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Dynamic Structural Analysis of Great Five-Axis Turning-Milling Complex CNC Machine

By C.C. Hong, Cheng-Long Chang & Chien-Yu Lin
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Abstract- The computer aided engineering (CAE) with commercial software is used to analyze the free vibration frequencies, linear dynamic stress and deformation for secondary shaft system, primary shaft system and machinery bed in great five-axis turning-milling complex computer numerical control (CNC) machine. It is reasonable to use CAE software in the CNC intelligent manufacturing processes for time saving, component quantity upgrading and engineer training. It is desirable to select the maximum displacement and natural frequencies values as the basic data to design the CNC machine in safety condition for avoiding resonance. It is also valuable to design and choose the good region of rotational speed for the motors in the CNC system to provide a smoothly operation by using not in the same values of natural frequencies. The natural frequencies, linear dynamic stresses and displacements of total CNC machinery are obtained by using the commercial computer software SOLIDWORKS® 2014 simulation module.

Keywords: *CAE, frequencies, dynamic, stress, deformation, CNC.*

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DYNAMICSTRUCTURALANALYSISOFGREATFIVEAXISTURNINGMILLINGCOMPLEXCNCMACHINE

Dynamic Structural Analysis of Great Five-Axis Turning-Milling Complex CNC Machine

C.C. Hong α, Cheng-Long Chang σ & Chien-Yu Lin ρ

Abstract- The computer aided engineering (CAE) with commercial software is used to analyze the free vibration frequencies, linear dynamic stress and deformation for secondary shaft system, primary shaft system and machinery bed in great five-axis turning-milling complex computer numerical control (CNC) machine. It is reasonable to use CAE software in the CNC intelligent manufacturing processes for time saving, component quantity upgrading and engineer training. It is desirable to select the maximum displacement and natural frequencies values as the basic data to design the CNC machine in safety condition for avoiding resonance. It is also valuable to design and choose the good region of rotational speed for the motors in the CNC system to provide a smoothly operation by using not in the same values of natural frequencies. The natural frequencies, linear dynamic stresses and displacements of total CNC machinery are obtained by using the commercial computer software SOLIDWORKS® 2014 simulation module.

Keywords: CAE, frequencies, dynamic, stress, deformation, CNC.

I. Introduction

It is desirable to reduce the development time for the machinery parts by using structural analysis program in computer aided engineering (CAE) and by preparing three dimensional (3D) diagram in computer aided design (CAD). In 2016, Wang et al. [1] used a CAD/CAE integrated reanalysis design system to shorten the design cycle for vehicular development. In 2015, Chen et al. [2] presented the intelligent manufacturing processes in a computer numerical control (CNC) system by using a cyber-physical system (CPS) models. In 2014, Mourtzis et al. [3] presented the CAE simulation in the computer aided technologies (CAx) is essential for digital manufacturing. In 2009, Lee and Han [4] predicted automotive fatigue by using the finite element (FE) model of CAE structural analysis. In 2006, Zhang and Han [5] reduced the development time for dynamic and acoustic of CAE analyses in engine designs. In 2003, Zhang et al. [6] used the CAE programs written with FORTRAN and C languages to investigate the dynamic behaviors of a CNC machining tool. In 1990, Doyle and Case [7] presented the CAE commercial software in the manufacturing engineering for the students education. There are some commercial CAE simulation software: e.g. CATIA®, ANSYS®, SOLIDWORKS®, Creo®, Inventor®, FreeCAD, NX™ Nastran®, Abaqus®, HyperSizer®, midas® etc.. In 2014, Vivekananda et al. [8] used ANSYS® to compute the natural frequency of vibration for ultrasonic assisted turning (UAT) in machining process. In 2013, Euan et al. [9] used the Matlab® to simulate dynamic cutting forces for ceramic milling tools.

For the great five-axis turning-milling complex CNC machine stiffness design, analysis and construction, in 2016, Hong et al. [10] used the SOLIDWORKS® CAE software to obtain the linearly static stresses and displacements for the secondary shaft system, primary shaft system and machinery bed. It is interesting to analyze the dynamic structural stiffness design of great five-axis turning-milling complex CNC machine by using commercial CAE software. In this paper, the natural frequencies, linearly dynamic stresses and displacements of secondary shaft system, primary shaft system and machinery bed of CNC machines are obtained by using the SOLIDWORKS® simulation module. The maximum values of linear dynamic stress and displacement are also provided to give a reference and prediction in the future construction of complex CNC machine.

II. Method of Simulations

In the linear dynamic structural analysis with considering inertial force, damping force and impact force, without considering the nonlinear state of the contact surface. A general matrix equation of mathematical model is used in the SOLIDWORKS® simulation module computer program to solve for vibration frequency, stress and displacement results as follows,

$$[M]\{\ddot{u}(t)\}+[C]\{\dot{u}(t)\}+[K]\{u(t)\}=\{f(t)\}, \quad (1)$$

where $[M]$ is material mass matrix, $[C]$ is damping matrix, $[K]$ is material stiffness matrix, $\{\ddot{u}(t)\}$ is acceleration vector varied with time t, $\{\dot{u}(t)\}$ is velocity vector varied with t, $\{u(t)\}$ is displacement vector varied with t, $\{f(t)\}$ is external load vector also varied with t.

To use the commercial CAE software and run the linear dynamic results for complex CNC machine, firstly it is necessary to prepare the assembling 3D parts

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of great five-axis turning-milling complex CNC machine as shown in Fig. 1 and presented by Hong et al. [10]. The dimensions of main parts are provided respectively, for machinery bed is 8470mm x 1463mm x 783mm, for primary shaft system is 1190.5mm x 940mm x 860mm, for secondary shaft system is 1397m x 845mm x 1426mm, for work piece is cylindrical column with diameter mm and length 5000mm. There are three positions (0mm, 4000mm and 6900mm) of secondary shaft system can be moved from 0mm to 6900mm, used to computed and analyzed for the CNC machine. Secondly, it is necessary to define the individual material of assembling 3D parts for great five-axis turning-milling complex CNC machine. The materials of main parts are given, for machinery bed, shaft systems and work piece are cast iron. The yield stress of cast iron material is 275MPa. To prevent failure in the CNC machine, the linear dynamic value of working stress in each material of components should smaller than its yield stress value. There are five types of clamp supported (4, 8, 14, 20 and 36 positions) boundary conditions of machinery bed are used to computed and analyzed for the CNC machine linear dynamic studies. The supported positions at one side are matched to another side, e.g. the total 36 positions with 18 positions at each side of machinery bed. To find the more suitable number meshes used in the computation and analyses for the CNC machine dynamic results, it is necessary to make convergence study of meshes. There are 200.00mm, 160.00mm, 155.00mm, 150.00mm and 145.00mm of maximum size lengths of five type meshes used to find the natural frequency converged values of total machinery bed.

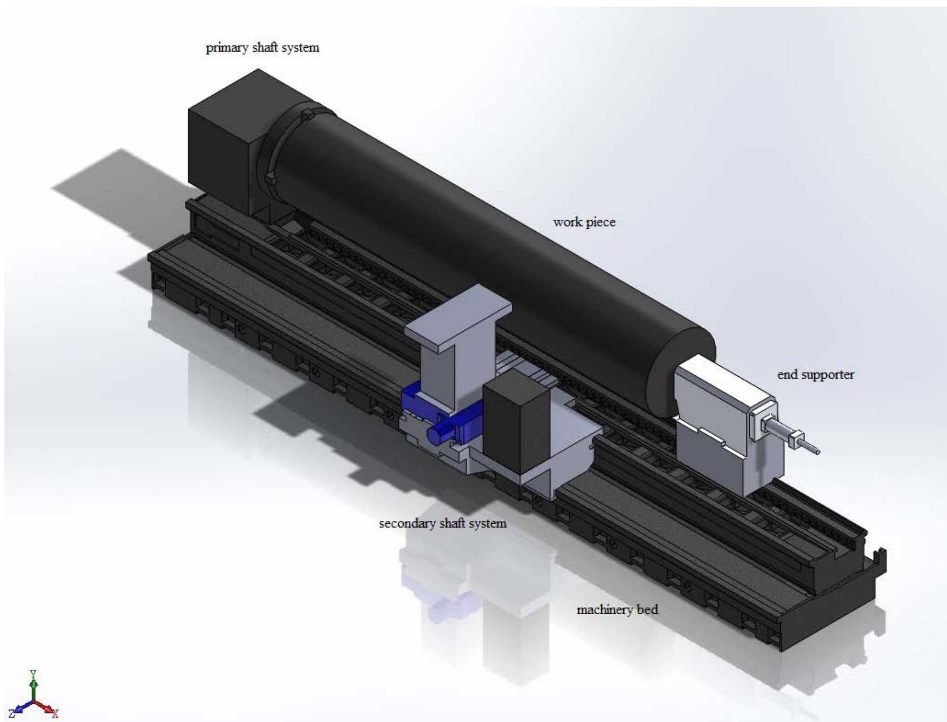

Figure 1: Assembling 3D parts of great five-axis turning-milling complex CNC machine

III. Results and Discussions

a) Convergence results

Convergence results of free vibration frequencies values of 1st mode in total 36 positions clamp supported machinery bed with secondary shaft system at 0mm location in CNC machine are listed in the Table 1. There are 200.00mm, 160.00mm, 155.00mm, 150.00mm and 145.00mm for maximum size length to calculate and study the vibration frequencies for first 1 mode of total machinery. The error of vibration frequencies is 7.783e-05 for 150.00mm and 145.00mm maximum size lengths. The mesh grids of maximum size length 150.00mm can be considered in good dynamical convergence condition, natural frequency converges to 25.694Hz and used this grids to calculate the stresses and displacements for further dynamic computation with the SOLIDWORKS® 2014 simulation module.

b) Dynamic results due to free vibration

Dynamic 1st mode displacement results of total 4, 8, 14, 20 and 36 positions clamp supported machinery bed (weight 13 tons) with secondary shaft system located at x axis: 0mm in CNC machine due to free vibration effect are shown in Figs. 2-6, the compared value of maximum displacement are shown in Table 2, the maximum value of dynamic 1st mode displacement is 8.641mm for total 4 clamp position, free vibration frequencies values of first 5 modes are shown

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in Table 3, the frequencies values of all first 5 modes are increasing with total numbers of clamps (e.g. from 16.238Hz to 25.694Hz for mode 1). When the secondary shaft system moved and located at x axis: 4000mm in CNC machine due to free vibration effect, dynamic first 5 modes displacement results of total 36 clamp positions are shown in *Figs. 7-11*, the maximum value of dynamic 5th mode displacement is 12.17mm. When the secondary shaft system moved and located at x axis: 6900mm in CNC machine due to free vibration effect, dynamic first 5 modes displacement results of total 36 clamp positions are shown in *Figs.12-16*, the maximum value of dynamic 5th mode displacement is 12.31mm. The compared values of first 5 modes maximum displacement and frequencies values due to free vibration effect for secondary shaft system located at x axis: 0mm, 4000mm and 6900mm of total 36 clamp positions are shown in *Tables 4-5*, respectively. The maximum displacement and frequencies values are selected as the basic data to design the CNC machine in safety condition for avoiding resonance, e.g. the rotational speed of motor used might not be in the low speed regions nearly 245.3596rpm for mode 1 of 36 positions clamp (25.694Hz).

c) Dynamic results under torque load

It needs a lot of computer memory 118GB to run the results of linear dynamic simulation, it is necessary for hard disk to occupy 500GB memory and execute its program. For secondary shaft system locates at x axis: 0mm of total 36 clamp positions of CNC machine under torque load 10000Nm applied at rotational head of primary shaft system, the linear dynamic results of stress and displacement are shown in *Figs.17-18*. The dynamic maximum stress (4.7MPa) occurred at the bottom corner of primary shaft system and maximum displacement (0.01889mm) occurred at jaw corner of primary shaft system are found. For secondary shaft system locates at x axis: 0mm, 4000mm and 6900mm of total 36 clamp positions of CNC machine under torque load 10000Nm applied at work piece, the linear dynamic results of stress and displacement are shown in *Figs.19-24*, respectively. The dynamic maximum stress (6.6MPa) and displacement (0.02168mm) occurred at jaw corner of primary shaft system are found when secondary shaft locates at x axis: 0mm, the dynamic maximum stress (6.7MPa) and displacement (0.02586mm) occurred at jaw corner of primary shaft system are found when secondary shaft locates at x axis: 4000mm, the dynamic maximum stress (6.8MPa) and displacement (0.02572mm) occurred at jaw corner of primary shaft system are found when secondary shaft locates at x axis: 6900mm.

