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A MATHEMATICAL APPROACH FOR FORMULATION OF GENERALIZED FIELD DATA BASED MODEL FOR PRODUCTIVITY ENHANCEMENT OF CYLINDER HEAD MOULDING OPERATION

RAHUL BACHUTE[1], DR. K S ZAKIUDDIN[2]

1. Scholar, Engg. Mechanical Engg. Dept, Priyadarshini College of Engineering, Nagpur: 440019, India.
2. Professor & Head, Mechanical Engg. Dept, Priyadarshini College of Engineering, Nagpur: 440019, India.

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Abstract: - In this paper an approach for formulation of generalized field data based model for cylinder head moulding operation. The aim of field data based modeling for cylinder head moulding operation is to improve the output by correcting or modifying the inputs. The goal of the research is to reduce human energy input required while performing cylinder head moulding operation. With the reduction in human energy input, automatically, the productivity of the process will also increase. The study identifies important ergonomic and other work environment related parameters which affect the productivity. The identified parameters are properties of sand, physical dimensions of tools, energy outflow of workers, anthropometric data of the workers, working conditions like relative humidity, ambient temperature. Out of all the variables responses and causes are identified. After dimensional analysis relationship between the dependent and independent parameters, a mathematical model is established having relationship between output parameters and input. To get the optimized values model is optimized using the optimization technique. Sensitivity analysis is a tool which can be used to find out the effect of input one parameter over the other. The model will be useful for an industrialist to select optimized inputs so as to get targeted responses.

Keywords: FDBM; Cylinder head moulding operation, Dimensional analysis, Mathematical Model.

Corresponding Author: MR. RAHUL BACHUTE

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INTRODUCTION

Metal Casting Process is not a single process but has several sub-processes such as Pattern making, sand preparation, moulding, melting, pouring, Cleaning and Finishing etc. Moulding activity can be described as follows -

The pattern with necessary allowances is over a moulding board. The size of moulding board is selected as per the size of the moulding box. That is it should not be either too small or too big than the flask. The drag part of the flask is placed over the moulding box. Properly conditioned moulding sand (i.e. sand with the proper amount of moisture, binding materials etc.) is poured over the pattern in the box.

The sand is rammed properly with the rammer so that packing is perfect. Too loose ramming or too hard ramming both Are undesirable. After ramming operation excess sand in the drag is leveled off with strike road. After leveling the sand venting operation sand, small holes are made with the vent wire in the moulding box to ensure that molten metal gas can be escaped through the mould after pouring. The parting sand is sprinkled over the sand; otherwise, the sand in cope would stick with the sand in the drag creating difficulties in removing the cope for taking out the pattern. The drag is cope is now placed over the drag in such a way that pins can be fitted in it to interlock the cope and drag. A sprue pin is kept vertically 2-3 cms away from the pattern for making runner and riser. The cope is filled with the sand, rammed and properly packed and vent holes are made. The cope is lifted off carefully. To remove the pattern the sand near the edges of the pattern is either wetted and / or slightly pattern is hammered. If edges of the mould are torn off, then they are repaired with the help of tools (Figure 5.5, 5.6, 5.7 and 5.8). The gate is cut connecting the bottom of the sprue opening to the cavity so that molten metal can flow towards the cavity. The mould surface is then coated with the coating material in order to improve surface finish and strengthen the mould. After removing the pattern the moulds are kept aside for pouring.

II. IDENTIFICATION OF SYSTEM CONSTANTS, CAUSES, EFFECTS AND EXTRANEOUS VARIABLES

System, Causes, Effects and Extraneous Variables are the four essential parameters for the occurrence of any activity. It can be realised as follows -

(a) **System**- This is a specific spot in a construction site with naturally available environment conditions of humidity, air circulation, ambient temperature etc.

(b) **Causes**- These are the issues which are actuating the system (which sets the system in action)

(c) **Effects**- These are the responses of the execution of an activity.

(d) **Extraneous Variables**- These are the Factors / Parameters / Causes which do influence the performance of the activity but which cannot be measured.

As regards the worker performing 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.

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).

Normally (Z3,) the quality of the process/product is considered. However, in this case, it is decided by visual inspection whether it is as per requirement or not. If it is not as per requirement for some observation then that observation is dropped out. In other words, for all observations, the quality of operation is considered as highest and equal. Hence, this model is not formed in this investigation.

III. FORMULATION OF MODEL IN EXPONENTIAL FORM

- **Dimensional Analysis**

The process variables, their symbols, and dimensions are listed in Table (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.

