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Formulation of a Field Data Based Model for a Surface Roughness using Response Surface Method

Mangesh R.Phate, Dr. V.H.Tatwawadi

Abstract— **This research paper focused on new approach of model formulation using response surface methodology (RSM) in the convectional turning (CT) of ferrous and nonferrous material. The data was collected from the actual field where the actual work is carried out. Random plan of experimentation based on the industry interests were considered for the data collection. The various independent parameters considered in this research are operator data, tool data, work piece data, cutting process parameters, machine data and the environmental parameters while the dependent parameter is surface quality achieved during the convectional turning process. The surface quality is measured in terms of surface roughness of the finished product.**

Index Terms— **Field data based Model, Response surface model, Bucking ham's pi therom and Convectional Turning.**

I. Introduction

Application of artificial neural networks is considerably simplifies the modelling methodology. There is no need to posses the function of input and output parameters in evident form. If only such a function exists it will be established through the network during the training process and it will be written down as weights individual neurons. However it is important that this function exists and has the regular and unique character. In most cases the failure of neural network creation is caused by the lack of the assignment function. Hence Response surface Methodology (RMS) is proposed to find out the relation between the group of input parameters and the response variable. H.S.Yoon et al. has proposed an orthogonal cutting force model based on slip-line field model for micro machining. Two material flow processes are being considered- chip formation process and ploughing. The paper takes into account the effects of parameters like effective rake angle, depth of deformation and minimum chip thickness. The edge radius effect is an important effect in machining processes. The tool can be scaled down to a large extent but the sharpness of the tool cannot be scaled down so drastically and proportionately. So, in micro machining ploughing force is a important factor instead of shearing force which is the dominant factor in conventional machining. Another important effect is the minimum chip thickness effect. When the undeformed chip thickness is below the minimum chip thickness, chip formation doesn't occur and there is only ploughing. However, when the unreformed chip thickness exceeds the minimum value, chip formation occurs. Some experimental analysis has shown that chip formation occurs only when the unreformed chip thickness is more than 30% of the tool edge radius. This paper is based on the assumption that the tool has a perfectly rounded tool edge. The cutting performed is assumed to be orthogonal. The material deforms plastically below the minimum chip thickness height. Another assumption is that the work material is not work-hardening. So, the shear stresses on all shear planes have the same values. The chip is also assumed to be a free body, such that the normal force on the shear plane is zero. The paper has also concentrated on the effect of the dead metal zones on micro machining. These zones act as stable built up edges on the tool, as stagnation zones where no material flow occurs. Several researchers have used this process for machining of wide variety of materials considering different process parameters. Suhail et al. optimizes the cutting parameters such as cutting speed, feed rate and depth of cut based on surface roughness and assistance of work piece surface temperature in turning process[1]. In machining operation the quality of surface finish is an important requirement for many turned work pieces. The work piece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimization process. So it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment. Kirby optimizes the turning process toward an ideal surface roughness target. This study seeks an actual target surface roughness value, which may allow for a higher feed rate depending upon that specified target[2]. In using the variation of the nominal the-best signal to noise formula, variation about a specified (ideal) value is explored and sought to be minimized. Singh optimizes tool life of Carbide Inserts for turned parts. The experiments were carried to obtain an optimal setting of turning process parameters- cutting speed, feed and depth of cut, this may result in optimizing tool life[3]. The relative power of feed in controlling variation and mean tool life is significantly smaller than that of the cutting speed and depth of cut. Mahto et al. optimizes the process parameters in vertical CNC mill machines[4]. The study was conducted in machining operation in hardened steel DIN GX40CRMOV5-1. The processing of the job was done by Tin coated carbide inserted end-mill tool under semi-finishing and finishing conditions of high-speed cutting. The milling parameters evaluated was cutting speed, feed rate and depth

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Mangesh R. Phate *,Assistant Professor, Mechanical Engg. Department, TSSM'S, Padmabhooshan Vasantdada Patil Institute of Technology, Bavdhan. Pune, MS, India, 91-9850330348.*

Dr.V.H.Tatwawadi*, Principal,Dr. Babasaheb Ambedkar Institute of Technology and Research ,Wanadongri,Nagpur, MS,India ,*

of cut. Thamizhmanii et.al analyses the surface roughness by turning process[5]. The optimum cutting conditions were predicted to get lowest surface roughness in turning SCM 440 alloy steel. The study revealed that the depth of cut has significant role to play in producing lower surface roughness followed by feed. Also the cutting speed has lesser effect on the surface roughness. Petropoulos et al. developed a predictive model of cutting force in longitudinal turning of St37 steel with a Tin coated carbide tool using Taguchi and Response surface techniques[6]. The model is formulated in terms of the cutting conditions namely feed, cutting speed and depth of cut.