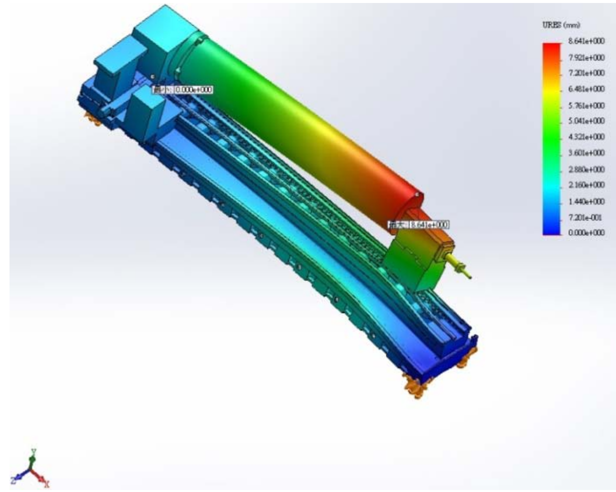


Figure 2: Dynamic 1st mode displacement for total 4 clamp positions for secondary shaft system at x axis: 0mm

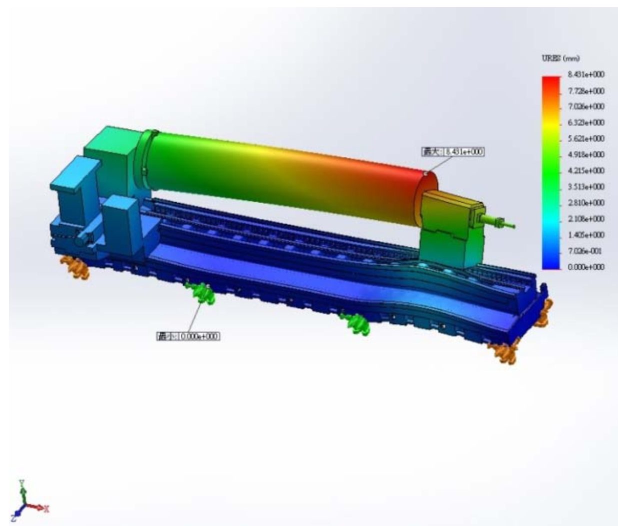


Figure 3: Dynamic 1st mode displacement for total 8 clamp positions for secondary shaft system at x axis: 0mm

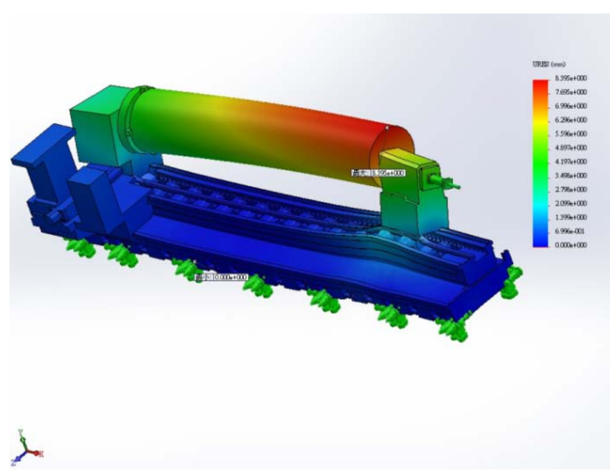
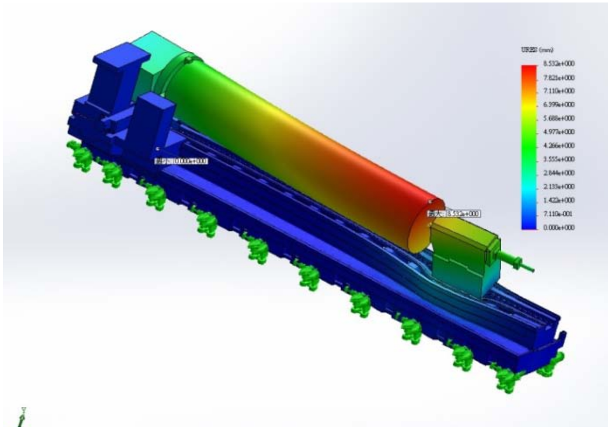


Figure 4: Dynamic 1st mode displacement for total 14 clamp positions for secondary shaft system at x axis: 0mm



Figurer 5: Dynamic 1st mode displacement for total 20 clamp positions for secondary shaft system at x axis: 0mm

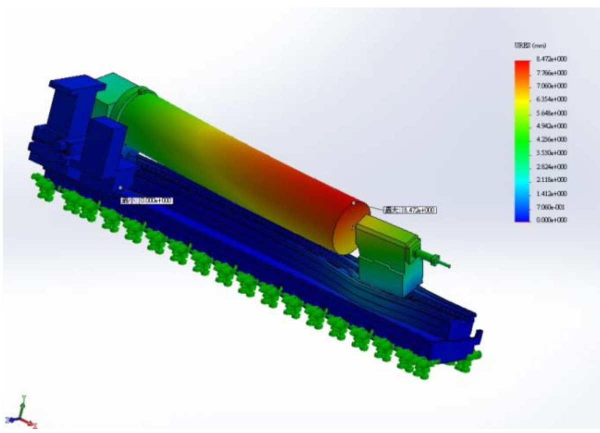


Figure 6: Dynamic 1st mode displacement for total 36 clamp positions for secondary shaft system at x axis: 0mm

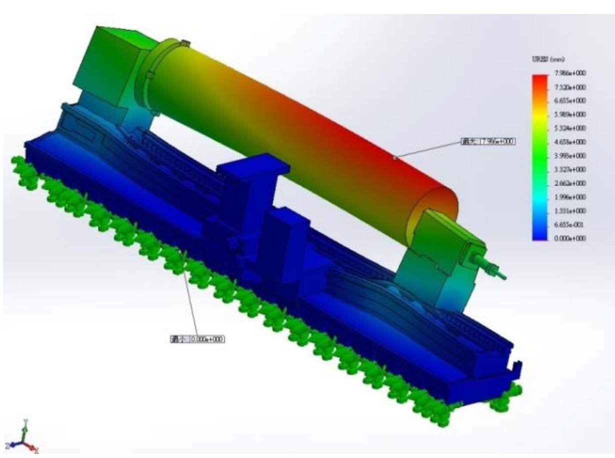


Figure 7: Dynamic 1st mode displacement for total 36 clamp positions for secondary shaft system at x axis: 4000mm

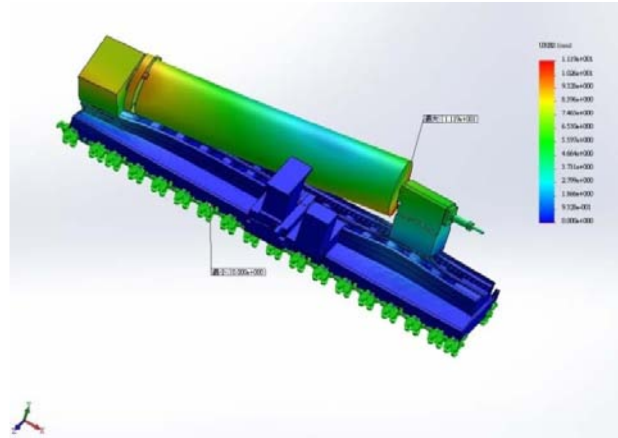


Figure 8: Dynamic 2nd mode displacement for total 36 clamp positions for secondary shaft system at x axis: 4000mm

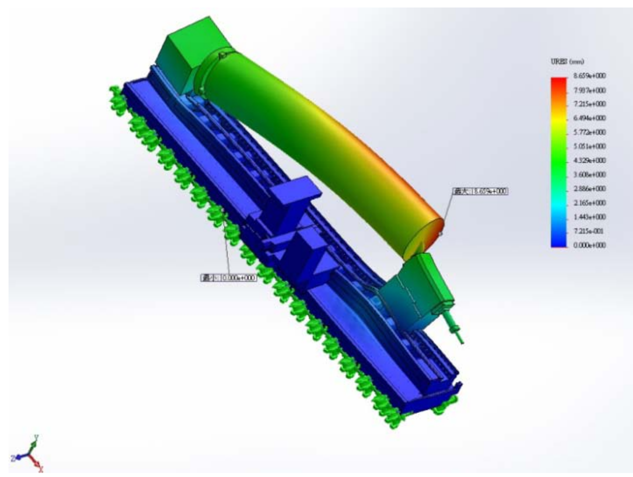


Figure 9: Dynamic 3rd mode displacement for total 36 clamp positions for secondary shaft system at x axis: 4000mm

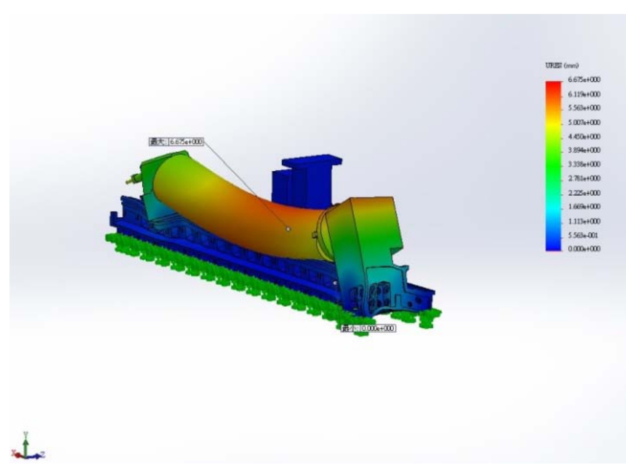


Figure 10: Dynamic 4th mode displacement for total 36 clamp positions for secondary shaft system at x axis: 4000mm

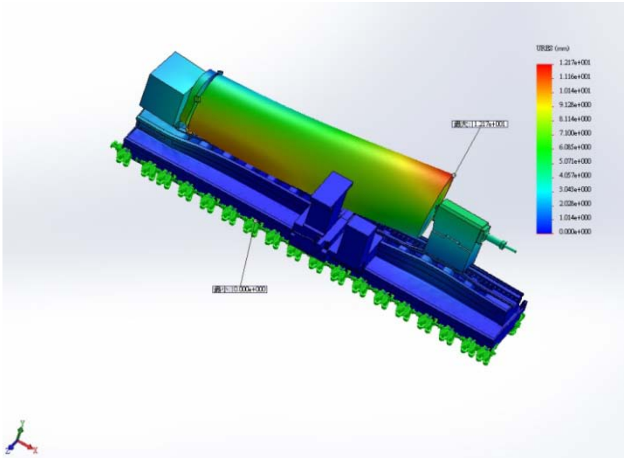


Figure 11: Dynamic 5th mode displacement for total 36 clamp positions for secondary shaft system at x axis: 4000mm

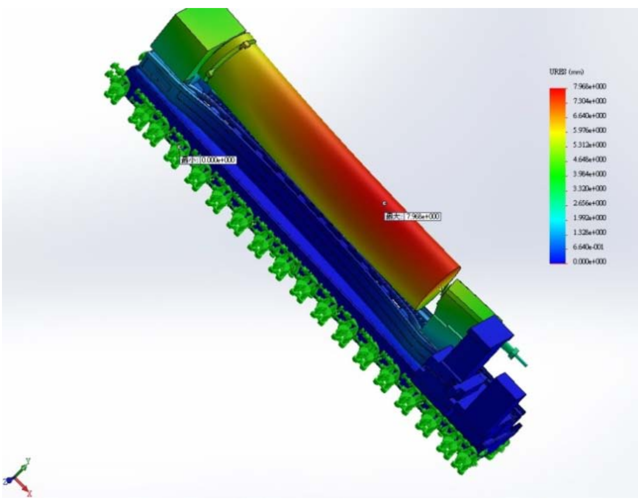


Figure12: Dynamic 1st mode displacement for total 36 clamp positions for secondary shaft system at x axis: 6900mm

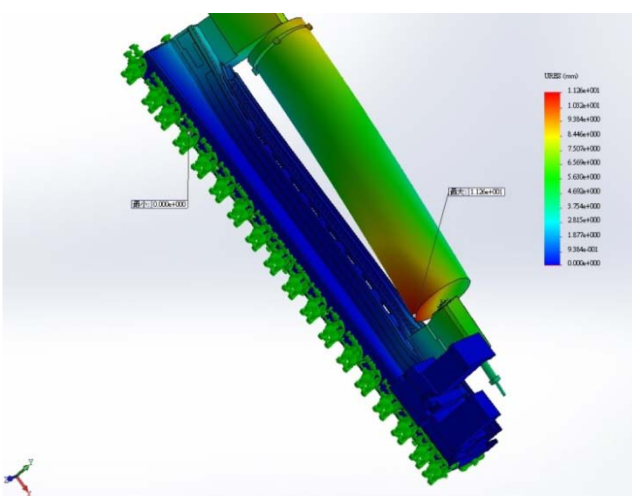


Figure 13: Dynamic 2nd mode displacement for total 36 clamp positions for secondary shaft system at x axis: 6900mm

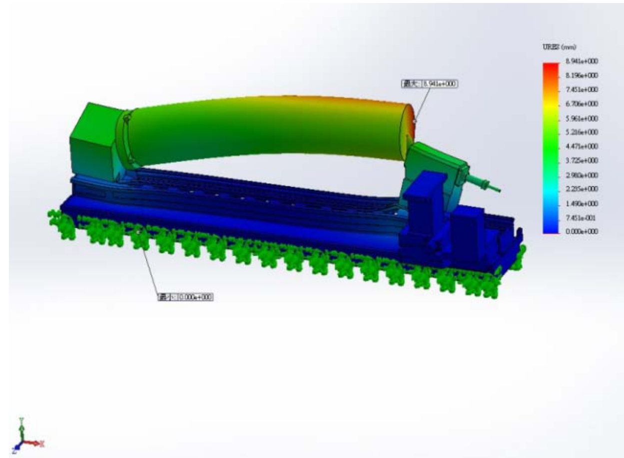


Figure 14: Dynamic 3rd mode displacement for total 36 clamp positions for secondary shaft system at x axis: 6900mm

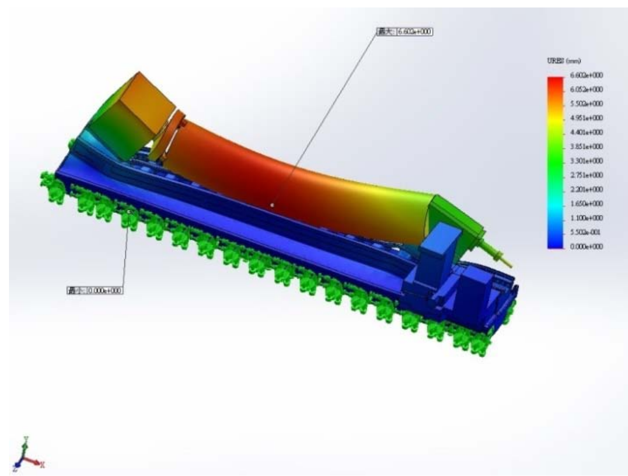


Figure 15: Dynamic 4th mode displacement for total 36 clamp positions for secondary shaft system at x axis: 6900mm

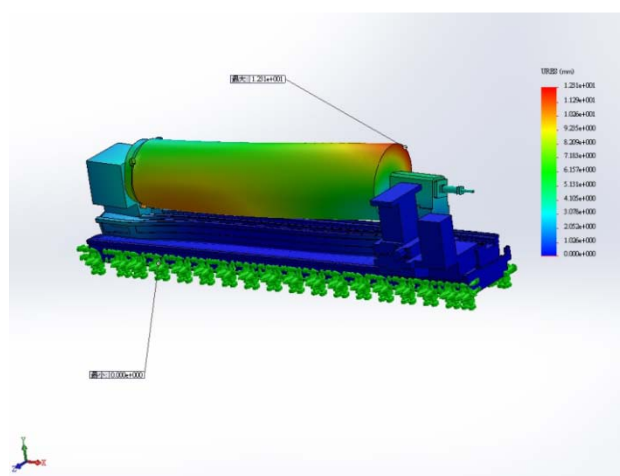


Figure 16: Dynamic 5th mode displacement for total 36 clamp positions for secondary shaft system at x axis: 6900mm

