and quantity of oil extracted. The objective functions identified here were naturally minimization of load toque and maximization of quantity of oil extraction. The models have non linear form; hence it was necessary to convert them into a linear form for optimization purpose. It can be achieved by taking log of both sides of the models. The linear programming technique was applied which is as detailed below.

$$\pi_{01}= K_1\,(\pi_1)^{a}{}_1\,(\pi_2)^{b}{}_1\,(\pi_3)^{c}{}_1\,(\pi_4)^{d}{}_1\,(\pi_5)^{e}{}_1\,(\pi_6)^{f}{}_1 \quad (15)$$

Taking log on both the sides of equation, we have

$$\lg \pi_{01} = \lg K_1 + a_1 \lg(\pi_1) + b_1 \lg(\pi_2) + c_1 \lg(\pi_3) + d_1 \lg(\pi_4) + e_1 \lg(\pi_5) + f_1 \lg(\pi_6) \quad (16)$$

Let $\lg \pi_{01} = Z$, $\lg K_1 = k_1$, $\lg(\pi_1)=X_1$, $\lg(\pi_2)=X_2$, $\lg(\pi_3)=X_3$, $\lg(\pi_4)=X_4$, $\lg(\pi_5)=X_5$, $\lg(\pi_6)=X_6$

Then linear model in the form of first degree polynomial can be written as

$$Z = k_1 + a_1X_1 + b_1X_2 + c_1X_3 + d_1X_4 + e_1X_5 + f_1X_6 \quad (17)$$

Thus, Equation (17) will be the objective function for the optimization or to be very specific to minimize π_{01} i.e. load torque, for the purpose of formulation of the linear programming problem. The next task was to define the constraints for the problem.

The constraint can be the boundaries defined for the various independent π terms involved in the function during the experimentation. During the experimentation the ranges for each independent π terms have been defined. These ranges will be the constraints for the problem. Thus, there will be two constraints for each independent π term as follows.

If we denote the maximum and minimum values of independent π term π_1, by π_{1max} and π_{1min} respectively then first two constraints for the problem will be obtained by taking log of these quantities and by substituting the values of multipliers of all other variables except the one under consideration equal to zero. Let the log of limits be defined, as C_1 and C_2 [i.e. C_1 =lg (π_{1max}) and C_2 =lg (π_{1min})].

Thus, each will have the two equations of constraints as under.

$$1X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \le C_1 \quad (18)$$

$$1X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \ge C_2 \quad (19)$$

The other constraints can be likewise found as given below

$$0X_1 + 1X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \le C_3 \quad (20)$$

$$0X_1 + 1X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \ge C_4 \quad (21)$$

$$0X_1 + 0X_2 + 1X_3 + 0X_4 + 0X_5 + 0X_6 \le C_5 \quad (22)$$

$$0X_1 + 0X_2 + 1X_3 + 0X_4 + 0X_5 + 0X_6 \ge C_6 \quad (23)$$

$$0X_1 + 0X_2 + 0X_3 + 1X_4 + 0X_5 + 0X_6 \le C_7 \quad (24)$$

$$0X_1 + 0X_2 + 0X_3 + 1X_4 + 0X_5 + 0X_6 \ge C_8 \quad (25)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 1X_5 + 0X_6 \le C_9 \quad (26)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 1X_5 + 0X_6 \ge C_{10} \quad (27)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 1X_6 \le C_{11} \quad (28)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 1X_6 \ge C_{12} \quad (29)$$

After solving this linear programming problem one will get the minimum value of the Z and the set of the values of variables to achieve this minimum value. The value of independent π term can then be obtained by finding the antilog of the values of Z, X_1, X_2, X_3, X_4, X_5, and X_6. The actual values of the multipliers and the variables were found and substituted in the above Equations (18) to (29) and the actual problem in this case can be stated as below. This problem can now be solved as a linear programming problem using the MS solver available in MS excel.

Thus the actual problem is to minimize Z, where

$$Z = k_1 + a_1X_1 + b_1X_2 + c_1X_3 + d_1X_4 + e_1X_5 + f_1X_6 \quad (30)$$

and

$$Z = \lg(1)+0.8187 \lg(\pi_1)+0.0511 \lg(\pi_2) - 1.7050 \lg(\pi_3) - 1.7799 \lg(\pi_4) + 0.1025 \lg(\pi_5) + 1.7301 \lg(\pi_6) \quad (31)$$

$$Z = 0+0.8187X_1+0.0511X_2 - 1.7050X_3 - 1.7799X_4 + 0.1025X_5 + 1.7301X_6 \quad (31)$$

Subject to the following constraints,

$$1X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \le 6.8305358 \quad (32)$$

$$1X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \ge 4.949129 \quad (33)$$

$$0X_1 + 1X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \le -1.69897 \quad (34)$$

$$0X_1 + 1X_2 + 0X_3 + 0X_4 + 0X_5 + 0X_6 \ge -1.69897 \quad (35)$$

$$0X_1 + 0X_2 + 1X_3 + 0X_4 + 0X_5 + 0X_6 \le 0.5591882 \quad (36)$$

$$0X_1 + 0X_2 + 1X_3 + 0X_4 + 0X_5 + 0X_6 \ge 0.20682 \quad (37)$$

$$0X_1 + 0X_2 + 0X_3 + 1X_4 + 0X_5 + 0X_6 \le 4.74777 \quad (38)$$

$$0X_1 + 0X_2 + 0X_3 + 1X_4 + 0X_5 + 0X_6 \ge 4.043126 \quad (39)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 1X_5 + 0X_6 \le 3.389166 \quad (40)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 1X_5 + 0X_6 \ge 0.768119 \quad (41)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 1X_6 \le 0.7781513 \quad (42)$$