II. INVESTIGATING MATERIAL & SURFACE ROUGHNESS

Ferrous and nonferrous materials are the most often species produced in the machining industry. These are delivered to the customer as semi-manufactured product or ready product in the form of long, round or squared bars, or (rarely) as sections, sheet metals and pipes. These are delivered as semi-manufactured product is manufactured as normalised; they reach customers after the normalising rolling or without any thermal processing (directly after the hot rolling). As ready products steels are delivered after heat treatment, manufactured according to conditions required by a customer or polish standards. As ready products steels are delivered after heat treatment, manufactured according to conditions required by a customer or polish standards.

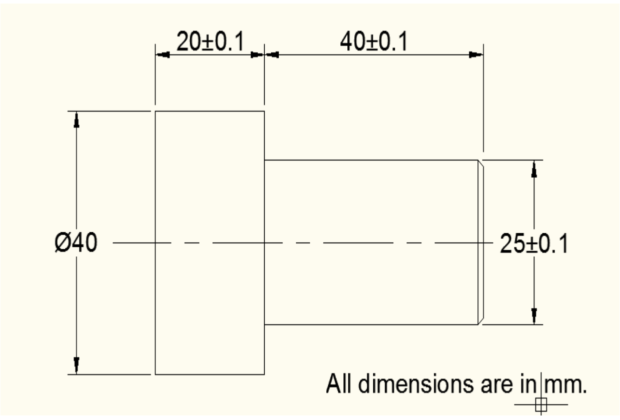

Fig 1 : Dimensions for the Finished Components .

Surface properties mainly surface roughness is a critical property related to the function ability of machine components. Increased understanding of the surface generation mechanisms can be used to optimize machining process and to improve component function ability. The research has shown two purposes. The first was to demonstrate numerous investigators have been conducted to determine the effect of parameters such as feed rate, tool nose radius, cutting speed and depth of cut on surface roughness in turning operation. The surface roughness decreases the use of Taguchi parameter design in order to identify the optimum surface roughness with particular combination of cutting parameters. The second was to demonstrate a systematic procedure using Taguchi design in process design of turning operations. In this experiment both were achieved. The surface roughness is given by the all four parameters such as Ra, Rq, Ry and Rt . The equation obtained by RSM method has agreement to the surface roughness by validation for set of input parameters.

III. PROCESS VARIABLES UNDER INVESTIGATION

The various process variables affecting the convectional turning are as mentioned in the table 1.

IV. FORMATION OF DIMENSIONLESS TERM

According to the theories of engineering experimentation by H. Schenck Jr. [12] the choice of primary dimensions requires at least three primaries, but the analyst is free to choose any reasonable set he wishes, the only requirement being that his variables must be expressible in his system. There is really nothing basis or fundamental about the primary dimensions. For this case, the variables are expressed in mass (M), length (L) and time (T).The final dimensionless pi term id as shown in table 2.

Total number of variables = 44; All these variables can be expressed in terms of three primary dimensions i.e. mass (M), Length (L) and Time (T). According to Bucking ham's theorem; One should get = 44 – 03 = 41 dimensionless terms

$$f(\Pi_1,\Pi_2,\Pi_3,\Pi_{4,}\ \Pi_5,\Pi_{6,}\ \Pi_7,\Pi_8,\Pi_9,\Pi_{10},\Pi_{11},\Pi_{12},\Pi_{13},\Pi_{13},\Pi_{14}-----,\Pi_{41})=0 \quad (1)$$

Choosing D, VC and FC as repeating variables, Still the number of term are too much which is very difficult to formulate the model on the basis of regression model . So by using grouping approach suggested by the H.Schenck [ ] six pi terms are formulated . The final dependent pi terms formulated are as shown in table 2.