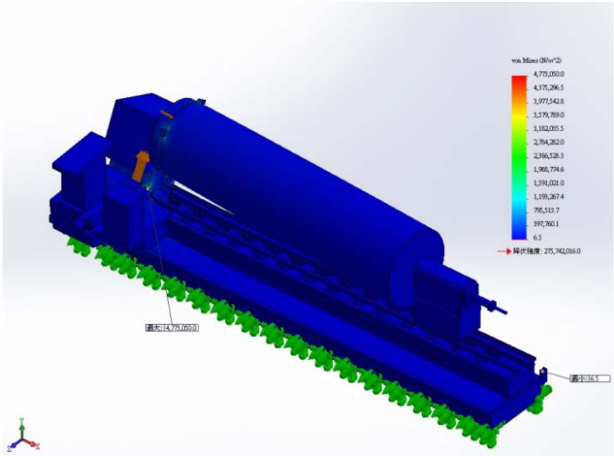


Figure 17: Stress for secondary shaft system at x axis: 0mm under torque 10000Nm at head of primary shaft

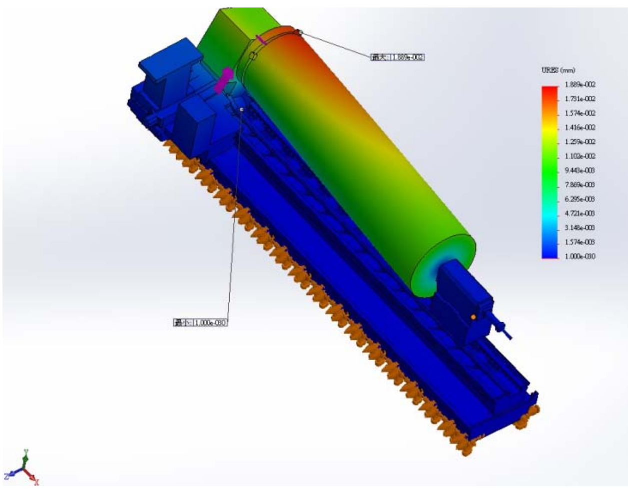


Figure18. Displacement for secondary shaft system at x axis: 0mm under torque 10000Nm at head of primary shaft

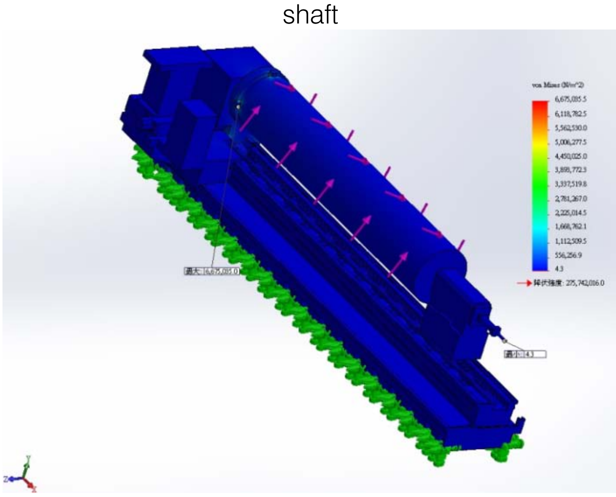


Figure 19: Stress for secondary shaft system at x axis: 0mm under torque 10000Nm at work piece

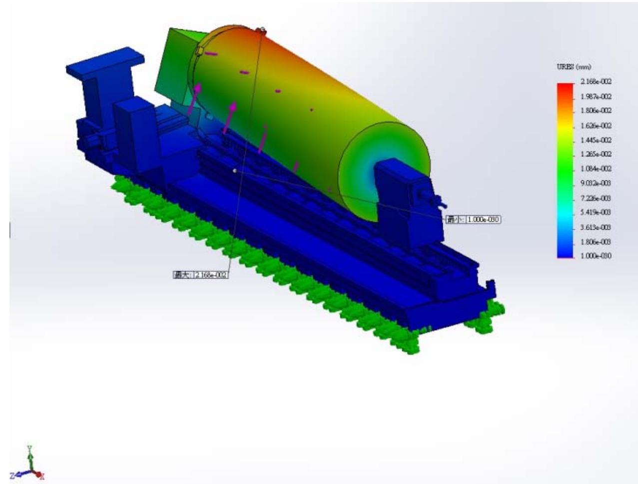


Figure 20: Displacement for secondary shaft system at x axis: 0mm under torque 10000Nm at work piece

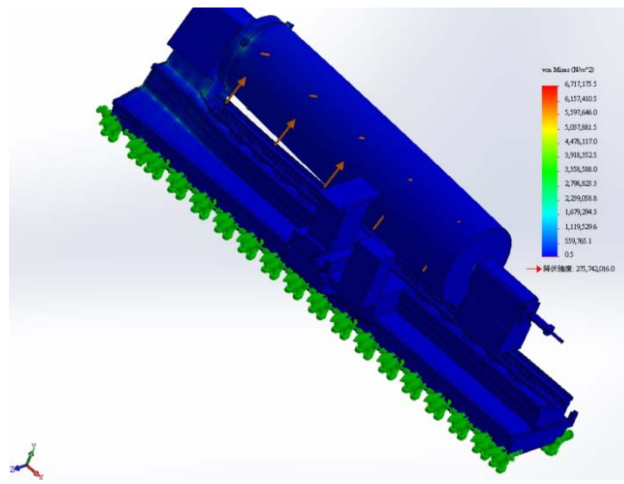


Figure 21: Stress for secondary shaft system at x axis: 4000mm under torque 10000Nm at work piece

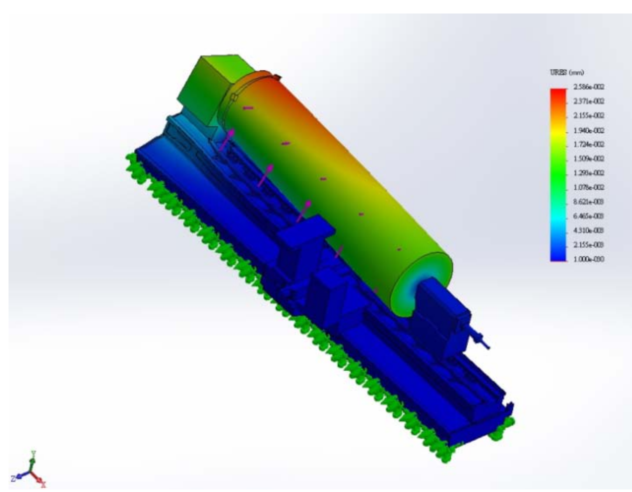


Figure 22: Displacement for secondary shaft system at x axis: 4000mm under torque 10000Nm at work piece

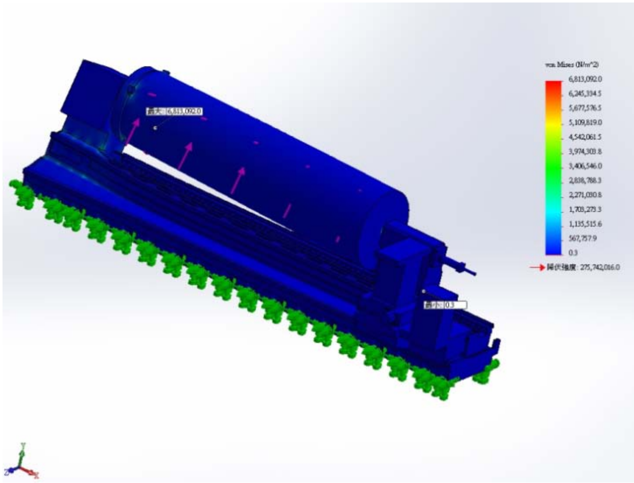


Figure 23: Stress for secondary shaft system at x axis: 6900mm under torque 10000Nm at work piece

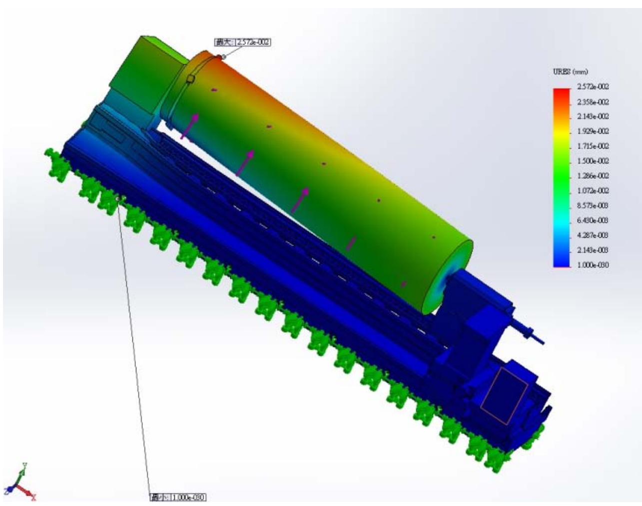


Figure 24: Displacement for secondary shaft system at x axis: 6900mm under torque 10000Nm at work piece

IV. Conclusion

In this paper, the free vibration frequencies values, linear dynamic stresses and displacements of secondary shaft system, primary shaft system and machinery bed of CNC machines are obtained by using the SOLIDWORKS® 2014 simulation module. The frequencies values, dynamic stress and displacement for five types of clamp supported boundary conditions and three positions of secondary shaft located in machinery bed under free vibration and torque loads are studied. It is desirable to select the maximum displacement and natural frequencies values as the basic data to design the CNC machine in safety condition for avoiding resonance. The maximum values of linear dynamic stress and displacement are also given and considered as the referred values for the judgments of yielding status and safety condition in the future construction of CNC machine.

V. Acknowledgements

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Table 1: Convergence results

Maximum mesh grid sizes	Frequencies of 1st mode
200.00mm	25.822Hz
160.00mm	25.743Hz
155.00mm	25.721Hz
150.00mm	25.694Hz
145.00mm	25.696Hz

Table 2: Maximum displacements (mm) when secondary shaft at x axis: 0mm

Modes	Boundary conditions				
	4 clamps	8 clamps	14 clamps	20 clamps	36 clamps
Mode 1	8.641mm	8.431mm	8.395mm	8.532mm	8.472mm
Mode 2	7.999mm	9.841mm	10.44mm	9.962mm	10.06mm
Mode 3	7.338mm	7.785mm	8.844mm	9.899mm	9.965mm
Mode 4	9.326mm	6.893mm	7.012mm	6.701mm	6.739mm
Mode 5	13.34mm	14.66mm	13.02mm	10.60mm	11.23mm

Table 3: Free vibration frequencies (Hz) when secondary shaft at x axis: 0mm

Modes	Boundary conditions				
	4 clamps	8 clamps	14 clamps	20 clamps	36 clamps
Mode 1	16.238Hz	21.135Hz	24.043Hz	25.106Hz	25.694Hz
Mode 2	25.579Hz	34.006Hz	38.533Hz	40.825Hz	41.344Hz
Mode 3	30.677Hz	37.979Hz	40.954Hz	43.559Hz	44.088Hz
Mode 4	31.408Hz	40.342Hz	45.080Hz	45.279Hz	46.734Hz
Mode 5	40.885Hz	53.836Hz	63.058Hz	66.638Hz	68.290Hz

Table 4: Maximum displacements (mm) for total 36 clamp positions

Modes	Secondary shaft system		
	at x axis: 0mm	at x axis: 4000mm	at x axis: 6900mm
Mode 1	8.472mm	7.986mm	7.968mm
Mode 2	10.06mm	11.19mm	11.26mm
Mode 3	9.965mm	8.659mm	8.941mm
Mode 4	6.739mm	6.675mm	6.602mm
Mode 5	11.23mm	12.17mm	12.31mm

Table 5: Free vibration frequencies (Hz) for total 36 clamp positions

Modes	Secondary shaft system		
	at x axis: 0mm	at x axis: 4000mm	at x axis: 6900mm
Mode 1	25.694Hz	24.616Hz	25.249Hz
Mode 2	41.344Hz	37.936Hz	38.738Hz
Mode 3	44.088Hz	43.413Hz	43.653Hz
Mode 4	46.734Hz	46.054Hz	46.268Hz
Mode 5	68.290Hz	68.723Hz	69.046Hz

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The Effect of Supersonic Flows on Different Profiles of Aircraft Wings

By Ahmed Soliman M. Sherif
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Abstract- When a supersonic stream flows around a thin profile, the pressure acting on the surface element does not depend on the shape of the rest of the profile, but depends only on the slope of the element itself, that is, on the local angle of attack. The local angle of attack is the angle between the surface element and the velocity vector of the undisturbed flow Coefficient of pressure.

Keywords: supersonic stream flows, angle of attack, angle of rotation, pressure of surface profiles, coefficient of pressure.

GJRE-A Classification: FOR Code: 120499

Strictly as per the compliance and regulations of:

The Effect of Supersonic Flows on Different Profiles of Aircraft Wings

Ahmed Soliman M. Sherif

Abstract- When a supersonic stream flows around a thin profile, the pressure acting on the surface element does not depend on the shape of the rest of the profile, but depends only on the slope of the element itself, that is, on the local angle of attack. The local angle of attack is the angle between the surface element and the velocity vector of the undisturbed flow Coefficient of pressure. $C_p = -\frac{2\cdot\Theta}{\sqrt{M_\infty^2-1}}$,

Θ– Angle of rotation (local angle of attack).

Keywords: supersonic stream flows, angle of attack, angle of rotation, pressure of surface profiles, coefficient of pressure.

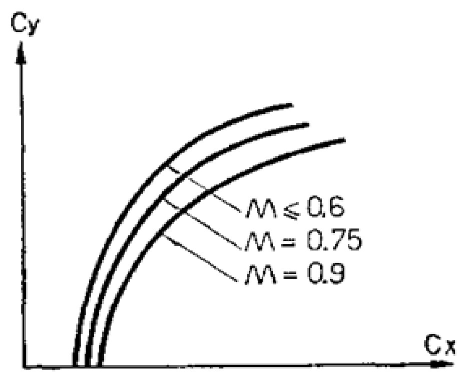

Fig.1

It can be seen from the graph **1**. that the most advantageous angle of attack of an airplane is greater than the most advantageous angle of attack of the wing by $(2^\circ \div 3^\circ)$.

I. Introduction

The aim of my research is Determining the coefficient of profile-wave resistance for the four profiles which shown with relative thickness $\bar{c}=5\%$, With the number $M_\infty=2.5$. Construct the pressure distribution diagram for each profile at angles of attack $\alpha = 0,-5^\circ,+5^\circ$.

