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ESTIMATION OF PRODUCTION CYCLE TIME USING DIMENSIONAL ANALYSIS: A CASE OF PRESS WORKING SHOP

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ABSTRACT

The objective of the present investigation is to develop a mathematical model for the press working operation. Simulation does not take into account the factors like anthropometry, workplace parameters and environmental conditions. To investigate the effect of these variables on cycle time the dimensional analysis is used. The independent variables are identified and are grouped together. The groups formed are anthropometric data, personnel factors of the operator, machine specifications, workplace parameters, specifications of the product and environmental conditions in press working shop. The parameters which are constant during the experiment are recorded first. The experiment is planned to record the cycle time. The mathematical model is developed to express the cycle time as a function of identified inputs. The results obtained have a correlation of 88% with experimental cycle time. The model is a strong estimator to simulate the process.

Key words: *Press Working, Dimensional Analysis and Cycle Time.*

1. Introduction

The objective of the present investigation is to formulate a mathematical model for the press working operation. The phenomenon of press working operation can be modeled with probabilistic simulation. The limitation of probabilistic simulation is that, it is not capable to explain which particular input influence the output. Simulation does not take into account the factors like anthropometry, workplace parameters and environmental conditions. The approach suggested here is to study the effect of these input variables on production cycle time using the dimensional analysis.

Often in industry the workstation is designed in an arbitrary manner, giving little consideration to the anthropometric measurements of the anticipated user [1]

A survey was conducted to investigate the relationship between environmental factors, job satisfaction that influence the workers' discomfort in four automotive manufacturing in Malaysia [2]. The exposure to noise may have both immediate and long-term effects on hearing of the tractor drivers and other farm workers [3].

Dimensional analysis was used to obtain a functional relationship between the cleaning efficiency density, feed rate, sieve oscillation frequency, threshing and independent variables viz. grain moisture content, and independent variables viz. grain moisture content, straw moisture content, grain bulk density, straw bulk cylinder speed, diameter of sieve hole, air velocity and particle density [4]. Dimensional analysis was used to develop the prediction equations for the torque and power requirements to overcome the rolling resistance of the self-propelled wheels of horticultural tractors [5]. These studies thus generate the need to evolve a technique which may lead to explore the effect of these input variables on cycle time as output.

2. About the Industry

The present research is carried out at M/S. Sunita Electro Engineering, S-13, M.I.D.C., Hingna Road, Nagpur. The unit is producing automobile components which are used in tractors and hydraulic cranes. The industrial unit is a vendor to Mahindra and Mahindra (Tractor division) Nagpur. The various components produced in the industry are hand hole cover, washer (for alternator mounting), shackle plate, horn mounting bracket etc. The operations performed on mechanical press are side trimming, flayering, U-bending, sharp bending, angle bending, hole punching, forming etc.

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3. Methods

The independent variables are identified and six groups of input are formed using dimensional analysis. The groups are as follows:

i. Anthropometric data of an operator: arm span, foot breadth, sitting knee height, height, arm reach
ii. Personnel factors of an operator: sex, qualification grade, BMI Prime, age , experience
iii. Machine specifications: power, stroke/seconds, age of machine, capacity, stroke speed
iv. Workplace parameters: height of operators stool, height of work table, spatial distance between centroid of stool top & work table, area of tabletop, spatial distance between centroid of stool top & WIP table
v. Specifications of the product: thickness, machinable length, length, breadth
vi. Environmental conditions: illumination, noise level with press stroke, dry bulb temperature, illumination at work table, noise level without stroke, wet bulb temperature

The Fig. 1 shows the anthropometric dimensions. These anthropometric dimensions of the press operator are recorded. The data for the other groups viz. personnel factors of an operator, machine specifications etc. is also collected.

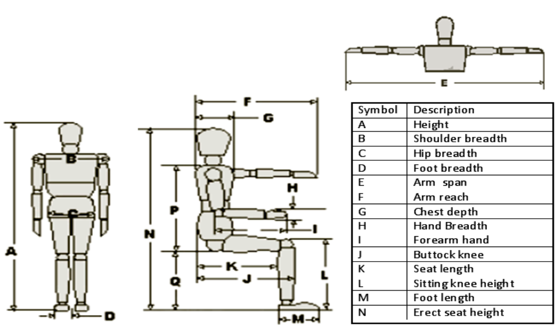

Fig. 1 Anthropometric Dimensions

The parameters constant with the experiment are recorded first. For example anthropometric dimensions, machine specifications, product parameters etc. The cycle time, environmental conditions are recorded at the time of field experimentation.
Thus six input pi terms referring to six different groups are formulated as follows:

i. Pi term of anthropometric data:
$\pi 1 = (As.Fb.Skh)/(H.Ar.Esh)$
ii. Pi term of Personnel factors of an operator:
$\pi 2 = (S.Qg.[BMI\ prime].A)/E$
iii. Pi term due to Machine specifications:
$\pi 3 = (P.Sps.Aom)/(C.Ss)$
iv. Pi term related to Work place parameters:
$\pi 4 = (Hos . Ht . Sd1)/(Areattop . Sd2)$
v. Pi term of Product Specifications:
$\pi 5 = (t . Mc\ Len)/(L . B . Mc\_criti)$
vi. Pi term related to environment:
$\pi 6 = (Isr . dBstroke . DBT)/(Iwt . dB .WBT)$