$$\Pi D_1 = f(\Pi_{i1},\Pi_{i2,},\Pi_{i3},\Pi_{i4},\Pi_{i5},\Pi_{i6})=0 \quad (2)$$

V. MODEL FORMULATION BY USING RESPONSE SURFACE METHOD

A. *What is Response Surface Method?*

Response surface methodology (RSM) is a mathematical and statistical technique for empirical model formulation. By careful design of experiments for the data collection, the basic objective of using response surface methodology is to optimize a response (output variable) which is influenced by several independent variables (input variables). In this research random plan experiment is used for the observed data. A field data based approach for the data collection is used in this research En1A, En8,SS304,Al6063 and Brass is as shown in the following equation , as follows:

$$y = f(x_1,.x_2)+e \quad (3)$$

where e represents the error observed in the response *y*. The surface represented by *f*(*x*1, *x*2) is called a response surface.

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The response can be represented graphically, either in the three-dimensional space or as contour plots that help visualize the shape of the response surface. Contours are curves of were used for the convectional turning (CT) process. Total 585 observations has taken to formulate the model. The basis RSM model constant response drawn in the *xi*, *xj* plane keeping all other variables fixed.

Table 1 : List of Process Variable under Investigation

S.N	Variables	Symbol
1	Anthropometric ratio of the operator.	An
2	Weight of the operator.	W_p
3	Age of the operator.	AGP
4	Experience	EX
5	Skill rating	SK
6	Educational qualifications	EDU
7	Psychological Distress	PS
8	Systolic Blood pressure	SBP
9	Diastolic Blood pressure	DBP
10	Blood Sugar Level during Working	BSG
11	Cutting Tool angles ratio.	CTAR
12	Tool nose radius	R
13	Tool overhang length	Lo
14	Approach angle	α
15	Setting angle	β
16	Single point cutting tool Hardness	BHN
17	Lip or Nose angle of tool	LP
18	Wedge angle	WG
19	Shank Length	LS
20	Total length of the tool	LT
21	Tool shank width	SB
22	Tool shank Height	SH
23	Work piece hardness	BHNW
24	Weight of the raw work piece.	W
25	Shear stress of the work piece material	τ
26	Density of the work piece material	DST
27	Length of the raw workpiece	LR
28	Diameter of the raw workpiece	DR
29	Cutting Speed	VC
30	Feed	f
31	Depth of cut	D
32	Cutting force	FC
33	Tangential Force.	FT
34	Spindle revolution	N
35	Machine Specification ratio	MSP
36	Power of the Machine motor	HP
37	Weight of the machine	Wm
38	Age of the machine	AGM
39	Atmospheric Humidity	Φ
40	Atmospheric Temperature	DT
41	Air Flow	Vf
42	Light Intensity	LUX
43	Sound level	DB
44	**Surface roughness**	**SURF**

A. Model Formulation by using Response Surface Method:

As there are six basic pi terms were formulated to analyze the effect of various parameters listed in the table 1 . RSM is a tool which considered only three variable i.e. x1 (variable along X axis and x2 (variable along Y axis). Two eliminate the limitation of the variables six basic pi terms are converted in to two basic pi terms. The researcher can use any rule to fund out the basis two pi terms according to his interest. To formulate the RSM based field data based Model (FDBM) use following variables as x1 and x2

$$x_1 = \Pi_{i1} * \Pi_{i2,} * \Pi_{i3} \quad (4)$$

$$x_2 = \Pi_{i4} * \Pi_{i5} * \Pi_{i6} \quad (5)$$

Table 2. Final Independent and Dependent dimensionless Pi term

S	ter	Dimensionless ratio	Nature
1	πi_1	An*SBP*SK*Ag*Wp *SPO2 / DBP*PS*EDU*EX*BSG*D^3	Operator
2	πi_2	AR * r * β * BHNT * LT*LP*LS / α * LO* SW * SH * WG	Cutting tool
3	πi_3	BHNW * W raw* LR * τ / D * FC * DST * DR	Work piece
4	πi_4	f * FT * N * $Temp_{wp}$* VB $_{Tool}$ / VB $_{Machine}$ * FC*VC	Cutting process
5	π_{i5}	SP * P_{HP} * $W_{m/c}$ / AGM* FC^2	Lathe Machine
6	πi_6	HUM*DTO *V_f *DB*VC*FC/ LUX*D^3	Environmental data
7	**π_{D1}**	**Ra * Rq / Ry * Rt**	**SURF**

The data of x_1 , x_2 and π_{D1} were import in the MATLAB and the best fit were find for the data . The best equation is known as the best fir RSM equation .The best fit response surface models for the Ferrous and nonferrous materials are as follows.