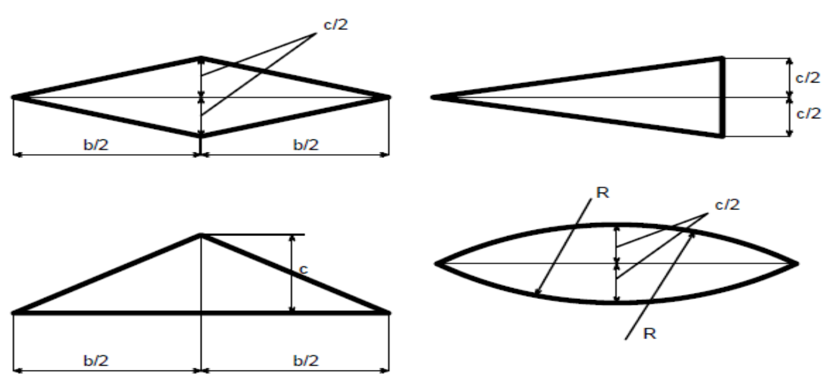

Fig. 2: four profiles shown with relative thickness

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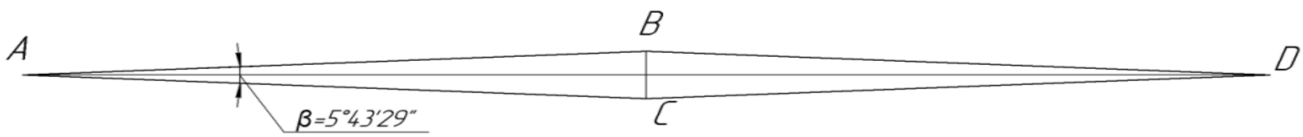
II. Working Process of the Research

Profile 1.

$$tg\left(\frac{\beta}{2}\right) = \frac{5}{100} = 0.05$$

$$\frac{\beta}{2} = 0.049958 \text{ rad} = 2.862405° = 2°51'45''$$

$$\beta = 0.099917 \text{ rad} = 5.724811° = 5°43'29''$$



Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{-5°} = \mathbf{-0.08727}$ rad

Area AB

$$\Theta_{AB} = \alpha - \frac{\beta}{2} = -0.08726646 - 0.0499584 =$$

$$= -0.13722 \text{ rad} = -7.86241° = -7°51'45''$$

$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.13722486)}{\sqrt{2.5^2 - 1}} = 0.1198$$

Area BD

$$\Theta_{BD} = \alpha + \frac{\beta}{2} = -0.08726646 + 0.0499584 = -0.03731 \text{ rad} = -2.13759° = -2°8'15''$$

$$C_p = -\frac{2 \cdot \Theta_{BD}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.03730806)}{\sqrt{2.5^2 - 1}} = 0.0326$$

Area AC

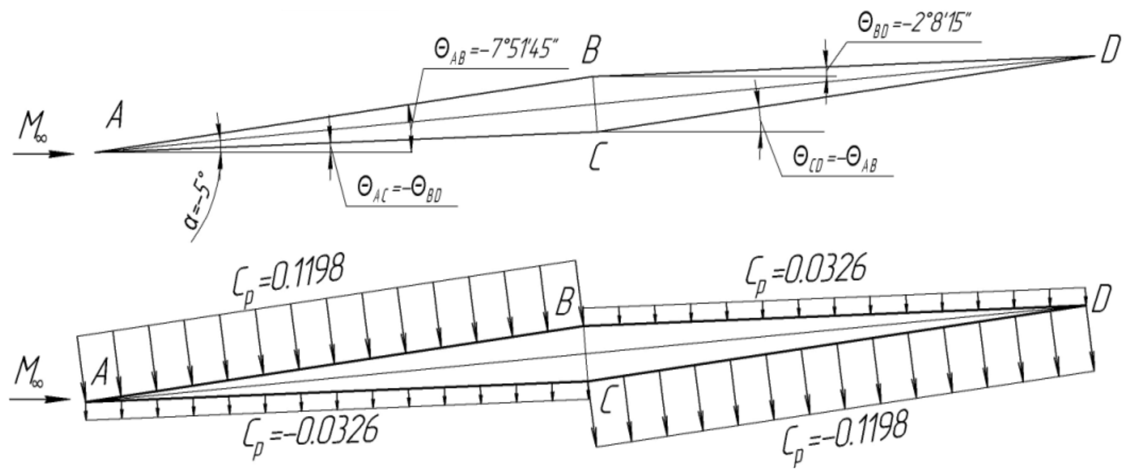
$$\Theta_{AC} = -\Theta_{BD} = 0.037308 \text{ rad} = 2.137594° = 2°8'15''$$

$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.03730806)}{\sqrt{2.5^2 - 1}} = -0.0326$$

Area CD

$$\Theta_{CD} = -\Theta_{AB} = 0.137225 \text{ rad} = 7.862405° = 7°51'45''$$

$$C_p = -\frac{2 \cdot \Theta_{CD}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.13722486)}{\sqrt{2.5^2 - 1}} = -0.1198$$



Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{0°{=}0}$ rad

Area AB

$$\Theta_{AB} = \alpha - \frac{\beta}{2} = 0 - 0.0499584 = -0.04996 \text{ rad} = -2.86241° = -2°51'45''$$

$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.0499584)}{\sqrt{2.5^2 - 1}} = 0.0436$$

Area BD

$$\Theta_{BD} = \alpha + \frac{\beta}{2} = 0 + \Theta_{CD} = -\Theta_{AB} = 0.049958 \text{ rad} = 2.862405° = 2°51'45''$$

$$C_p = -\frac{2 \cdot \Theta_{BD}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot 0.0499584}{\sqrt{2.5^2 - 1}} = -0.0436$$

Area AC

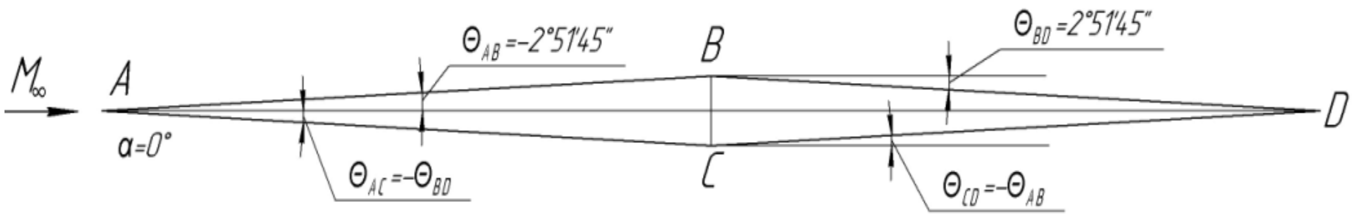
$$\Theta_{AC} = -\Theta_{BD} = -0.04996 \text{ rad} = -2.86241° = -2°51'45''$$

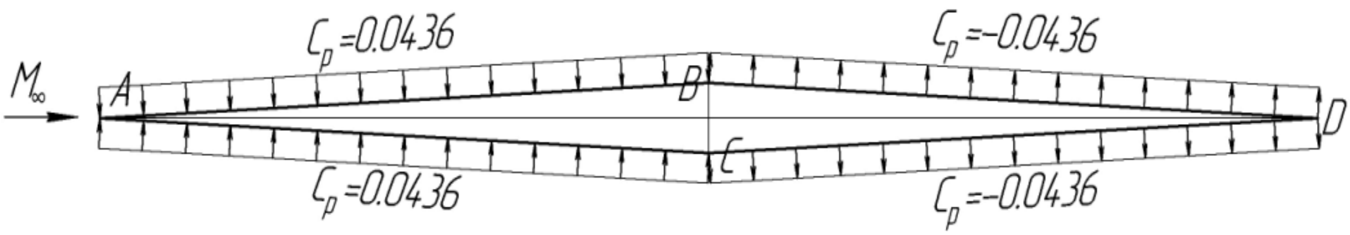
$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.0499584)}{\sqrt{2.5^2 - 1}} = 0.0436$$

Area CD

$$\Theta_{CD} = -\Theta_{AB} = 0.049958 \text{ rad} = 2.862405° = 2°51'45''$$

$$C_p = -\frac{2 \cdot \Theta_{CD}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.0499584)}{\sqrt{2.5^2 - 1}} = -0.0436$$





Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{5°{=}0.087266}$ rad

Area AB

$$\Theta_{AB} = \alpha - \frac{\beta}{2} = 0.08726646 - 0.0499584 = 0.037308 \text{ rad}{=}2.137594°{=}2°8'15''$$

$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot 0.03730806}{\sqrt{2.5^2 - 1}} = -0.0326$$

Area BD

$$\Theta_{BD} = \alpha + \frac{\beta}{2} = 0.08726646 + \Theta_{CD} = -\Theta_{AB} = 0.137225 \text{ rad}{=}7.862405°{=}7°51'45''$$

$$C_p = -\frac{2 \cdot \Theta_{BD}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot 0.13722486}{\sqrt{2.5^2 - 1}} = -0.1198$$

Area AC

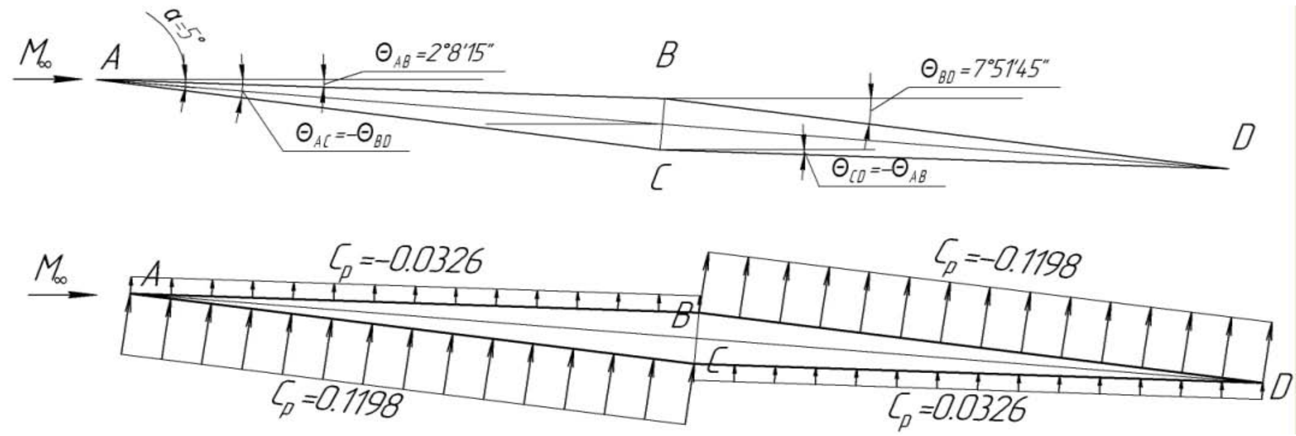
$$\Theta_{AC} = -\Theta_{BD} = -0.13722 \text{ rad}{=}-7.86241°{=}-7°51'45''$$

$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.13722486)}{\sqrt{2.5^2 - 1}} = 0.1198$$

Area CD

$$\Theta_{CD} = -\Theta_{AB} = -0.03731 \text{ rad}{=}-2.13759°{=}-2°8'15''$$

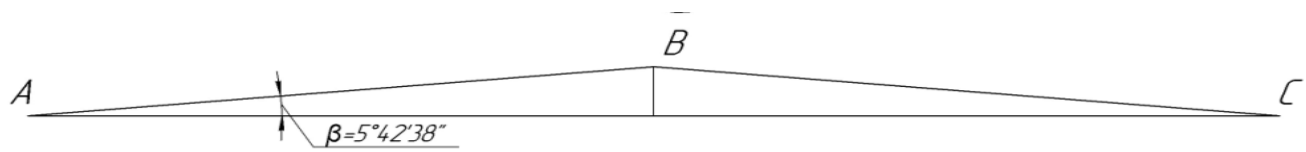
$$C_p = -\frac{2 \cdot \Theta_{CD}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.03730806)}{\sqrt{2.5^2 - 1}} = 0.0326$$



Profile 2.

$$tg(\beta)=\frac{2\cdot 5}{100}=0.1$$

$$\beta = 0.099669\ \text{rad}=5.710593°=5°42'38''$$



Angle of Attack Profile : $\boldsymbol{\alpha = -5° = -0.08727}$ rad

<u>Area AB</u>

$$\Theta_{AB} = \alpha-\beta = -0.08726646-0.09966865 =$$

$$= -0.18694\ \text{rad}= -10.7106°= -10°42'38''$$

$$C_p = -\frac{2\cdot\Theta_{AB}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(-0.18693511)}{\sqrt{2.5^2-1}} = 0.1632$$

<u>Area AC</u>

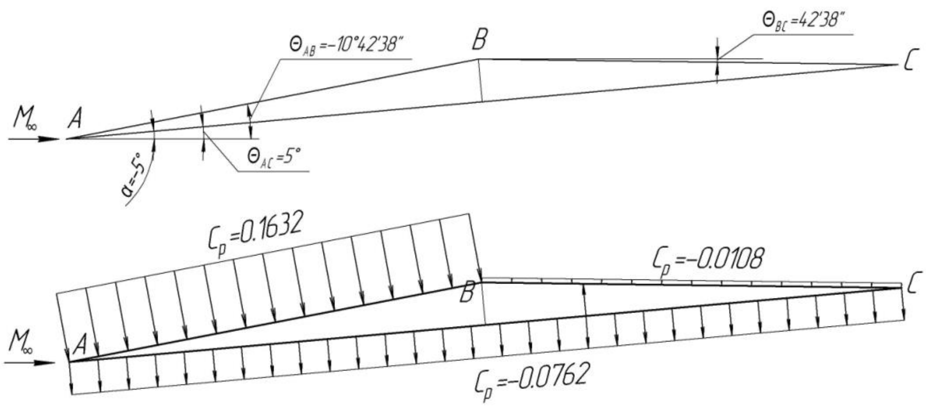
$$\Theta_{AC} = -\alpha = 0.087266\ \text{rad}=5°$$

$$C_p = -\frac{2\cdot\Theta_{AC}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(0.08726646)}{\sqrt{2.5^2-1}} = -0.0762$$

<u>Area BC</u>

$$\Theta_{BC} = \alpha+\beta = -0.08726646+0.09966865 = 0.012402\ \text{rad}=0.710593°=0°42'38''$$

$$C_p = -\frac{2\cdot\Theta_{BC}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(0.01240219)}{\sqrt{2.5^2-1}} = -0.0108$$



Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{0°{=}0}$ rad

<u>Area AB</u>

$\Theta_{AB} = \alpha - \beta = 0 - 0.09966865 = -0.\ 09967$ rad$= -\ 5.71059°= -\ 5°42'38''$

