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A NOVEL APPROACH FOR PRODUCTIVITY IMPROVEMENT OF A MAN MACHINE SYSTEM – A FIELD DATA BASE MODEL WAY

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ABSTRACT

A Man-Machine System means an activity occurring/occurred with the involvement of a human being with the help of some tools used to interact with the material. In small foundries the moulding process is manual & labours have to work in different psychological moods, stress and strain, without training on ergonomic posture, in different environmental factors such as temperature, vibrations, noise dust which affects the productivity and also amount of human energy input to produce the component. This paper makes an attempt to develop a mathematical model to relate the productivity with various parameters and identify the most sensitive parameter to control the productivity.

Keywords: Human Energy Input, Quality of Mould, Productivity, Mathematical Model, ANN Analysis, Optimization, Field database modeling, Sand Moulding, Cylinder Head.

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1. INTRODUCTION

India is one of the ten prime manufacturers of ferrous and non-ferrous castings in the world. One of the major sectors in the Indian economy is foundry, having more than 7000 foundries grouped under small, medium, and large sectors. Foundries are labour intensive, employing @ 5,50,000 people directly and @1,75,000 people indirectly. Small and some of the medium scale foundries are primarily depended on upon labour, however, large and medium scale foundries are semi automized or largely automated.

Metal Casting Process is not a single process, but is combination of several sub-processes such as Pattern making, sand preparation, moulding, melting, pouring, Cleaning and Finishing etc. Sand casting is the most widely used metal casting process.

The cylinder head of air compressor is the key element of the air compressor. The desired geometry cannot be implemented by all casting methods. The shape and position of the intake and exhaust duct determine the overall geometry of the cylinder head. Sand casting method has become very popular for producing the cylinder head.

In Foundry labours have to work in different psychological moods, stress and strain, without training on ergonomic posture, in different environmental factors such as temperature, vibrations, noise dust which affects the productivity and also amount of human energy input to produce the component. Improper work posture causes –

- Decrease in productivity
- Increase in work compensation
- Increase in stress level
- Increase in medical expenditure
- Shorter work life [1]

The work load in the foundry is highly connected with poor working postures and unfavourable arrangement of work space as well as with poor workplace environment, particularly in terms of dust and noise, Forward bending and squatting positions occupied 70-90 % of the actual working time handling large-sized casts, while the work using a table allowed workers more frequent erect standing postures. [2]

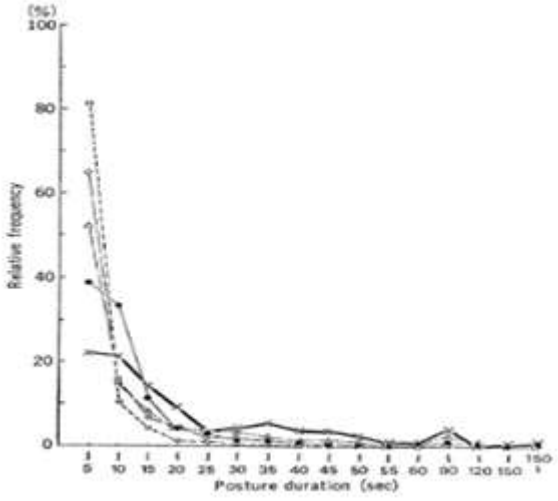

Figure 1 Frequency distribution of duration of working postures during manual molding work on the floor. Standing posture ○ Slight forward bending □ Deep forward bending △ forward bending with maximum inclination ✖ Squatting

In number of ways temperature and humidity affects the performance of the workers. In everyday work, the temperature of the workroom may manipulate the effectiveness and/or safety of the workpeople. Laboratory and on site study shows that skillful performance depreciates quickly if the effective temperature crossed the region 27° to 30°C. it is shown that the time taken for loading the coal tubs increases slowly with the increase in effective temperature from 19°C to 28°C. The effect of temperature increase was more significant over

age of 30 years particularly over 50 years. In warm and humid environment evaporation of sweat will be absent cause's reduction in efficiency of the workers [3].

Parameters such as anthropometric data of worker, posture adopted in performing the activity, attitude, aptitude, skill, experience, health status habits and tool specification etc. govern the performance of any man machine system. Apart from these variables extraneous parameters such as atmospheric temperature, humidity, noise level, dust and air circulation also governs the performance.

The moulding operation is a complex physical phenomenon to the extent that formulation of logic based model is not possible correlating cause and response. In such situations field databased model is a proper choice.