Model 1: For Surface Roughness for the ferrous and nonferrous material

Goodness of fit:
SSE: 9.046
R-square: 0.06384
Adjusted R-square: 0.04812
RMSE: 0.1299

- Correlation Coefficient = 0.552103
- Root Mean Square =0.132766
- Reliability = 89.617%

$$\Pi D_1 = 2.148 - 3.279\,x_1 + 5.908 * x_2 + 0.2577\,x_1^2 - 0.5281\,x_1 x_2 + 0.06052\,x_2^2 - 0.005428\,x_1^3 + 0.01283\,x_1^2 x_2 - 0.00524\,x_1 x_2^2 + 0.002132\,x_2^3 \quad (6)$$

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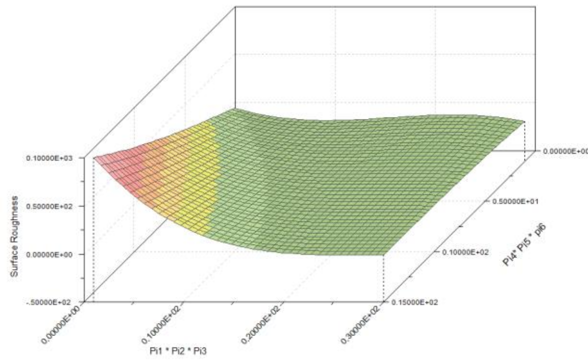

Fig 2 : Best fit response surface for the ferrous and the nonferrous materials.

Model 2: For Surface Roughness for the ferrous material

Goodness of fit:
SSE: 5.948
R-square: 0.09045
Adjusted R-square: 0.06487

RMSE: 0.1363

- Correlation Coefficient = 0.5996998
- Root Mean Square =0.14799877
- Reliability = 88.4930%

$$\prod D_1 = -99.21 + 11.3x_1 + 0.1717x_2 - 0.4356x_1^2 - 0.009121x_1x_2 - 0.03378x_2^2 + 0.005511x_1^3 + 0.0003651x_1^2x_2 - 0.001068x_1x_2^2 + 0.001806x_2^3 \quad (7)$$

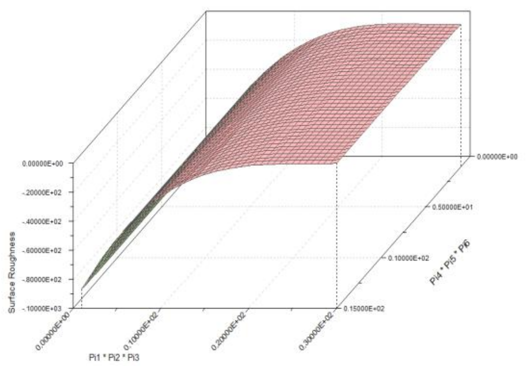

Fig 3 : Best fit response surface for the ferrous materials.

Model 3: For Surface Roughness for the nonferrous material

Goodness of fit:
SSE: 2.44
R-square: 0.1983
Adjusted R-square: 0.1632
RMSE: 0.1088

- Correlation Coefficient = 0.6442784
- Root Mean Square =0.117937
- Reliability = 90.5597%

$$\prod D_1 = 144.1 - 20.69x_1 + 6.338x_2 + 1.361x_1^2 - 2.215x_1x_2 - 1.794x_2^2 - 0.03467x_1^3 + 0.08414x_1^2x_2 - 0.08169x_1x_2^2 + 0.005317x_2^3 \quad (8)$$

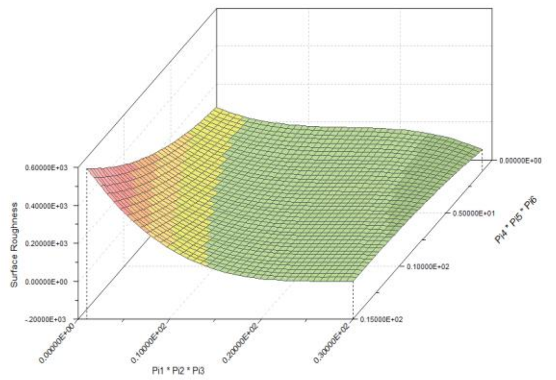

Fig 4 : Best fit response surface for the nonferrous materials.