$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.09966865)}{\sqrt{2.5^2 - 1}} = 0.087$$

<u>Area AC</u>

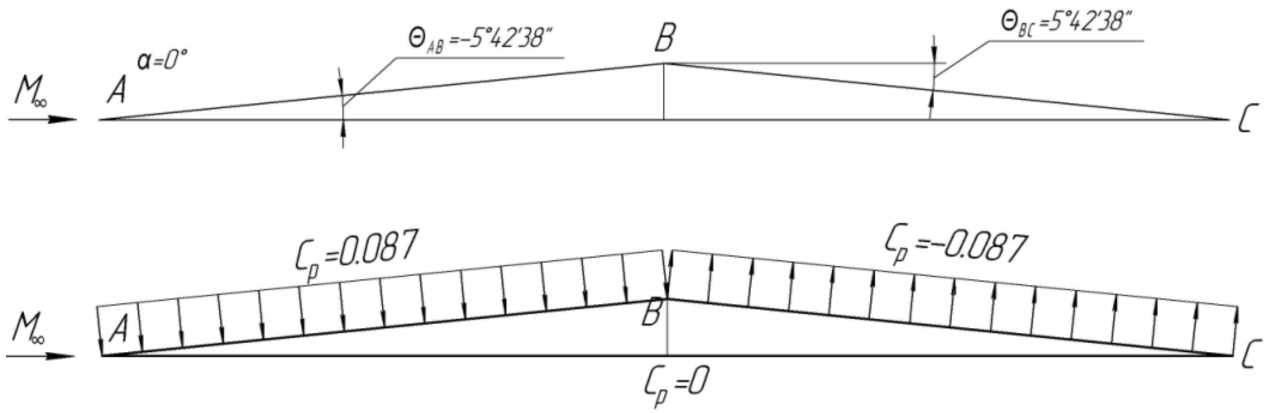
$$\Theta_{AC} = -\alpha = 0 \text{ rad}{=}0°$$

$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0)}{\sqrt{2.5^2 - 1}} = 0$$

<u>Area BC</u>

$$\Theta_{BC} = \alpha + \beta = 0 + 0.09966865 = 0.099669 \text{ rad}{=}5.710593°{=}5°42'38''$$

$$C_p = -\frac{2 \cdot \Theta_{BC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.09966865)}{\sqrt{2.5^2 - 1}} = -0.087$$



Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{5°{=}0.087266}$ rad

Area AB

$\Theta_{AB} = \alpha - \beta = 0.08726646 - 0.09966865 = -0.0124$ rad$= -0.71059° = -0°42'38''$

$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.01240219)}{\sqrt{2.5^2 - 1}} = 0.0108$$

Area AC

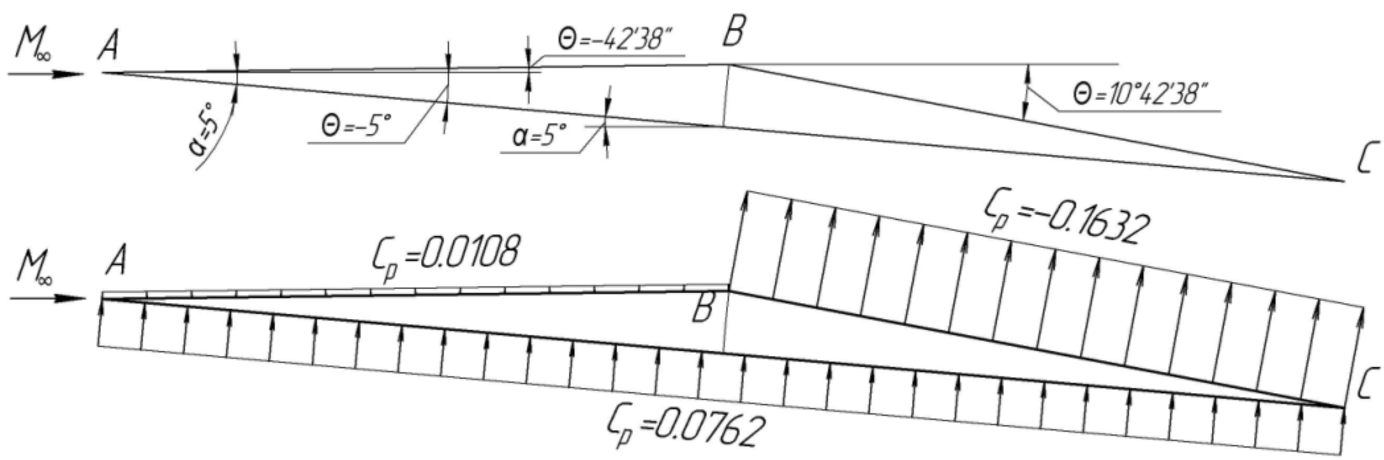
$$\Theta_{AC} = -\alpha = -0.08727 \text{ рад} = -5°$$

$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.08726646)}{\sqrt{2.5^2 - 1}} = 0.0762$$

Area BC

$\Theta_{BC} = \alpha + \beta = 0.08726646 + 0.09966865 = 0.186935$ rad$=10.71059°=10°42'38''$

$$C_p = -\frac{2 \cdot \Theta_{BC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.18693511)}{\sqrt{2.5^2 - 1}} = -0.1632$$



Profile 3.

$$tg\left(\frac{\beta}{2}\right) = \frac{5}{2 \cdot 100} = 0.025$$

$$\frac{\beta}{2} = 0.024995 \text{ rad} = 1.432096° = 1°25'56''$$

$$\beta = 0.04999 \text{ rad} = 2.864192° = 2°51'51''$$

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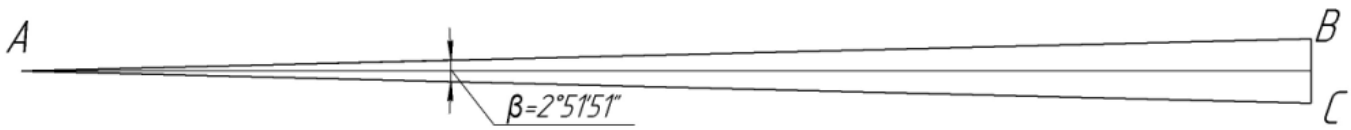


Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{-5°= -\ 0.08727}$ rad

<u>Area AB</u>

$$\Theta_{AB} = \alpha - \frac{\beta}{2} = -0.08726646 - 0.02499479 =$$

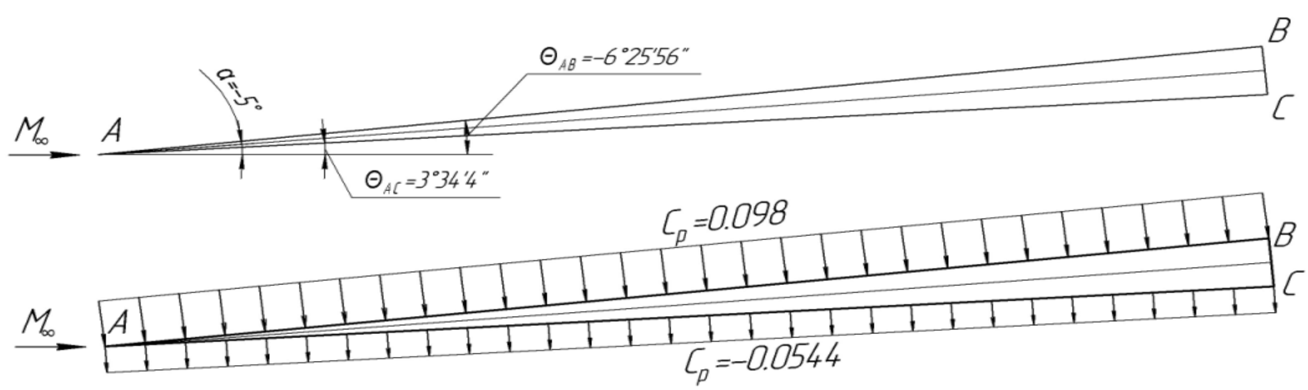
$$= -0.11226 \text{ rad} = -\ 6.4321° = -\ 6°25'56''$$

$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.11226125)}{\sqrt{2.5^2 - 1}} = 0.098$$

<u>Area AC</u>

$$\Theta_{AC} = -\alpha - \frac{\beta}{2} = - -0.08726646 - 0.02499479 = 0.062272 \text{ rad} = 3.567904° = 3°34'4''$$

$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.06227167)}{\sqrt{2.5^2 - 1}} = -0.0544$$



Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{0°=0}$ rad

<u>Area AB</u>

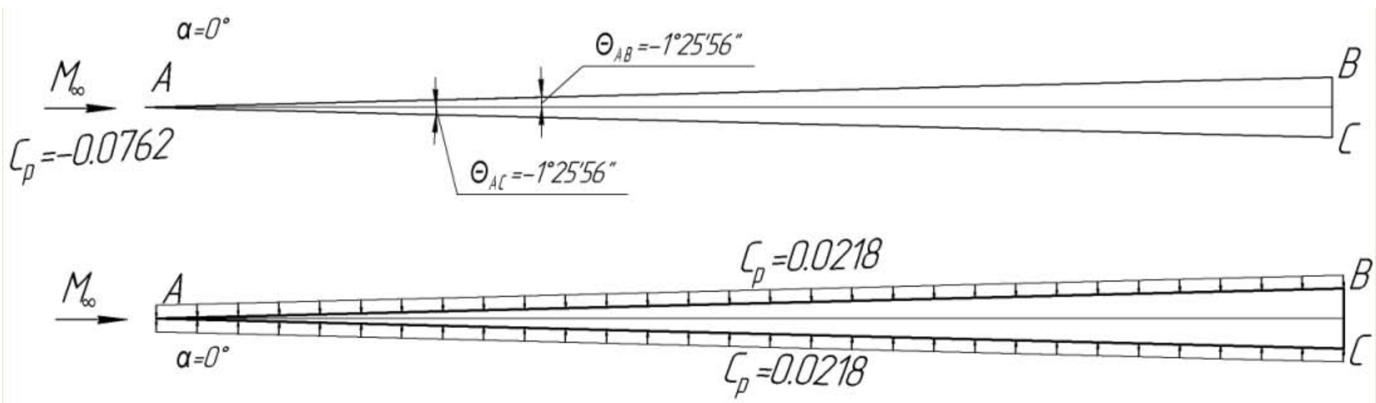
$$\Theta_{AB} = \alpha - \frac{\beta}{2} = 0 - 0.02499479 = -0.02499 \text{ rad} = -\ 1.4321° = -\ 1°25'56''$$

$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.02499479)}{\sqrt{2.5^2 - 1}} = 0.0218$$

Area AC

$$\Theta_{AC} = -\alpha - \frac{\beta}{2} = -0 - 0.02499479 = -0.02499 \text{ rad} = -1.4321° = -1°25'56''$$

$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.02499479)}{\sqrt{2.5^2 - 1}} = 0.0218$$



Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{5°=0.087266}$ rad

Area AB

$$\Theta_{AB} = \alpha - \frac{\beta}{2} = 0.08726646 - 0.02499479 = 0.062272 \text{ rad} = 3.567904° = 3°34'4''$$

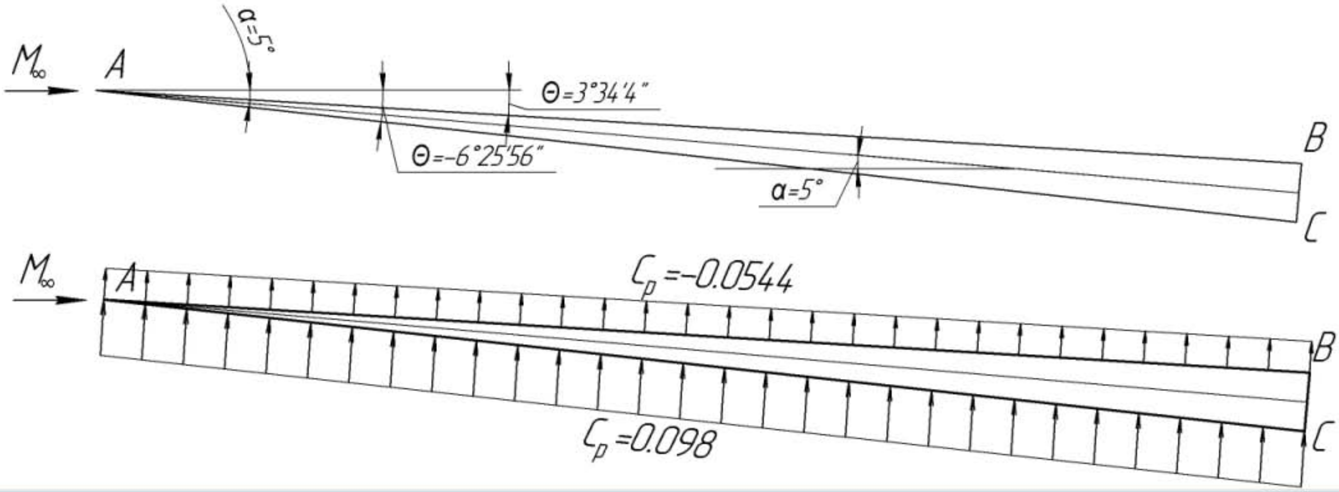
$$C_p = -\frac{2 \cdot \Theta_{AB}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot 0.06227167}{\sqrt{2.5^2 - 1}} = -0.0544$$

Area AC

$$\Theta_{AC} = -\alpha - \frac{\beta}{2} = -0.08726646 - 0.02499479 =$$

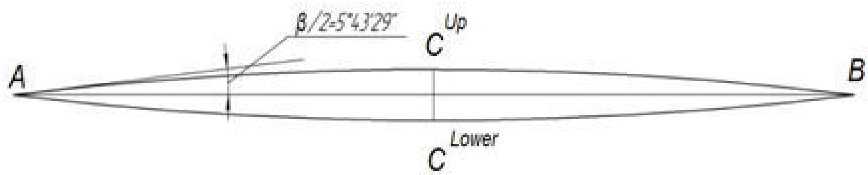
$$= -0.11226 \text{ rad} = -6.4321° = -6°25'56''$$

$$C_p = -\frac{2 \cdot \Theta_{AC}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.11226125)}{\sqrt{2.5^2 - 1}} = 0.098$$



Profile 4.