$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 + 1X_6 \ge 0.30103 \quad (43)$$

On solving the above problem by using MS solver we get

X_1 = 4.919429, X_2 = -1.69897004, X_3 = 0.559188189, X_4 = 4.74777, X_5 = 0.768119, X_6 = 0.301029996 and Z = -8.48607133

Thus π_{01min} = antilog (-8.48607133) =3.26E-09 and corresponding to this value of π_{01min} the values of independent π terms were obtained by taking the antilog of X_1, X_2, X_3, X_4, X_5 and X_6. These values were 83067.09, 0.01999999836, 3.624, 55946.123, 5.8629 and 1.999953. This shows that minimum value of dependent π term involving load torque should be selected based on the results of optimization.

Similarly for the second model or objective function considered was to maximize π_{02} i.e. quantity of oil extracted. On solving the above problem by using the MS solver one get $\pi_{02max=}$ antilog (10.8488) = 7.0599E10 and corresponding to this value of the π_{02max} the values of independent π terms was obtained by taking the antilog of X_1, X_2, X_3, X_4, X_5 and X_6. These values were 88946.52, 0.01999999836, 3.624, 55946.123, 5.863001, and 5.999991. This shows that maximum value of dependent π term involving quantity of oil extracted should be selected based on the results of optimization.

4.3 Reliability of the model

Reliability of model is established by using the relation, reliability = 100 – percentage mean error and

$$\text{mean error} = \frac{\Sigma x_i * f_i}{\Sigma f_i}$$

where, x_i is % error and f_i is frequency of occurrence.

System reliability (R) is given by the relation

$$R = 1 - \prod_{i=1}^{n}(1-R)$$
$$= 1 - [(1-R_1)*(1-R_2)]$$

where, R_1 and R_2 were the reliability of individual models i.e. instantaneous load torque and quantity of oil extracted.

Therefore total reliability of models developed here was equal to

1-[(1-0.824913)* (1-0.7928619)] =0.9637253 or 96.372%

5 Conclusion

From the interaction with farmers and manufactures of oil press, literature cited and the cursory survey conducted in state of Maharashtra (INDIA) the following conclusions are drawn:

1) The design data, economic viability and feasibility, low cost of fabrication will help them to start small scale industry.

2) The relationship between various inputs such as geometric dimensions, average size of oil seed and the outputs as load torque and quantity of oil extracted of the system was not known to them quantitatively. The data in the present work was collected by performing actual experimentation. Due to this the findings of the present study seemed to be reliable.

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

4) From the 2-D graphical analysis of mathematical models it was found that traditional position has an advantage over suggested position.

5) Empirical models predict the performance of the human powered oil press, which establish the optimal values of various parameters arrived at, on the basis of experimentation.

6) It is observed that the phenomenon is complex. Because the variation in the dependent π terms were in a fluctuating form mainly due to continuous variation in the angular speed of the oil seed presser shaft. This variation in the angular speed of the oil seed presser was exponentially dropping. This in term was due to nonlinearly varying load torque on the oil seed presser shaft. Due to the process resistance and inertia resistances, which were likely to be instantaneous speed, dependent upon the clutch engagement, the energy stored in the flywheel gets exhausted in 20 s to 35 s.

7) It was observed that the torque falls constantly during the pressing period even if the speed of the presser shaft falls.

8) It was further hypothesized that the quantity of oil extracts was a function of available energy for pressing, resistance torque and average angular speed of the presser shaft.

9) The ergonomics analysis of the energy storing system was not carried out.

10) The effect of the gear ratio on the dynamics of the machine was analyzed by ignoring the loss of energy impact of jaws of the spiral jaw clutch.

11) It was analyzed that π_6 was the most sensitive π term with respect to π_{01} and π_4 was the least sensitive π term. The sequence of the various π terms in the descending order of sensitivity was π_6, π_1, π_2, π_5, π_3 and π_4.

12) It was analyzed that π_3 was the most sensitive π term with respect to π_{02} and π_1 was the least sensitive π term. The sequence of the various π terms in the descending order of sensitivity was π_3, π_6, π_4, π_2, π_5 and π_1.

13) It was analyzed that behavior of the model for instantaneous torque on the shaft was mostly dependent on the gear ratio. As per influence analysis, sensitivity analysis and graphical analysis other terms viz. π_3 and π_4 have least effect on the instantaneous load torque.

14) It was analyzed that behavior of the model for quantity of oil extracts on the shaft was mostly dependent on the average size of oil seed. As per the influence analysis, sensitivity analysis and graphical analysis other terms viz. π_5 and π_1 have least effect on the instantaneous load torque.

15) The value of the dependent π terms for minimum instantaneous load torque, was found to be 0.043863 Nm

16) The value of dependent π terms for maximum quantity of oil extracted was found to be 9.022 kg/hm^2

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