2. PHILOSOPHY OF A FIELD DATA BASED MODEL

2.1. Man Machine System

A man machine means any activity which is carried out with the involvement of human being may be male or female with the help of some tools for interaction with the material. In daily life some activities such as inventory operation, inspection, raw material processing etc. can be planned only with partial perfection. Every such activity is a Man-Machine system [4]

All the activities of man machine system cannot be planned fully for the purpose of experimentation and it is not possible to adopt test planning part of experimentation. In such situations one has to permit the activity to execute either the way it takes place or execute it as planned by others. This happens when one wishes to formulate model for -

a. Any industrial activity such as Inventory Operation, Raw Material Processing, Inspection, and Human Assembly, Civil Construction Activity
b. Any activity in underground / open cast mining: Drilling, Manual Shoveling, Roof Bolting etc.
c. Moulding operation :

2.2. System, Causes, Effects and Extraneous Variables

System, Causes, Effects and Extraneous Variables are the four essential parameters for occurrence of any activity. Activity of tree plantation is illustrated here. For example for the purpose of tree plantation the worker is performing digging operation on the land. It can be realized as follows -

System: - It is a specific location on the land with natural atmospheric conditions of surrounding temperature, relative humidity, air circulation etc.

Causes: - Issues responsible to put system into action

Effects: - These are the reaction of the system after activity execution.

Extraneous Variables: - These are the immeasurable Factors / Parameters / Causes influencing activity performance.

Establishment of relationships between causes and effects (i.e. inputs and outputs) is essential. This is necessary to find out strengths and weaknesses of the activity as per existing method of the activity.

After knowing the weaknesses, improvement in present method of execution of activity is possible. Hence, it is required to establish the relation between cause and effect conceptualized as Field databased model to improve the performance of the activity.

The relationship will be formulated as follows-

A1=f1[(W1,W2,W3,W4,W5,W6) (X1,X2,X3,X4,X5),(Y1,Y2,Y3,Y4),(Z1,Z2,Z3,Z4)]------ (4.1.1)

A2=f2[(W1,W2,W3,W4,W5,W6) (X1,X2,X3,X4,X5),(Y1,Y2,Y3,Y4),(Z1,Z2,Z3,Z4)]------ (4.1.2)

A3=f3[(W1,W2,W3,W4,W5,W6) (X1,X2,X3,X4,X5),(Y1,Y2,Y3,Y4),(Z1,Z2,Z3,Z4)]------(4.1.3)

Once relationships are established then only it is feasible to improve the method of working. A mathematical model of simulation of moulding process is developed to know the strength and weakness of the current process. Its purpose is to improve the process, manage the process and reduction of fatigue to the workers and musculo-skeletal injuries.

3. MATHEMATICAL MODEL

It is tradition that while designing of the equipments without considering human characteristics, ergonomics. Ergonomics helps to improve the productivity, improving method and modifying the work station and its layout. In order to establish relation between productivity, human energy input and influencing variables for this complex moulding process mathematical simulation is used.

As regards the worker performing the moulding operation causes would be Anthropometric Information about the operator - dimension from foot fingers to knee, from knee to waist, waist to chest, knee to chest, from shoulder to elbow, elbow to fingers etc.

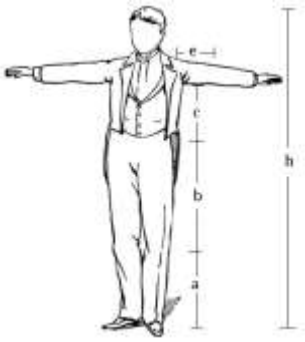

Figure 2 Anthropometric Dimensions of Labour

Dimensions of tools used for the activity- Weight of Pattern, Ram and Moulding box

Responses (i.e. effects) (Z) would be: Productivity (Z1), Human Energy input (Z2).

3.1. Formulation of Model in Exponential Form

In this activity there are 176 observations and there are 7 unknowns as discussed. The process variables, their symbols and dimensions are listed in Table (5.1) along with nomenclature of various parameters involved in this activity as independent and dependent physical quantities/parameters. Dimensional analysis by Buckingham's method is done and dimensionless Pi terms are obtained.