$$\frac{\beta}{2} = 0.099917 \text{ rad=5.724822°= } 5°43'29''$$



Angle of Attack Profile : $\boldsymbol{\alpha} = \mathbf{5°=0.087266}$ rad

$$\Theta_A^{up} = \alpha - \frac{\beta}{2} = (0.08726646) - 0.099917 = -0.01265 \text{ rad=} - 0.72482° = - 0°43'29''$$

$$C_p = -\frac{2 \cdot \Theta_A^{up}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.01265054)}{\sqrt{2.5^2 - 1}} = 0.011$$

$$\Theta_C^{up} = \alpha = 0.087266 \text{ rad=5}$$

$$C_p = -\frac{2 \cdot \Theta_C^{up}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.08726646)}{\sqrt{2.5^2 - 1}} = -0.0762$$

$$\Theta_B^{up} = \alpha + \frac{\beta}{2} = (0.08726646) + 0.099917 = 0.187183 \text{ rad=10.72482°=10°43'29''}$$

$$C_p = -\frac{2 \cdot \Theta_B^{up}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.18718346)}{\sqrt{2.5^2 - 1}} = -0.1634$$

$$\Theta_A^{Lower} = -\alpha - \frac{\beta}{2} = (-0.08726646) - 0.099917 =$$

$$= -0.18718 \text{ rad} = -10.7248° = -10°43'29''$$

$$C_p = -\frac{2 \cdot \Theta_A^{Lower}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.18718346)}{\sqrt{2.5^2 - 1}} = 0.1634$$

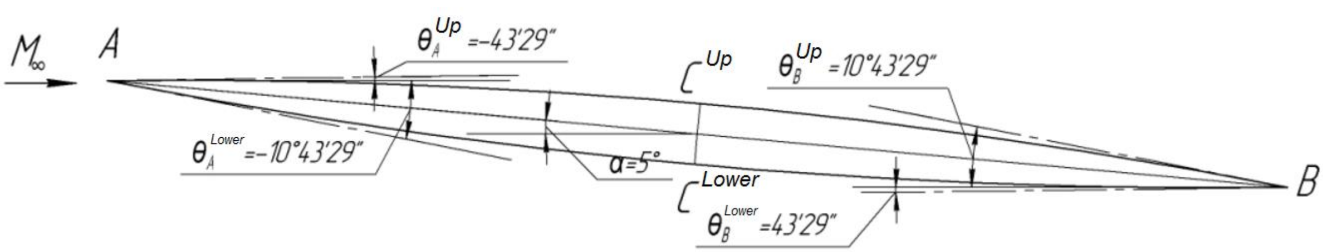
$$\Theta_C^{Lower} = -\alpha = -0.08727 \text{ rad} = -5$$

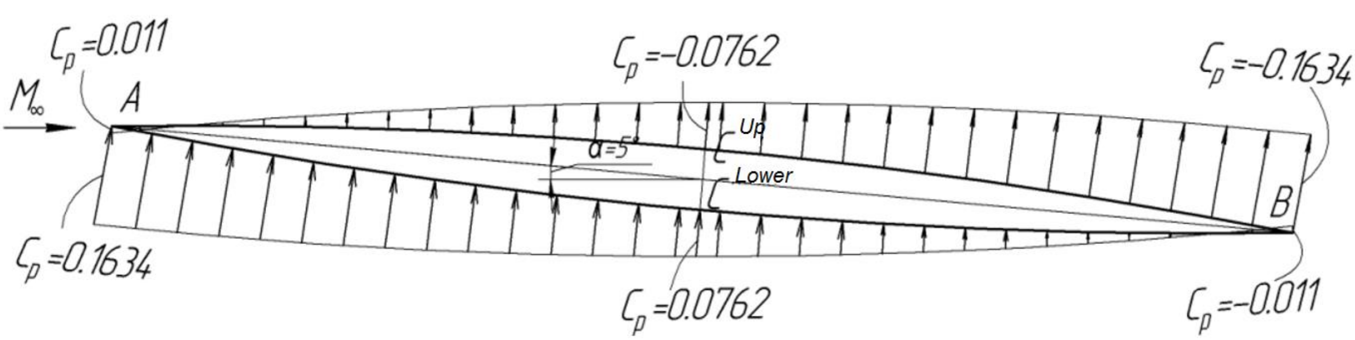
$$C_p = -\frac{2 \cdot \Theta_C^{Lower}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.08726646)}{\sqrt{2.5^2 - 1}} = 0.0762$$

$$\Theta_B^{Lower} = -\alpha + \frac{\beta}{2} = (-0.08726646) + 0.099917 =$$

$$= 0.012651 \text{ rad} = 0.724823° = 0°43'29''$$

$$C_p = -\frac{2 \cdot \Theta_B^{Lower}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.01265054)}{\sqrt{2.5^2 - 1}} = -0.011$$





Angle of Attack Profile : $\boldsymbol{\alpha = 0° = 0 \text{ rad}}$

$$\Theta_A^{up} = \alpha - \frac{\beta}{2} = (0) - 0.099917 = -0.09992 \text{ rad} = -5.72482° = -5°43'29''$$

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$$C_p = -\frac{2\cdot\Theta_A^{up}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(-0.099917)}{\sqrt{2.5^2-1}} = 0.0872$$

$$\Theta_C^{up} = \alpha = 0 \text{ rad}=0$$

$$C_p = -\frac{2\cdot\Theta_C^{up}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(0)}{\sqrt{2.5^2-1}} = 0$$

$$\Theta_B^{up} = \alpha + \frac{\beta}{2} = (0) + 0.099917 = 0.099917 \text{ rad}=5.724822°=5°43'29''$$

$$C_p = -\frac{2\cdot\Theta_B^{up}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(0.099917)}{\sqrt{2.5^2-1}} = -0.0872$$

$$\Theta_A^{Lower} = -\alpha - \frac{\beta}{2} = (-0) - 0.099917 = -0.09992 \text{ rad}= -5.72482°= -5°43'29''$$

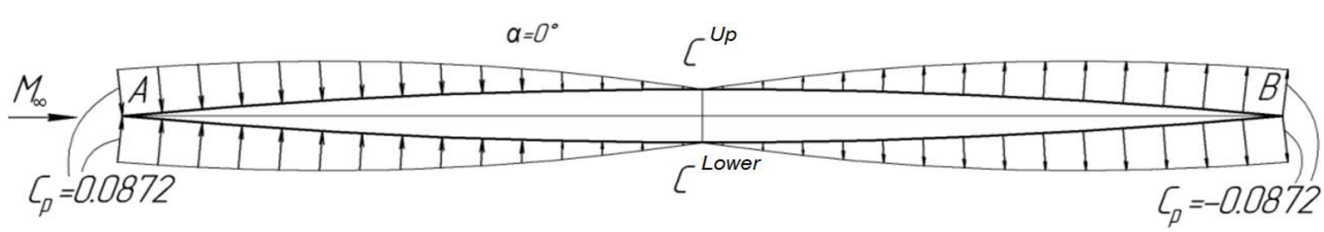
$$C_p = -\frac{2\cdot\Theta_A^{Lower}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(-0.099917)}{\sqrt{2.5^2-1}} = 0.0872$$

$$\Theta_C^{Lower} = -\alpha = 0 \text{ rad}=0$$

$$C_p = -\frac{2\cdot\Theta_C^{Lower}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(0)}{\sqrt{2.5^2-1}} = 0$$

$$\Theta_B^{Lower} = -\alpha + \frac{\beta}{2} = (-0) + 0.099917 = 0.099917 \text{ rad}=5.724822°=5°43'29''$$

$$C_p = -\frac{2\cdot\Theta_B^{Lower}}{\sqrt{M_\infty^2-1}} = -\frac{2\cdot(0.099917)}{\sqrt{2.5^2-1}} = -0.0872$$



Angle of Attack Profile : $\boldsymbol{\alpha = -5° = -0.08727}$ rad

$$\Theta_A^{up} = \alpha - \frac{\beta}{2} = (-0.08726646) - 0.099917 =$$

$$= -0.18718 \text{ rad} = -10.7248° = -10°43'29''$$

$$C_p = -\frac{2 \cdot \Theta_A^{up}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.18718346)}{\sqrt{2.5^2 - 1}} = 0.1634$$

$$\Theta_C^{up} = \alpha = -0.08727 \text{ rad} = -5$$

$$C_p = -\frac{2 \cdot \Theta_C^{up}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.08726646)}{\sqrt{2.5^2 - 1}} = 0.0762$$

$$\Theta_B^{up} = \alpha + \frac{\beta}{2} = (-0.08726646) + 0.099917 = 0.012651 \text{ rad} = 0.724823° = 0°43'29''$$

$$C_p = -\frac{2 \cdot \Theta_B^{up}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.01265054)}{\sqrt{2.5^2 - 1}} = -0.011$$

$$\Theta_A^{Lower} = -\alpha - \frac{\beta}{2} = (- -0.08726646) - 0.099917 =$$

$$= -0.01265 \text{ rad} = -0.72482° = -0°43'29''$$

$$C_p = -\frac{2 \cdot \Theta_A^{Lower}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (-0.01265054)}{\sqrt{2.5^2 - 1}} = 0.011$$

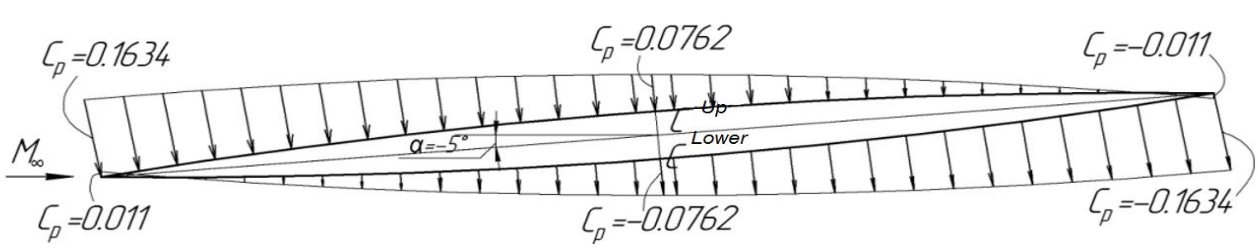
$$\Theta_C^{Lower} = -\alpha = 0.087266 \text{ rad} = 5$$

$$C_p = -\frac{2 \cdot \Theta_C^{Lower}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.08726646)}{\sqrt{2.5^2 - 1}} = -0.0762$$

$$\Theta_B^{Lower} = -\alpha + \frac{\beta}{2} = (- -0.08726646) + 0.099917 =$$

$$= 0.187183 \text{ rad} = 10.72482° = 10°43'29''$$

$$C_p = -\frac{2 \cdot \Theta_B^{Lower}}{\sqrt{M_\infty^2 - 1}} = -\frac{2 \cdot (0.18718346)}{\sqrt{2.5^2 - 1}} = -0.1634$$



Determination of the coefficient of profile-wave resistance for given angles of attack

The coefficient of profile-wave resistance:

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot \bar{c}^2}{\sqrt{M_\infty^2 - 1}}$$

Parameter K1 depends on the shape of the profile:

$$K_1 = 2 \int_0^1 \left[\left(\frac{d\overline{y_U}}{d\bar{x}} \right)^2 + \left(\frac{d\overline{y_L}}{d\bar{x}} \right)^2 \right] d\bar{x}$$

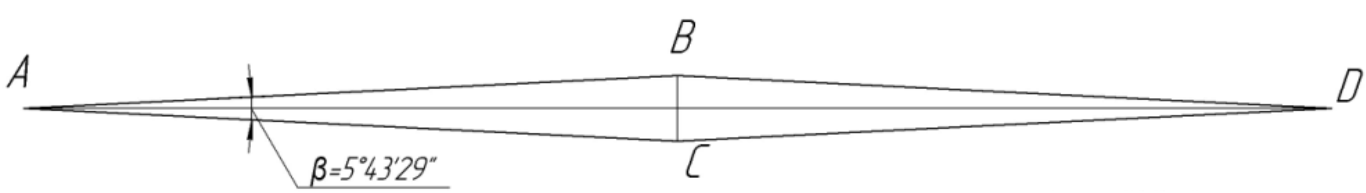
$$\frac{d\overline{y_U}}{d\bar{x}} = \frac{1}{\bar{c}} \cdot \frac{dy_U}{dx}$$

$\frac{dy_U}{dx}$ – *Angle of inclination of the upper profile area to the profile chord*

$$\frac{d\overline{y_L}}{d\bar{x}} = \frac{1}{\bar{c}} \cdot \frac{dy_L}{dx}$$

$\frac{dy_L}{dx}$ – *Angle of inclination of the lower profile area to the profile chord*

Defining the value of the parameter K1 for profile 1:



$$\bar{c} = \frac{\beta}{2}$$

$$\frac{dy_U}{dx} = \frac{\beta}{2}, \quad \frac{d\overline{y_U}}{d\bar{x}} = 1 \quad - \mathit{for\ the\ platform\ AB}$$

$$\frac{dy_U}{dx} = -\frac{\beta}{2}, \quad \frac{d\overline{y_U}}{d\bar{x}} = -1 \quad - \mathit{for\ the\ platform\ BD}$$

$$\frac{dy_L}{dx} = -\frac{\beta}{2}, \quad \frac{d\overline{y_L}}{d\bar{x}} = -1 \quad - \mathit{for\ the\ platform\ AC}$$

$$\frac{dy_L}{dx} = \frac{\beta}{2}, \quad \frac{dy_L}{d\bar{x}} = 1 - \mathit{for\ the\ platform\ CD}$$

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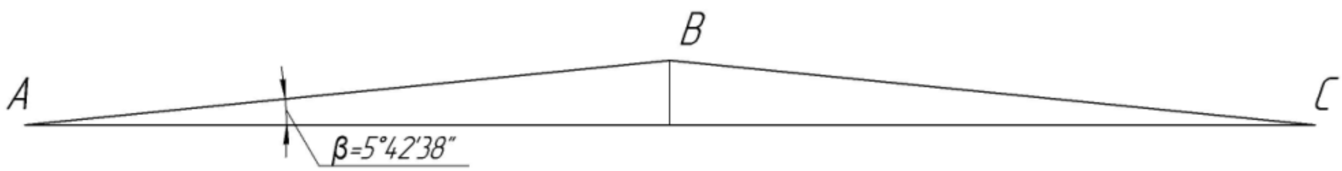
Then the parameter K1 for profile 1 will be equal to

$$K_1 = 2 \cdot (1^2 \cdot 0.5 + (-1)^2 \cdot 0.5 + (-1)^2 \cdot 0.5 + 1^2 \cdot 0.5) = 2 \cdot 2 = 4$$