Π term	Variables	Symbol	Unit	$M^0L^0T^0$	Type of Variable
01	Productivity	P	--	--	D
02	Human Energy	HE	Joules	$M L^2 T^{-2}$	D
1	Sand Compression Strength	S_s	N/cm^2	$M^1 L^{-2} T^1$	I
2	Gravitational acceleration	g_a	cm/s^2	$M^0 L^1 T^{-2}$	I
3	Weight of the Ram	M_R	Kg	$M^1 L^0 T^0$	I
4	Weight of Moulding Box	Mb	Kg	$M^1 L^0 T^0$	I
5	Weight of Pattern	Mp	Kg	$M^1 L^0 T^0$	I
6	Casting cooling time	T_c	Min	$M^0 L^0 T^1$	I

7	Ground to Knee	a	cm	$M^0 L^1 T^0$	I
8	Knee to Waist	b	cm	$M^0 L^1 T^0$	I
9	Waist to Chest	c	cm	$M^0 L^1 T^0$	I
10	Knee to Chest	d	cm	$M^0 L^1 T^0$	I
11	Shoulder to elbow	e	cm	$M^0 L^1 T^0$	I
12	Knee To Shoulder + Knee to Waist	f	cm	$M^0 L^1 T^0$	I
13	Buttocks	g	cm	$M^0 L^1 T^0$	I
14	Ground to head	h	cm	$M^0 L^1 T^0$	I
15	Sand grain size – AFS Number	S_g	--	$M^0 L^0 T^0$	I
16	Sand Compactibility	S_c	%	$M^0 L^0 T^0$	I
17	Relative Humidity	RH	%	$M^0 L^0 T^0$	I
18	Temp. Of molten metal	Tm	^{0}C	$M^0 L^0 T^0$	I
19	Ambient air Temp	T_a	^{0}C	$M^0 L^0 T^0$	I

D - Dependent , I – Independent

Table 1 – Dependent and Independent variables

Using Buckingham's Π Theorem Method for Dimensional Analysis

P =f (HE, S_S, g_a, M_R,M_b,M_p, T_c, a,b,c,d,e,f,g,h,j,k,S_g, S_c, , RH, Tm, T_a)

f (HE, S_S, g_a, M_R,M_b,M_p, T_c, a,b,c,d,e,f,g,h,j,k,S_g, S_c, , RH, Tm, T_a) = 0

Total no of actual variable (n) = 14

Total no of repeating variable (m) = 3

Consider repeating variables as 'S_s, g_a, and T_c

Therefore No. of Π terms = n – m = 14 – 3 = 11

Equation S_s, g_a, and T_c can be written as

$f(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9, \Pi_{10}, \Pi_{11},) = 0$

$\Pi_{1=} (S_s)^{a1} (g_a)^{b1} (T_c)^{c\,1}(M_R)$

$(M^0 L^0 T^0)_= (M^1 L^{-2} T^0)^{a1} (M^0 L^1 T^{-2})^{b1} (M^0 L^0 T^1)^{c\,1} (M^1 L^0 T^0)$

For 'M'	For 'L'	For 'T'
M⃞ 0 = a_{1} + 1	L⃞0 = -2a_1 + b_1	T⃞0 = -2b_1 + c_1
a_1 = -1	0 = 2 + b_1	0 = 4 + c_1
	b_1 = -2	c_1 = -4

$\Pi_{1=} (S_s)^{-1} (g_a)^{-2} (T_c)^{-4} (M_R)$

Hence, Weight of Ram

$$\pi 1 = \frac{M_R}{\mathrm{S_S}\, x\, \mathrm{g}_a^2\, x\, \mathrm{T}_c^4}$$

Similarly,

For weight of Moulding box

$$\pi 2 = \frac{M_b}{\mathrm{S_S}\, x\, \mathrm{g}_a^2\, x\, \mathrm{T}_c^4}$$

For weight of Pattern

$$\pi 3 = \frac{M_p}{\mathrm{S_S}\, x\, \mathrm{g}_a^2\, x\, \mathrm{T}_c^4}$$

$\Pi 4_{=} (S_s)^{a1} (g_a)^{b1} (T_c)^{c\,1} (a)$

$(M^0 L^0 T^0)_{=} (M^1 L^{-2} T^0)^{a1} (M^0 L^1 T^{-2})^{b1} (M^0 L^0 T^1)^{c\,1} (M^0 L^1 T^0)$

For 'M'	For 'L'	For 'T'
M⃞ 0 = a_{1} + 0	L⃞0 = -2a_1 + b_1+1	T⃞0 = - 2b_1 + c_1
a_1 = 0	0 = 1 + b_1	0 = 2 + c_1
	b_1 = -1	c_1 = -2

$\Pi 4_{=} (g_a)^{-1} (T_c)^{-2} (a)$

Hence ground to Knee

$$\pi 4 = \frac{a}{\mathrm{g}_a\, x\, \mathrm{T}_c^2}$$

Similarly

For knee to Waist

$$\pi 5 = \frac{b}{g_a \, x T_c^2}$$

For Waist to Chest

$$\pi 6 = \frac{c}{g_a \, x T_c^2}$$

For Knee to Chest

$$\pi 7 = \frac{d}{g_a \, x T_c^2}$$

For Shoulder to elbow

$$\pi 8 = \frac{e}{g_a \, x T_c^2}$$

For Knee To Shoulder + Knee to Waist

$$\pi 9 = \frac{f}{g_a \, x T_c^2}$$

For Buttocks

$$\pi 10 = \frac{g}{g_a \, x T_c^2}$$

For Ground to head

$$\pi 11 = \frac{h}{g_a \, x T_c^2}$$

Reduction of Pi terms

Related to weight of Ram/Pattern/Moulding box

$$\pi 1 = \left(\frac{M_R}{S_S \, x g_a^2 \, x T_c^4} \frac{M_b}{S_S \, x g_a^2 \, x T_c^4} \frac{M_p}{S_S \, x g_a^2 \, x T_c^4} \right)$$