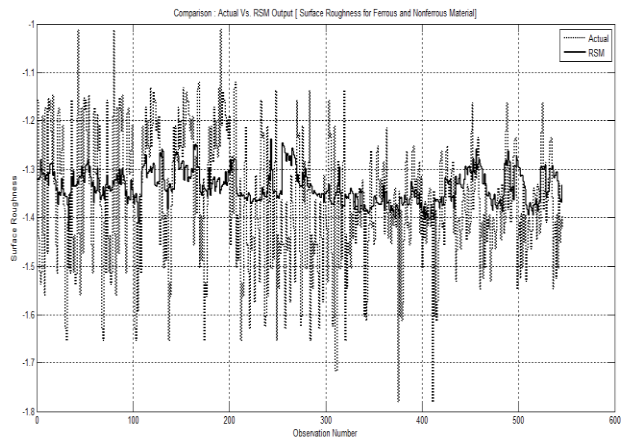

Fig 5 : Comparison between actual and Computed values for surface roughness by RSM for ferrous and nonferrous material.

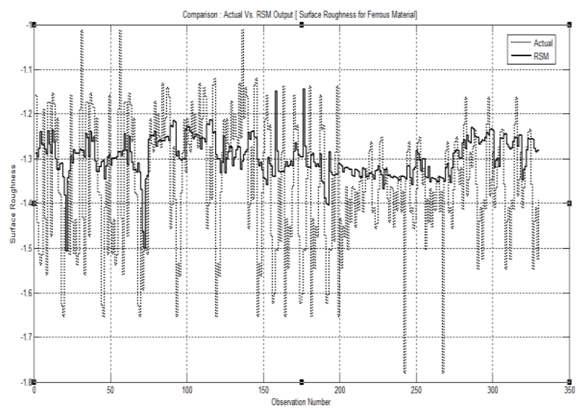

Fig 6 : Comparison between actual and Computed values for surface roughness by RSM by RSM for ferrous material.

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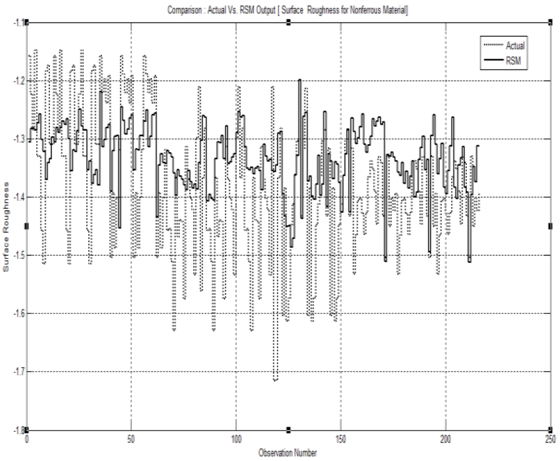

Fig 7 : Comparison between actual and Computed values for surface roughness by RSM by RSM for nonferrous material.

VI. ANALYSIS OF THE FORMULATED MODEL

The models have been formulated by using response surface method. A best fit response surface field data based models are evolved for predicating the surface roughness in the turning of ferrous and nonferrous materials. This includes application of Dimensional Analysis is quite simple way in which a given test can be made compact in operating plan. In this research we may be able to recognize all the variables that influence the response surface , but we should realize that they and their dimensional equation have reality whether or not it is apparent. The response equation and the surface of the model shows how the phenomenon is getting affected because of the interaction of various independent pi terms in the models. The obtained 3D Surface plots of Surface roughness pi term vs. group of input parameters along X and Y axis are shown in figures 2, 3 and 4. These figures were obtained using response surface methodology (RSM) according to their response surface best fit equation using LABFIT software.