Defining the value of the parameter K1 for profile 2:



$$\bar{c} = \frac{\beta}{2}$$

$$\frac{dy_U}{dx} = \beta, \quad \frac{d\overline{y_U}}{d\bar{x}} = 2 \quad - for\ the\ platform\ \ AB$$

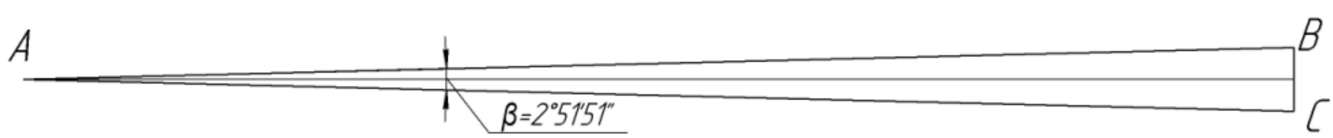
$$\frac{dy_U}{dx} = -\beta, \quad \frac{d\overline{y_U}}{d\bar{x}} = -2 \ - for\ the\ platform\ BC$$

$$\frac{dy_L}{dx} = 0 \ - for\ the\ platform\ \ AC$$

Then the parameter K1 for profile 2 will be equal to

$$K_1 = 2 \cdot ((2)^2 \cdot 0.5 + (-2)^2 \cdot 0.5 + (0)^2 \cdot 1) = 2 \cdot 4 = 8$$

Defining the value of the parameter K1 for profile 3:



$$\bar{c} = \beta$$

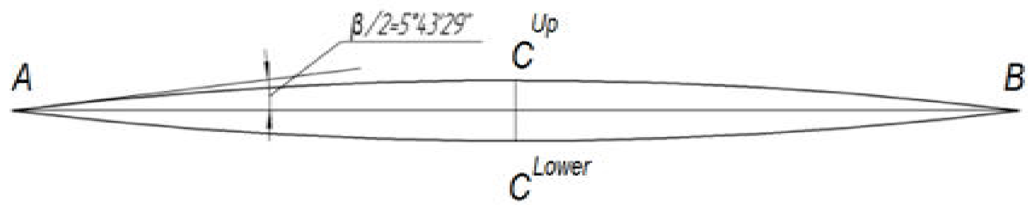
$$\frac{dy_U}{dx} = \frac{\beta}{2}, \quad \frac{d\overline{y_U}}{d\bar{x}} = 0.5 \quad - for\ the\ platform\ AB$$

$$\frac{dy_L}{dx} = -\frac{\beta}{2}, \quad \frac{d\overline{y_L}}{d\bar{x}} = -0.5 \ - for\ the\ platform\ AC$$

Then the parameter K1 for profile 3 will be equal to

$$K_1 = 2 \cdot ((0.5)^2 \cdot 1 + (-0.5)^2 \cdot 1) = 2 \cdot 0.5 = 1$$

Defining the value of the parameter K1 for profile 4:



III. Results

By determining the parameter K1 for each profile, we can calculate the coefficients of the profile-wave resistance for given angles of attack:

$$K_1 = \frac{16}{3}$$

Profile 1.

$K_1 = 4$

$\alpha = 0° = 0 \text{ rad}$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0^2}{\sqrt{2.5^2 - 1}} + \frac{4 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.0044$$

$\alpha = \pm 5° = \pm 0.087266 \text{ rad}$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0.08726646^2}{\sqrt{2.5^2 - 1}} + \frac{4 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.0177$$

Profile 2.

$K_1 = 8$

$\alpha = 0° = 0 \text{ rad}$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0^2}{\sqrt{2.5^2 - 1}} + \frac{8 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.0087$$

$\alpha = \pm 5° = \pm 0.087266 \text{ rad}$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0.08726646^2}{\sqrt{2.5^2 - 1}} + \frac{8 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.022$$

Profile 3.

$K_1 = 1$

$\alpha = 0° = 0 \text{ rad}$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0^2}{\sqrt{2.5^2 - 1}} + \frac{1 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.0011$$

$$\alpha = \pm 5° = \pm 0.087266 \text{ rad}$$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0.08726646^2}{\sqrt{2.5^2 - 1}} + \frac{1 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.0144$$

Profile 4.

$$K_1 = \frac{16}{3} = 5.333$$

$$\alpha = 0° = 0 \text{ rad}$$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0^2}{\sqrt{2.5^2 - 1}} + \frac{5.333 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.0058$$

$$\alpha = \pm 5° = \pm 0.087266 \text{ rad}$$

$$C_x = \frac{4 \cdot \alpha^2}{\sqrt{M_\infty^2 - 1}} + \frac{K_1 \cdot c^2}{\sqrt{M_\infty^2 - 1}} = \frac{4 \cdot 0.08726646^2}{\sqrt{2.5^2 - 1}} + \frac{5.333 \cdot 0.05^2}{\sqrt{2.5^2 - 1}} = 0.0191$$

IV. Conclusions

1. As the angle of attack increases to a certain value, the aerodynamic quality increases. At a certain angle of attack, the quality reaches a maximum value of K_{max}. This angle is called the most advantageous angle of attack, $\alpha_{The\ most\ advantageous}$.
2. On the angle of attack of the zero lifting force, where C_Y=0, the aerodynamic quality will be zero.
3. The effect on the aerodynamic quality of the profile shape is related to the relative thickness and curvature of the profile. The shape of the profile contours, the shape of the sock and the position of the maximum profile thickness along the chord
4. To obtain large values of K_{max}, the optimum thickness and curvature of the profile, the shape of the contours and the extension of the wing are selected.
5. To obtain the highest quality values, the best shape of the wing is elliptical with a rounded leading edge.
6. The zero lifting force angle α_0 is at the intersection of the polar with the axis C_x. At this angle of attack, the coefficient of lift is zero (C_Y=0). For the wings of modern aircraft, usually (α_0=2°÷0°). For modern wings, $\alpha_{The\ most\ advantageous}$ lies within (α_0=4°÷6°).

7. The angle of attack of the zero lifting force (α) of the aircraft is practically no different from the angle of attack of the zero lift of the wing. Since the lifting force is zero on the angle, at this angle of attack only the vertical movement of the aircraft downward, called a vertical dive, or a vertical hill at an angle of 90 ° is possible.
8. Angles of attack with the same aerodynamic quality are carried out from the origin of the coordinates of the secant to the field. At the points of intersection, we find the angles of attack (α_1 & α_2) When flying, where the aerodynamic quality will be the same and necessarily smaller

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Design, Construction and Performance Analysis of a 5 Kg Laboratory Ball Mill

By C. C. Ugwuegbu, A. I. Ogbonna, U. S. Ikele, J. U. Anaele, U. P. Ochieze & A.Onwuegbuchulam
Federal University of Technology

Abstract- In this study, a 5 kg laboratory ball mill has been designed, constructed, and its performance analysed. This was achieved by using Bond's equation to calculate the specific and shaft powers required to drive the mill at the specified capacity, and also to size the mill. After the fabrication of the ball mill, grinding test was conducted with the mill, using limestone as the feed material. This was followed by the particle size analysis of the ground product from the mill in order to determine the performance of the mill. The design results show that the minimum shaft power required to drive the ball mill is 0.2025 horsepower, the length of the mill at a fixed mill diameter of 210 mm is 373 mm, and the required shaft length and diameter are 712.2 mm and 30 mm respectively. The results of the particle size analysis, before and after the grinding test, show that the values of F50, F80, P50, and P80 of the limestone that was fed into the mill are 650 microns, 1950 microns, 47.5 microns and 85 micronsectively.

Keywords: laboratory ball mill, bond's equation, shaft power, milling efficiency.

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Design, Construction and Performance Analysis of a 5 Kg Laboratory Ball Mill

C. C. Ugwuegbu[α], A. I. Ogbonna[σ], U. S. Ikele[ρ], J. U. Anaele[Ѡ], U. P. Ochieze[¥] & A.Onwuegbuchulam[§]

Abstract- In this study, a 5 kg laboratory ball mill has been designed, constructed, and its performance analysed. This was achieved by using Bond's equation to calculate the specific and shaft powers required to drive the mill at the specified capacity, and also to size the mill. After the fabrication of the ball mill, grinding test was conducted with the mill, using limestone as the feed material. This was followed by the particle size analysis of the ground product from the mill in order to determine the performance of the mill. The design results show that the minimum shaft power required to drive the ball mill is 0.2025 horsepower, the length of the mill at a fixed mill diameter of 210 mm is 373 mm, and the required shaft length and diameter are 712.2 mm and 30 mm respectively. The results of the particle size analysis, before and after the grinding test, show that the values of F_{50}, F_{80}, P_{50}, and P_{80} of the limestone that was fed into the mill are 650 microns, 1950 microns, 47.5 microns and 85 microns respectively. The fabricated ball mill is efficient in its performance as the value of P_{80} of the products from the mill (85 microns) is less than P_{80} (100 microns) used in the design of the ball mill.

Keywords: laboratory ball mill, bond's equation, shaft power, milling efficiency.

I. Introduction

Size reduction, or comminution, is an important operation in mining and mineral processing. It is important because it can be used to: (i) produce a finer, more marketable product, with specific size distribution; (ii) expose or liberate a valuable mineral so that it can be extracted from the ore; or (iii) increase the surface area available for subsequent processing (Kelly, 1992). Size reduction is accomplished through the process of crushing and grinding. Crushing, which is the first mechanical stage of comminution, is accomplished by reducing the size of run-of-mine ore down to 25 mm (1 in) using equipment that compress the ore against rigid surfaces. The equipment can also reduce the size of the ore by impacting it against surfaces in a constrained path. Grinding is the final stage of comminution. It accepts feed from the crushing stage, which ranges in size from 5 – 25 mm, and reduces it to a size of about 10 – 200 microns.

The principle purposes of grinding are: (i) to obtain the correct degree of liberation in mineral processing; and (ii) to increase the specific area of the valuable minerals for hydrometallurgical treatment, i.e. leaching. Grinding can be accomplished by using rod mills or ball mills. Rod mills are generally used as coarse grinding machines while fine grinding is performed in ball mills, using steel balls as the grinding medium.

A ball mill consists of a cylindrical vessel mounted on a stand at both ends which allows rotation of the vessel around the center axis. The mill is driven by a girth gear bolted to the shell of the vessel and a pinion shaft moved by a prime mover. The prime movers are usually synchronous motors equipped with an air clutch or gear transmission. After the mill is charged with the starting material (rock, ore, etc.) and the grinding ball media (balls), the milling process takes place. The milling process occurs during rotation as a result of the transfer of kinetic energy of the moving grinding media into the grinding product.

The design of a ball mill can vary significantly depending on the size of the required mill, the equipment used to load the starting material (feeders), and the system for discharging the output product. The size of a mill is usually characterized by the "length-to-diameter" ratio, which frequently varies from 0.5 to 3.5. The starting material can be loaded either through a spout feeder or by means of a single or double helical scoop feeder. Based on the discharge system, ball mills are commonly classified as overflow discharge mills, grate discharge mills, and center periphery discharge mills. Several ball mills have been invented for laboratory size reductions, pilot scale reductions, and industrial grinding purposes. All these inventions have been done to proffer solutions to the problem of size reduction in mineral processing.

Irrespective of the ball mill inventions mentioned above, which have been developed to solve the problems encountered during size reduction in mineral processing, laboratory ball mills are seldom available in Nigerian markets. Most times, these ball mills are imported from other countries. Again, with the need for Nigeria to revitalize her manufacturing sector in order to increase productivity that will help to boost Nigeria's Gross Domestic Product (GDP), there is the need to encourage the design and production of locally made ball mills, which will be used in the country's educational sector and the solid mineral sector. These have prompted the drive to design and fabricate this laboratory ball mill, hence, supporting the industrialization of the country.

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II. Design Methodology

a) Milling Sizing

The Bond's method was used in sizing the laboratory ball mill. This method is based on two power calculation approaches used in ball and rod mill design processes due to its simplicity and workability. The first approach, which is specific power calculation, determines the power required to grind an ore from a given feed size to a specific product size. The second approach, the shaft power calculation, determines the power required for a given mill capacity. These approaches are explained in the next section.

i. Specific Power Calculation

The mill power per tonne of 80% feed and product passing a particular screen size is estimated by using the Bond's equation given below:

$$E = W_i\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right) \quad (1)$$

where:

W_i = workindex of material to be ground by the mill;
P_{80} = 80% of product passing a given sieve size;
F_{80} = 80% of feed passing a given sieve size.

The P_{80} (product) and F_{80} (feed) characteristics required in Bond's equation were defined to enable the calculation of the specific power required by the laboratory ball mill.

Feed Characteristics

The laboratory ball mill was designed for grinding limestone, meaning that the work index required for the specific power calculation was assumed to be the work index of limestone, which is 11.6 KWh/t, with a specific gravity of 2.6 g/cm^3 or 2600 kg/m^3. The feed size (F_{80}) of the ball mill was assumed to be 2 mm (2000 microns). This is the size of the ore particles that are retained on a 10 mesh sieve.

Product Characteristic

The product characteristic is defined as the target fineness at P_{80} (80% of the products passing a given sieve size). The value of P_{80} depends on the use of the ground limestone. Target uses of ground limestone are:

a. Agricultural uses – for production of fertilizers, coated seed applications, buffering agents in beef cattle diets, and dietary applications in egg production of hens.
b. Industrial uses – raw material for cement production, filler in paper making, industrial coatings and suspension applications.
c. Mineral Processing and oil production uses – for mining, drilling, and geotechnological applications.

For all these uses, the size of the ground limestone is within 100 microns. Thus P_{80} for the ball mill design was assumed to be 100 microns.

Efficiency Factors

In practice, the Bond's equation is modified by multiplying the right hand side of the equation by correction factors (C) to allow for milling conditions. The modified form of Bond's equation is given as:

$$E = C \times W_i\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right) \quad (2)$$

where:

$$C = C1 \times C2 \times C3 \times C4 \times C5 \times C6 \times C7 \times C8 \times C9$$

Considering the important correction factors, we have that:

C1 (the correction factor for wet and dry grinding) is equal to 1.3 for dry grinding;

C2 is the correction factor for open circuit grinding and is a function of the degree of control required on the circuit product. The values of C2 are shown in Table 1. Since for the ball mill design we are using 80% passing, the required value of C2 for the ball mill will be equal to1.20.