The cycle time as an output variable is formulated as $\pi 7 = (Tc/To)$ where "Tc" is total cycle time and "To" is actual machine operation time required to perform the operation on mechanical press.

To simplify the model formulation process, a computer program is developed using Visual Basic (version 6.0) as front end and Microsoft access as back end. A separate table is created for all the pi terms. The relationships are defined as per table requirements depending on the attributes. Each table is defined by a key attributes which are used for indexing and appropriate data. The table and the structure of the data base are designed logically.

A field experiment is planned to record the cycle time as output variable. The observations of the field experimentation are recorded. The observations table obtained at the end of field experimentation is created in Microsoft Access database.

To compute the values of π1 to π7 a query in access is used to fetch the values of independent variables from respective tables. To develop a mathematical model to express the cycle time as a function of input pi terms, the output variable is written as

$$\boldsymbol{\pi_7 = a_0\ \pi_1^{a1} \times \pi_2^{a2} \times \pi_3^{a3} \times \pi_4^{a4} \times \pi_5^{a5} \times \pi_6^{a6}}$$

This is a nonlinear relationship. The logarithmic transformation of the output function provides a log-linear form which is convenient and commonly used in analyses using linear regression techniques. It is simplified by taking log of both sides as

$$\text{Log}\ \pi 7 = a_0 + a1\log\pi 1 + a_2\log\pi 2 + a_3\log\pi 3 + a_4\log\pi 4 + a_5\log\pi 5 + a_6\log\pi 6$$

To determine the values of index and constant the following equation in matrix form used is
$[X] \times [A] = [Y]$

Refer Figure 2(a) for matrix X and Figure 2(b) for matrix A and Y. The first row of basic matrix is as shown below. The first element of the first row is the sum of total number of observations. All other elements in the first row are summation of log of each Pi value of pi terms from Pi1 to Pi6. Other values are summation of product of log of Pi1 value with log of Pi1 and so on. In the similar way the values are computed for subsequent rows.

1	log(π1)	log(π2)	log(π3)	log(π4)	log(π5)	log(π6)
∑ 1 X 1	∑ log(π1) X 1	∑ log(π2) X 1	∑ log(π3) X 1	∑ log(π4) X 1	∑ log(π5) X 1	∑ log(π6) X 1
∑ 1 X log(π1)	∑ log(π1) X log(π1)	∑ log(π2) X log(π1)	∑ log(π3) X log(π1)	∑ log(π4) X log(π1)	∑ log(π5) X log(π1)	∑ log(π6) X log(π1)
∑ 1 X log(π2)	∑ log(π1) X log(π2)	∑ log(π2) X log(π2)	∑ log(π3) X log(π2)	∑ log(π4) X log(π2)	∑ log(π5) X log(π2)	∑ log(π6) X log(π2)
∑ 1 X log(π3)	∑ log(π1) X log(π3)	∑ log(π2) X log(π3)	∑ log(π3) X log(π3)	∑ log(π4) X log(π3)	∑ log(π5) X log(π3)	∑ log(π6) X log(π3)
∑ 1 X log(π4)	∑ log(π1) X Log(π4)	∑ log(π2) X log(π4)	∑ log(π3) X log(π4)	∑ log(π4) X log(π4)	∑ log(π5) X log(π4)	∑ log(π6) X log(π4)
∑ 1 X log(π5)	∑ log(π1) X log(π5)	∑ log(π2) X log(π5)	∑ log(π3) X log(π5)	∑ log(π4) X log(π5)	∑ log(π5) X log(π5)	∑ log(π6) X log(π5)
∑ 1 X log(π6)	∑ log(π1) X log(π6)	∑ log(π2) X log(π6)	∑ log(π3) X log(π6)	∑ log(π4) X log(π6)	∑ log(π5) X log(π6)	∑ log(π6) X log(π6)

Fig. 2(a) Matrix A

a_0
a_1
a_2
a_3
a_4
a_5
a_6

	log(π7)
1	∑ log(π7) x 1
log(π1)	∑ log(π7) x log(π1)
log(π2)	∑ log(π7) x log(π2)
log(π3)	∑ log(π7) x log(π3)
log(π4)	∑ log(π7) x log(π4)
log(π5)	∑ log(π7) x log(π5)
log(π6)	∑ log(π7) x log(π6)

Fig. 2 (b) Matrix A and Matrix Y

The matrix X is converted to unity matrix by dividing all the elements in i^{th} row by diagonal element to ensure diagonal element to be 1. Now we need all the elements in i^{th} column equal to zero (excluding diagonal elements which are to be equal to 1). To get this Rj in matrix X when $(i \neq j)$ is transformed using rule Rj = Rj – R x Xij. Note that the rule of transformation is to be extended to matrix Y.