Table 1 Process variables, their symbols

Π	Variables	Symbol	Type of Variable
01	Productivity	P	Dependent
02	Human Energy	HE	Dependent
1	Sand Compression Strength	Ss	Independent
2	Gravitational acceleration	ga	Independent
3	Weight of the Ram	MR	Independent
4	Weight of Moulding Box	Mb	Independent
5	Weight of Pattern	Mp	Independent
6	Casting cooing time	Tc	Independent
7	Groud to Knee	a	Independent

8	Knee to Waist	b	Independent
9	Waist to Chest	c	Independent
10	Knee to Chest	d	Independent
11	Shoulder to elbow	e	Independent
12	Knee To Shoulder + Knee to Waist	f	Independent
13	Buttocks	g	Independent
14	Ground to head	h	Independent
15	Sand grain size – AFS Number	Sg	Independent
16	Sand Compactibility	Sc	Independent
17	Relative Humidity	RH	Independent
18	Temp. of molten metal	Tm	Independent
19	Ambient air Temp	Ta	Independent

It means

$$P = f\left(HE, \mathrm{S_S}, \mathrm{g}_a, M_R, M_b, M_p, \mathrm{T}_c, a, b, c, d, e, f, g, h, j, k, \mathrm{S}_g, \mathrm{S}_c, RH, \mathrm{T}_m, \mathrm{T}_a\right)$$

After applying Buckingham's pi theorem and grouping the terms following mathematical model is formed.

Hence final equation for dependent Pi term is as follows-

1. For productivity

$$\pi_{01} = f\left(\frac{M_R M_b M_p}{\mathrm{S_S^3}\, x\, \mathrm{g}_a^6\, x\, \mathrm{T}_c^{12}} \frac{a\, b c d e f\, g h j k}{\mathrm{g}_a^{10}\, x\, \mathrm{T}_c^{20}}\ \mathrm{S}_g\, \mathrm{S}_c\, RH \left(\frac{\mathrm{T}_m}{\mathrm{T}_a}\right)\right)$$

$$P = K\, f\left(\frac{M_R M_b M_p}{\mathrm{S_S^3}\, x\, \mathrm{g}_a^6\, x\, \mathrm{T}_c^{12}} \frac{a\, b c d e f\, g h j k}{\mathrm{g}_a^{10}\, x\, \mathrm{T}_c^{20}}\ \mathrm{S}_g\, \mathrm{S}_c\, RH \left(\frac{\mathrm{T}_m}{\mathrm{T}_a}\right)\right) \quad (1)$$

Dimensional analysis can be used primarily as experimental tool to combine many experimental variables into one. The main purpose of this technique of dimensional analysis is making experimentation compact without the loss of control. [5]

Table 2 Grouping of pi terms

π	Ratio	Dimension less π term
1	Weight of Ram/Pattern/Moulding box	$\pi 1 = \left(\frac{M_R M_b M_p}{\mathrm{S_S^3}\, x\, \mathrm{g}_a^6\, x\, \mathrm{T}_c^{12}}\right)$
2	Anthropometric data of workers	$\pi 2 = \left(\frac{a\, b c d e f\, g h}{\mathrm{g}_a^8\, x\, \mathrm{T}_c^{16}}\right)$
3	Sand grain size – AFS Number	$\pi 3 = (\mathrm{S}_g)$
4	Sand Compactibility	$\pi 4 = (\mathrm{S}_c)$
5	Relative Humidity	$\pi 5 = (RH)$
6	Temp. Of molten metal	$\pi 6 = \left(\frac{\mathrm{T}_m}{\mathrm{T}_a}\right)$

The above equation is stated in alternative simplified form as under -

$$\pi_{01} = K_1' (\pi_1)^{a1} (\pi_2)^{b1} (\pi_3)^{c1} (\pi_4)^{d1} (\pi_5)^{e1} (\pi_6)^{f1}$$

Where K1' is Curve Fitting Constant and a1, b1, c1, ……. f1 are exponents of π terms.

3.2. Results

In this activity there are 176 observations and there are 7 unknowns, This will give rise to $176^7 = 5.23105^{15}$ combinations i.e. values. To solve so many sets will be a tedious task. This is solved using Multiple Regression Analysis. Regression equation should be in the form

$$Z = K + a*A + b*B + c*C...$$

We have Equation for Productivity

$$\pi 01 = K1' (\pi 1)a1 * (\pi 2)\, b1 * (\pi 3)c1 * (\pi 4)\, d1 * (\pi 5)\, e1 * (\pi 6)\, f1$$

Taking logs of both sides of equation to convert it in-to a linear form,

$$\text{Log } \pi_{01} = \log K1' + a1\,(\log \pi 1) + b1\,(\log \pi 2) + c1\,(\log \pi 3) + d1\,(\log \pi 4) + e1\,(\log \pi 5) + f1\,(\log \pi 6)$$

Let

$$\log \pi_{01} = Z1, \quad \log K1' = K1, \quad \log \pi 1 = A, \quad \log \pi 2 = B,$$

$$\log \pi 3 = C, \quad \log \pi 4 = D, \quad \log \pi 5 = E, \quad \log \pi 6 = F,$$

Substituting these values in the equation, regression equation will be as

$$Z1 = K1 + a1*A + b1*B + c1*C + d1*D + e1*E + f1*F$$

Log π01 is calculated from H.E.Input. Means Z1 is known.