VII. CONCLUSION

The models values of the dependent pi terms are computed. The observed and computed values of the surface roughness pi terms are compared by calculating their reliability ,root mean square and the correlation coefficient. In order to check the accuracy of the predicted / computed values of the Response surface methodology is found to be a successful technique to perform trend analysis of surface roughness with respect to various combinations of input variables (Operator, tool, work piece, cutting process, machine and environmental parameters).

1) The best fit model with third -order mathematical models are found to adequately represent the surface roughness.

2) It is observed that the predicted and measured values are close to each other. Therefore the proposed model can be used to predict the corresponding surface roughness of ferrous and nonferrous materials at different parameters in turning.

3) With the model equations obtained, a designer can subsequently select the best combination of design variables for achieving optimum or minimum surface roughness and corresponding input parameters during turning process. This eventually reduces the surface roughness which can provide better surface quality

APPENDIX

Sample value of the measured and predicted surface roughness ratio.

S.N	X_1	X_2	Measur	Predicted
1	24.7490	14.3261	-1.1585	-1.428709
2	23.2739	13.82427	-1.4435	-1.445735
3	22.4276	13.51722	-1.5136	-1.420312
4	21.7979	12.80473	-1.5378	-1.386769
5	22.1999	13.31398	-1.5155	-1.407791
6	21.5843	13.54287	-1.1904	-1.405901
7	22.2250	13.65929	-1.4338	-1.421733
8	23.0612	13.86187	-1.5603	-1.443443
9	24.6489	14.44959	-1.1747	-1.419964
10	21.2155	13.53761	-1.1741	-1.404112
61	21.9913	12.70308	-1.1741	-1.386022
62	22.6360	13.44375	-1.3102	-1.421878
63	23.4867	13.65183	-1.3102	-1.443566
64	25.4088	14.29166	-1.1871	-1.397347
65	24.6763	14.76886	-1.2621	-1.389321
66	23.8775	14.91843	-1.2107	-1.405727
67	23.1390	14.92619	-1.3756	-1.435745
68	22.7321	14.74953	-1.3826	-1.453651
69	21.8396	14.35715	-1.6287	-1.459565
70	19.8834	12.38927	-1.6538	-1.428579
71	19.3983	12.04357	-1.4099	-1.506564
72	19.6431	12.09232	-1.3524	-1.479394
73	19.9191	12.31175	-1.5141	-1.434356
74	24.7368	14.96759	-1.1585	-1.356312
75	23.2432	14.39351	-1.4435	-1.447346
76	22.3564	14.08877	-1.5136	-1.440819
77	21.8964	13.81444	-1.4373	-1.424058
78	21.8491	13.75923	-1.5378	-1.420664
79	22.2136	13.92698	-1.5155	-1.432842
80	21.5949	13.85674	-1.1904	-1.425035

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Author Profile

Mangesh R.Phate born in Amravati, MS, INDIA in 1980. He received Bachelor of Engineering degree from Amravati University and M.Tech degree in Production Engineering from Nagpur University in 2002 and 2005 respectively. He also received M.B.A degree in human resources management in 2008. He is pursuing Ph.D degree in Mechanical Engineering from RTM Nagpur University. He has more than 10 publications in the national and international journals and conferences. He is now working as an Assistant Professor in TSSM'S, Padmabhooshan Vasantdada Patil institute of Technology ,Bavdhan ,Pune,MS, INDIA. His main interest is in Designing, Manufacturing, Modeling and Simulation. He is having 10 year of teaching and Industrial experience. He is a life member of ISTE. He received Gold Medals from RTM Nagpur University in M.Tech 2005 examination, Nagpur.

Dr. V. H. Tatwawadi is working as a Principal, Dr. Babasaheb Ambedkar Institute of Technology & Research s,Wanadongri,Nagpur, India. He is B.E. (Mechanical), M.Tech (Production Engg.) and Ph.D. in Mechanical Engineering. His research areas are Mechanical Engineering, Production Engineering and ergonomics. He was Head of Production Engg. Department at YCCE, Nagpur (India). He is in the field of teaching for last twenty five years. Dr Tatwawadi has several publications in National and International Journals. He has attended 2009 summer faculty program at Arizona State University.