The procedure of transformation of matrix X to unity gives us the matrix A as the indices of the various input pi terms. The matrix Y indicates the values of Pi7.

4. Results

The matrix X is transformed to unit matrix. The elements of matrix A are the indices of the desired equation. The Visual Basic program generates the mathematical model obtained between six input pi values and cycle time (π_7). Refer Table 1 for the equations.

Table 1: Mathematical Models for the Cycle Time

All Products	$\pi_7 = 0.54711\ \pi_1^{(-0.892)}\ \pi_2^{(0.3963)}\pi_3^{(0.6812)}\ \pi_4^{(0.0778)}\ \pi_5^{(-0.2545)}\ \pi_6^{(0.7576)}$
Product p1	$\pi_7 = 1.43907\ \pi 1^{(-0.1275)}\ \pi 2^{(0.0188)}\pi 3^{(-0.1475)}\ \pi 4^{(-0.8472)}\ \pi 5^{(0.0492)}\ \pi 6^{(1.1371)}$
Product p2	$\pi_7 = 0.19916\ \pi 1^{(-1.4061)}\ \pi 2^{(0.351)}\pi 3^{(0.8461)}\ \pi 4^{(-0.9606)}\pi 5^{(-0.2549)}\pi 6^{(0.5156)}$
Product p3	$\pi_7 = 2.97546\ \pi 1^{(0.374)}\ \pi 2^{(0.3034)}\pi 3^{(-0.1251)}\ \pi 4^{(0.156)}\pi 5^{(-0.1459)}\pi 6^{(-1.0903)}$
Product p4	$\pi_7 = 9.4060\ \text{E-03}\ \pi 1^{(0.0285)}\ \pi 2^{(1.0556)}\ \pi 3^{(0.4907)}\ \pi 4^{(-0.0855)}\ \pi 5^{(-2.2202)}\ \pi 6^{(2.625)}$

The relationship of actual and computed values of the model developed for product p1, p2, p3, p4 and for all products taken together is represented in Figure 3, Figure 4, Figure 5, Figure 6, and Figure 7 respectively.

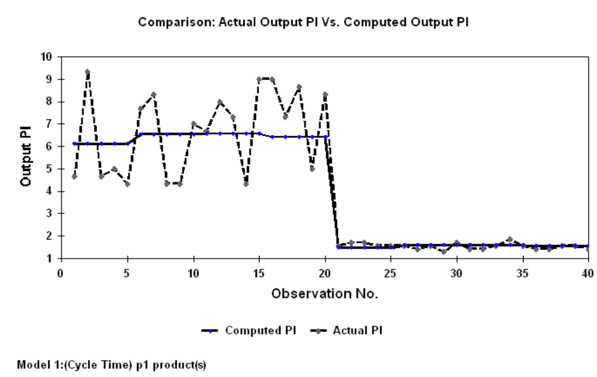

Fig. 3 Actual and Computed Value of Output π7 with for Product p1

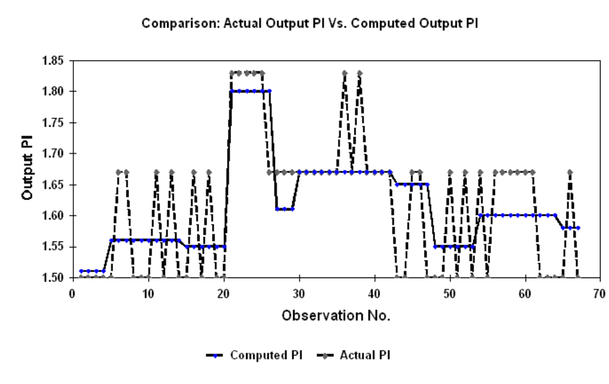

Fig. 4 Actual and Computed Value of Output π7 with for Product p2.