$$\pi 1 = \left(\frac{M_R M_b M_p}{S_S^3 \, x g_a^6 \, x T_c^{12}} \right)$$

Related to Anthropometric data of workers

$$\pi 2 = \left(\frac{a}{g_a x T_c^2} \frac{b}{g_a x T_c^2} \frac{c}{g_a x T_c^2} \frac{d}{g_a x T_c^2} \frac{e}{g_a x T_c^2} \frac{f}{g_a x T_c^2} \frac{g}{g_a x T_c^2} \frac{h}{g_a x T_c^2} \right)$$

$$\pi 2 = \left(\frac{a\, b c d e f g h}{g_a^8 \, x T_c^{16}} \right)$$

Related to Sand grain size – AFS Number

$$\pi 3 = \left(S_g \right)$$

Related to Sand Compactibility

$$\pi 4 = \left(S_c \right)$$

Related to Relative Humidity

$$\pi 5 = \left(RH \right)$$

Related to Temperature of molten metal and Ambient air Temp

$$\pi 6 = \left(\frac{T_m}{T_a} \right)$$

Hence equation for productivity becomes,

$$P = f \left(\frac{M_R M_b M_p}{S_S^3 \, x g_a^6 \, x T_c^{12}} \frac{a\, b c d e f g h j k}{g_a^{10} \, x T_c^{20}} \; S_g \, S_c \, RH \left(\frac{T_m}{T_a} \right) \right)$$

Dimensional analysis for dependent Pi terms

1. Productivity

*П01= (*P*)*

2. Human Energy input

$\Pi 02 = (S_s)^{a1} (g_a)^{b1} (T_c)^{c1} (HE)$

$(M^0 L^0 T^0) = (M^1 L^{-2} T^0)^{a1} (M^0 L^1 T^{-2})^{b1} (M^0 L^0 T^1)^{c1} (M L^2 T^{-2})$

For 'M'	For 'L'	For 'T'
$M \rightarrow 0 = a_1 + 1$	$L \rightarrow 0 = -2a_1 + b_1 + 2$	$T \rightarrow 0 = -2b_1 + c_1 - 2$
$a_1 = -1$	$0 = 2 + b_1 + 2$	$0 = 8 - 2 + c_1$
	$b_1 = -4$	$c_1 = -6$

$\Pi 02 = (S_s)^{-1} (g_a)^{-4} (T_c)^{-6} (HE)$

$$\pi 02 = \left(\frac{HE}{S_S\ g_a^4\ T_c^6} \right)$$

Hence final equation for dependent Pi term is as follows-

1. For productivity

$$\pi 01 = f\left(\frac{M_R M_b M_p}{S_S^3\, x g_a^6\, x T_c^{12}} \frac{a\, b c d e f g h j k}{g_a^{10}\, x T_c^{20}}\ S_g\, S_c\, RH \left(\frac{T_m}{T_a} \right) \right)$$

$$P = K\, f\left(\frac{M_R M_b M_p}{S_S^3\, x g_a^6\, x T_c^{12}} \frac{a\, b c d e f g h j k}{g_a^{10}\, x T_c^{20}}\ S_g\, S_c\, RH \left(\frac{T_m}{T_a} \right) \right) \quad \text{.................................(1)}$$

2. Human energy input

$$\pi 02 = f\left(\frac{M_R M_b M_p}{S_S^3\, x g_a^6\, x T_c^{12}} \frac{a\, b c d e f g h j k}{g_a^{10}\, x T_c^{20}}\ S_g\, S_c\, RH \left(\frac{T_m}{T_a} \right) \right)$$

$$(HE) = K S_S\ g_a^4\ T_c^6\, f\left(\frac{M_R M_b M_p}{S_S^3\, x g_a^6\, x T_c^{12}} \frac{a\, b c d e f g h j k}{g_a^{10}\, x T_c^{20}}\ S_g\, S_c\, RH \left(\frac{T_m}{T_a} \right) \right)$$

$$(HE) = K\, f\left(\frac{M_R\, M_b\, M_p}{S_S^2\, x g_a^2 x T_c^6}\ \frac{a\, b c d e\, f\, g\, h\, j\, k}{g_a^{10}\, x T_c^{20}}\ S_g\, S_c\, RH \left(\frac{T_m}{T_a} \right) \right) \qquad \text{……………………….(2)}$$

IV. CONCLUSION

It is seen for cylinder head moulding operation the dependent and independent terms were identified. The number of variables involved was large which are reduced by using dimensional analysis & pi terms. Buckingham pi theorem is used to set up dimensional equations to get the correlation between dependent and independent terms. A mathematical correlation is established between output parameters and input. The mathematical correlation reveals that which of the causes are to be maximized or minimized to optimize the responses. After formulation of the model, optimization will be carried out by using optimization techniques. The model will be useful for industries to select optimized inputs so as to get targeted responses.

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