To determine the regression hyper plane, it is necessary to solve 7x7 matrix to determine the indices a1, b1, c1, d1, e1 and f1

$$\sum Z1*1 = nK1 + a1*\sum A + b1*\sum B + c1*\sum C + d1*\sum D + e1*\sum E + f1*\sum F$$

$$\sum Z1*\sum A = K1*\sum A + a1*\sum A*A + b1*\sum B*A + c1*\sum C*A + d1*\sum D*A + e1*\sum E*A + f1*\sum F*A$$

$$\sum Z1*\sum B = K1*\sum B + a1*\sum A*B + b1*\sum B*B + c1*\sum C*B + d1*\sum D*B + e1*\sum E*B + f1*\sum F*B$$

$$\sum Z1*\sum C = K1*\sum C + a1*\sum A*C + b1*\sum B*C + c1*\sum C*C + d1*\sum D*C + e1*\sum E*C + f1*\sum F*C$$

$$\sum Z1*\sum D = K1*\sum D + a1*\sum A*D + b1*\sum B*D + c1*\sum C*D + d1*\sum D*D + e1*\sum E*D + f1*\sum F*D$$

$$\sum Z1*\sum E = K1*\sum E + a1*\sum A*E + b1*\sum B*E + c1*\sum C*E + d1*\sum D*E + e1*\sum E*E + f1*\sum F*E$$

$$\sum Z1*\sum F = K1*\sum F + a1*\sum A*F + b1*\sum B*F + c1*\sum C*F + d1*\sum D*F + e1*\sum E*F + f1*\sum F*F$$

Values of terms on L.H.S. i.e. $\sum Z1*1$, $\sum Z1*\sum A$, $\sum Z1*\sum B$, $\sum Z1*\sum C$ and so on are known. Similarly the values of multipliers of K_1, a_1, b_1, c_1..... e_1 such as N, $\sum A$, $\sum B$, $\sum C$, $\sum D$, $\sum E$ and so on are also known. Values of L.H.S. terms & multipliers of K_1, a_1, b_1, c_1..... e_1 are substituted in 7 equations. Values of the unknown viz. K_1, a_1, b_1, c_1..... e_1 are now to be computed. Substituting these values, 7 equations are obtained. These equations are solved simultaneously to get the values of K_1, a_1, b_1, c_1, d_1…. f_1, The Matrix Analysis is carried out by using MATLAB software. Values of K_1, a_1, b_1, c_1, d_1…. f_1 have been obtained as below.

1. Results obtained from MATLAB
2. Solution for matrix to establish relation for π_{01}

K1	a	b	c	d	e	f
19.81682	-0.03525	-0.00634	-0.55716	-1.94657	0.875742	-0.10197

Substituting the values obtained from MATLAB

$$\pi_{01}\,(\text{Productivity}) = K_1'(\pi_1)^{a1} * (\pi_2)^{b1} * (\pi_3)^{c1} * (\pi_4)^{d1} * (\pi_5)^{e1} * (\pi_6)^{f1}$$

Substituting known values it becomes ….

$$\pi_{01}\,(\text{Productivity}) = 19.8168 * (\pi_1)^{-0.03524} * (\pi_2)^{-0.00634} * (\pi_3)^{-0.5571} * (\pi_4)^{-1.9465} * (\pi_5)^{0.8757} * (\pi_6)^{-0.1019}$$

4. CONCLUSIONS

Arranging in descending order of indices is -

$$(\pi_5)^{0.8757}\,(\pi_4)^{-1.9465}\,(\pi_3)^{-0.5571}\,(\pi_6)^{-0.1019}\,(\pi_1)^{-0.03524}\,(\pi_2)^{-0.00634}$$

The exponential form crystallizes the influence of individual independent π term on the dependent π terms.

π_6 = Ratio of Molten metal temp & Ambient Temp.

π_1 = Weight of Ram, Pattern & Moulding box

π_2 = Anthropometric data of workers

Highest influence on Productivity π 01 is of π_5, then π4, π3, π6, π1, π2

π_5 means RH – it has got positive influence and π_4, π3, π_6, π_1 and π_2 has got negative influence on the Productivity. i.e. These values are to be decreased to improve Productivity.

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