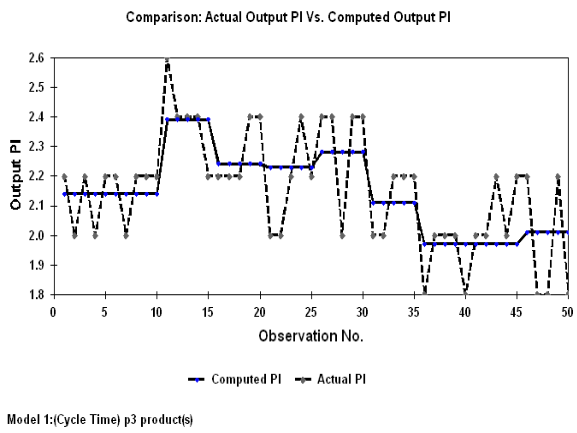

Fig. 5 Actual and Computed Value of Output π7 with for Product p3

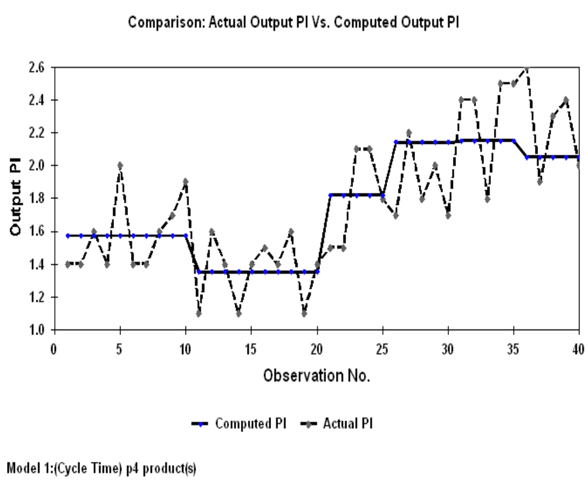

Fig. 6 Actual and Computed Value of Output π7 with for Product p4

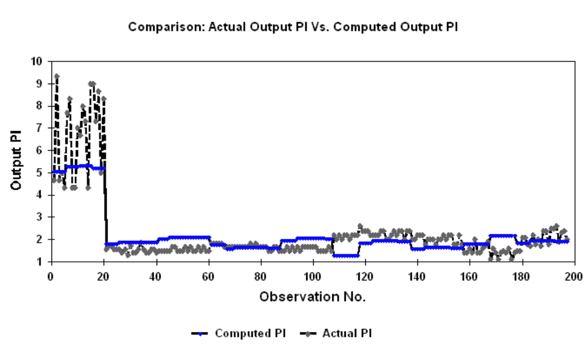

Fig.7 Actual and Computed Value of Output π7 with for All Products Taken Together

5. Conclusions

Mathematical model is developed for the press working operation using dimensional analysis. The cycle time of the press working operation is expressed as a function of anthropometric data of the operator, personnel factors of the operator, machine specifications, workplace parameters, specifications of the product and environmental conditions on shop floor.

The RMS error and the correlation coefficient for all products taken together and individual products p1, p2, p3, and P4 are as shown. Refer Table 2.

Table 2: RMS Error and Correlation Coefficient for the Models

Category	RMS error	correlation coefficient
All products	0.860353897	0.8823038
p1	1.280130254	0.8972371
P2	0.076407471	0.7034107
p3	0.135729401	0.7024931
p4	0.259546359	0.77604

The results obtained have a correlation of 88% for all products taken together with experimental cycle time. The model is a strong estimator to simulate the process.

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Nomenclature

Symbol	Meaning	Unit
As	Arm span	cm
Fb	Foot breadth	cm
Skh	Sitting knee Height	cm
H	Height	cm
Ar	Arm reach	cm
Esh	Erect sit height	cm
S	Sex	dimensionless
Qg	Qualification	dimensionless
BMI prime	*BMI Prime	dimensionless
A	Age	years
E	Experience	months
P	Power HP	H.P.
Aom	Age of Machine	years
C	Capacity of press	tons
Ss	Stroke speed	mm/s
Hos	Height of stool	cm
Ht	Height of work table	cm
Sd1	Spatial distance between centroid of stool top & work table	cm
Areattop	Area of tabletop	cm^2
Sd2	Spatial distance between centroid of stool top & WIP table	cm
t	Thickness	mm
Mc_Len	Machinable length	mm
L	Length	mm
B	Breadth	mm
lsr	Illumination sight range (average)	Lux
dBstroke	Noise level with stroke	dBA
DBT	Dry bulb temperature	ºC
lwt	Illumination at work table	Lux
dB	Noise level without stroke	dBA
WBT	Wet bulb temperature	ºC

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*Body mass index is defined as the individual's body weight divided by the square of his or her height.

BMI Prime is the ratio of actual BMI to upper limit BMI (currently defined at BMI 25). As defined, BMI Prime is also the ratio of body weight to upper body weight limit, calculated at BMI 25. BMI Prime is a dimensionless number.