C3 is the correction factor for mill diameter and is given as;

$$C3 = \left(\frac{2.44}{D}\right)^{0.2} \quad (3)$$

However, it is important to note that C3 =0.914 if the mill diameter is greater than 3.81m. The cylindrical vessel used in producing the ball mill was got from a steel pipe that has an internal diameter of 210 mm. This means that the ball mill has a fixed internal diameter of 210mm, meaning that C3 will be:

$C3 = \left(\frac{2.44}{D}\right)^{0.2}$, Where D = 210mm = 0.21 m

$$C3 = \left(\frac{2.44}{0.21}\right)^{0.2} = (11.619)^{0.2} = 1.6332$$

C4 is the correction factor for feed size and is given as:

$$C4 = 1 + \left[\frac{(W_i - 7)\times\left(\frac{F_{80}}{4000\sqrt{\frac{13}{W_i}}} - 1\right)}{\frac{F_{80}}{P_{80}}}\right] \quad (4)$$

This equation applies only if W_i > 14kWh/t or/and if feed is F_{80}> 4mm. Since for the ball mill design, W_i< 14 kWh/t and F_{80}< 4 mm, we have that C4 will be:

$$C4 = 1 + \left[\frac{(11.6 - 7)\times\left(\frac{2000}{4000\sqrt{\frac{13}{11.6}}} - 1\right)}{\frac{2000}{100}}\right]$$

$$\boldsymbol{C4} = 1 + \left[\frac{4.6 \times -0.5277}{20}\right] = C4 = 1 + \left[\frac{-2.4274}{20}\right] = C4 = 1 - 0.1213 = 0.8786$$

$C5$ is the correction factor for product fineness and is given as:

$$C5 = \frac{P_{80} + 10.3}{1.145 \times P_{80}} \quad (5)$$

Equation 5 is used to calculate C5 if $P_{80} < 75$ microns. However, if $P_{80} > 75$ microns, C5 is assumed to be 1.0. For the ball mill design, $P_{80} > 75$ microns (100 microns), this implies that the value of C5 = 1.0.

$C6$ is the correction factor for high efficiency separators (cyclones) and is assumed to be equal to 1.0.

Therefore, the correction factor, C, for the ball mill design is given as:

C = C1 × C2 × C3 × C4 × C5 × C6 = 1.3 × 1.2 × 1.6332 × 0.8786× 1.0 × 1.0 = 2.2385.

Estimated Mill Specific Power

Using equation 2, the specific power required to reduce the size of the limestone from F_{80} = 2000 microns to P_{80} = 100 microns will be:

$$\boldsymbol{E} = 2.2385 \times 11.6\left(\frac{10}{\sqrt{100}} - \frac{10}{\sqrt{2000}}\right) = 2.2385 \times 11.6\,(1 - 0.2236) = 2.2385 \times 11.6\,(0.7764) = 20.160 \text{ kWh/t.}$$

Considering that the laboratory ball mill is of small capacity, the specific power was converted to kWh/Kg instead of kWh/t. This was done as follows:

1000 kg = 1 tonne, therefore, 20.160/1000 = 0.02016 kWh/kg (The Mill's Specific Power).

Mill Capacity (Production Target)

Production target or mill capacity looks at the amount or tonnage of ore a mill can grind in an hour. Based on the capacity of existing laboratory ball mills, the mill was assumed to have a capacity or target production of 5 Kg/h.

ii. *Shaft Power Calculation*

Using the calculated specific power or energy (E) for the desired mill diameter, the required shaft power for the desired mill capacity was estimated from the following equation:

$$P = QE\ (in\ KW) \quad (6)$$

Where P = shaft power; Q = mill capacity. Thus the shaft power of the mill is

$$P = 5\ (kg/h) \times 0.02016\ (kWh/kg)\ 0.1008\ kW$$

This implies that the shaft power required to drive the ball mill is 0.1008 kW.

The motor horsepower is computed from the power required to grind the material from a given feed size to a given product size. This is the power of the shaft given in horsepower.

Since 1 kW = 1.341 horsepower, 0.1008 kW in horsepower will be given as:

0.1008 kW × 1.341 = 0.135 horse power.

Using a factor of safety of 1.5for the design, the motor horsepower required will be = 1.5 × 0.135 = 0.2025 horse power.

Therefore, a motor with a horsepower that ranges from 0.5 to 1.0 horse power can be selected for the mill.

iii. *Mill Sizing Parameters*

The important mill sizing parameters required for the ball mill design are: the mill speed (critical speed at which the mill should operate), the filling degree, and the length of the ball mill. These parameters for the mill have been derived as follows:

Critical Speed

Critical speed is the speed at which the contents of a mill would simply ride over the roof of the mill due to centrifugal action. The critical speed (rpm) is given by the following equation:

$$critical\ speed(N_c) = \frac{42.3}{\sqrt{D-d}} \quad (7)$$

where: N_c = critical speed; D = mill diameter; d = charge diameter (diameter of balls).

Mills operate at a speed of a given percentage of the critical speed, i.e.:

$$Mill\ speed = N\% \times critical\ speed \quad (8)$$

Ball mills, according to Schlanz (1987), are normally operated at around 70 to 80% of critical speed. A speed of 75% of critical speed was assumed for the laboratory ball mill. Based on this assumption, the mill speed of the ball mill was estimated as follows:

$(N_c) = \frac{42.3}{\sqrt{D-d}}$, where D = 0.21m and diameter of the steel ball, d = 0.06m

$$(N_c) = \frac{42.3}{\sqrt{0.21-0.06}} = \frac{42.3}{\sqrt{0.15}} = \frac{42.3}{0.3873} = 109.22 \text{ rpm}$$

Therefore the mill speed, using equation 3.7, is given as:

Mill speed = 75% × 109.22 rpm = 81.914 rpm.

Filling Degree

The filling degree gives the amount of feed and charge balls that occupy the volume of the ball mil in percentage. It can be estimated by using the curve shown in Fig. 1. As can be seen from Fig. 1 and assuming a H/D ratio of 0.618, the filling degree of the laboratory ball mill is 35%.

Length of the Ball Mill

According to Schlanz (1987), the mill shaft power can be related to the mill dimensions. This is given as:

$$P = 7.33 \times C \times J \times Vcr \times (1 - 0.937J) \times \left[1 - \frac{0.1}{2^{9-10Vcr}}\right] \times s.g \times L \times D^{2.3} \qquad (9)$$

where: C = 1 if overflow mill is assumed or 1.16 if grate mill is assumed; J = volume load in %; Vcr = % of critical speed; s.g = bulk density of the ball charge in t/m^3; L = mill length (in m); D = mill internal diameter (in m).

All values in equation 9 have either been determined or can be specified. Thus at the value of the calculated shaft power, the length of the mill can be determined. This is done as follows:

P = 0.1008 kW; J = 0.35; Vcr = 0.75; s.g of steel = 7.85 g/cm^3 = 7.85 t/m^3, D = 0.21m, L =?

$$0.1008 = 7.33 \times 0.35 \times 0.75 \times (1 - 0.937 \times 0.35) \times \left[1 - \frac{0.1}{2^{9-10\times0.75}}\right] \times 7.85L \times 0.21^{2.3}$$

$$0.1008 = 1.9241 \times 0.67205 \times 0.9646 \times 0.21676L$$

$$0.1008 = 0.27037L; \qquad L = \frac{0.1008}{0.27037} = 0.3728\text{m} \approx 373\text{mm}$$

b) *Shaft Design*

A shaft is a rotating member usually of circular cross-section (solid or hollow), which is used to transmit power and rotational motion. Elements such as gears, pulleys (sheaves), flywheels, clutches, and sprockets are mounted on the shaft and are used to transmit power from the driving device (motor or engine) through a machine. The rotational force (torque) is transmitted to these elements on the shaft by press fit, keys, dowel, pins and splines. The shaft rotates on rolling contact or bush bearings.

According to Yung and Nyberg (2010), two basic approaches are considered in shaft design. In the first approach, the shaft is made large enough (and therefore strong enough) to drive the specified load without breaking. Mechanical engineers, according to Yung and Nyberg (2010), define this approach as the ability to transmit the required torque without exceeding the maximum allowable torsional shearing stress of the shaft material. In practice, this usually means that the minimum shaft diameter can withstand at least two times the rated torque of the motor. In the second approach, the minimum diameter needed to prevent torsional deflection (twisting) during service is calculated. To engineers, this means that the allowable twisting moment, or torque, is a function of the allowable torsional shearing stress (in psi or k Pa) and the polar section modulus (a function of the cross-sectional area of the shaft) (Yung and Nyberg, 2010). The two approaches have been used to develop equations for determining minimum shaft sizes. These equations can be obtained from the Machinery's handbook.

i. *Shaft Diameter*

The size of the shaft (shaft diameter) required to drive the ball mill can be estimated by using the equation stated below:

$$D = \sqrt[3]{\frac{1.33 \times 10^6 \times P}{N}}\ mm \qquad (10)$$

where: P = shaft power of the mill = 0.5 hp; N = 75% of critical speed of the mill = 81.914 rpm. Therefore, the shaft diameter will be:

$$D = \sqrt[3]{\frac{1.33 \times 10^6 \times 0.5}{81.914}} = 20.098\ mm$$

Due to availability, safety and machine cost savings, a shaft of diameter of 30 mm, greater than the minimum required size, has been selected for the ball mill.

ii. *Shaft Length*

Shafts must be designed so that deflections are within acceptable levels. Too much deflection can cause noise and vibration problem. It can also result to the degradation of gear performance. Since the ball mill is subjected to torsional stress and bending stress, at a maximum allowable torsional angular deflection (θ) of 0.0045 rad/m, the required length of the shaft can be calculated by using the torsional angular equation given below:

$$\theta = \frac{T \times L \times 32}{G \times \pi \times D^4} \qquad (11)$$

where: T = applied torque =1.231 Nm; L = length of the shaft; G = modulus of rigidity = 2.45 x 10^9 Pa ; D = diameter of the shaft = 30mm.

Solving for L from equation 3.11, we have that:

$$L = \frac{0.0045 \times 2.45 \times 10^9 \times 3.142 \times 0.03^4}{1.231 \times 32} = 0.712205\ m \approx 712.2\ mm$$

A shaft length of about 700 mm, close to the calculated value, was used in the fabrication of the ball mill. This shaft length comprises both the mill and the shafts at both ends of the mill.

c) Pulley Size Calculation

The size or diameter of the pulley required to drive the ball mill (the driven pulley) is an important factor that will determine if the ball mill will operate at the required speed (75% of its critical speed). The equation used to calculate the diameter of the mill shaft pulley is given as:

$$diam.of\ driven\ pulley = \frac{diam\ .of\ driver\ \times rpm\ of\ driver}{rpm\ of\ driven\ pulley} \qquad (12)$$

Where: diameter of driver pulley (motor pulley) = 200 mm; rpm of driven pulley (motor speed) = 25 rpm; rpm of driven pulley (75% of critical speed of the mill) = 81.914 rpm. Solving for the diameter of the driven pulley, we have that:

$$diam.of\ driven\ pulley = \frac{200 \times 25}{81.914} = 61.04\ mm$$

A pulley of 62.5 mm diameter, close to the calculated value, was used in order to prevent the belt groove from intersecting with the mill shaft.

d) Construction Procedure

i. *Working Drawings*

The ball mill fabrication was done based on the dimensions given in the working drawings that are shown in Fig. 2 and Fig. 3.

ii. *Materials Selection*

Shown in Table 2 are the materials selected for the fabrication of the laboratory ball mill.

iii. *Fabrication*

Mill Cylindrical Vessel

The steel pipe procured to serve as the mill chamber was cut to the required mill length (375 mm). Three rectangular bars, equidistant from each other, were welded to the steel pipe internally as lifters (Fig. 4). Two steel rings with diameters of 210 mm to be welded on both ends of the mill chamber were machined on a lathe. Six holes equidistant from each other, having a pitch diameter of 184 mm, were given to the steel rings. The six holes on the rings were threaded before the rings were welded to the steel pipe (Fig. 5).

Flanges

The shaft required for the ball mill fabrication was cut into two with lengths of 175 mm each. Two steel round plates, 210 mm in diameter, were used as flanges. The shafts were welded to the flanges. This was done by first boring a hole having the same diameter as that of the shaft (35 mm) on the flanges. The shafts were then fit into the bored holes and welded (Fig. 6). Registers were made on the flanges with a circular step equal to the inside diameter of the rings to receive the rings at the ends of the mill cylinder (Fig. 7). Registering of the flanges was made to accuracy, to enhance concentricity during assembly and operation. These flanges were further drilled to align with the rings and then fastened with M8 bolts (Fig. 8).

Machining

The complete ball mill chamber assembly was mounted on the lathe and scribed with a four-jaw chuck and dial indicator. The machining was done in stages: (i) the shaft was machined down to 30 mm, the diameter of the bearing; (ii) the flanges were machined to a thickness of 6mm; (iii) the welded edges between the barrel and the ring was smoothen by turning; (iv) the body of the mill was further machined for concentricity and to remove dynamic imbalance. All these were done to make sure the mill runs concentric without wobbling during operation (Fig. 9).

Ball Mill Stand

The 76.2 x 76.2 mm angle irons were measured, marked and cut to lengths of four pieces of 460 mm and two pieces of 260 mm. The edges of each of the angle irons were cut to an angle of 50° so that the mill legs will be spread to an angle of 100° when welded. The pillow blocks (bearing housings) were centralized on the 260 mm length angle irons. The holes for fastening them were marked, punched and drilled with a 10 mm drill bit. The shafts were fit into centralized bearing housings up to a distance of 30 mm from the flange covering the mill. The remaining angle irons of 50.8 x 50.8 mm were cut to a length of 550 mm (i.e. length from one end of the first pillow block to the end of the other pillow block internally). Their edges were drilled for mechanical fastening of the stand using bolts and nuts.

These angle irons were welded together to form two stands with their legs spread at an angle of 100° from the base (Fig. 10). These legs were also drilled. The 2" x 2" angle irons were fastened to the legs formed using M8 bolts and nuts. Hence, the mill stand is formed as shown in Fig. 11. After the fabrication of the mill stand, the mill vessel was mounted on the stand and the pillow blocks fastened with M16 bolts and nuts (Fig. 11)

Feed and Discharge Opening

A square hole of 80 x 80 mm, after levelling of the mill vessel and the stand, was cut out from the vessel using an electric hand filing machine. This hole serves as the feed and discharge point of the mill (Fig. 12). A dynamic imbalance was observed in the vessel (i.e. the part with the hole always stayed down when the vessel steadied after rotation). This is an advantage for discharging the ground product. The square metal piece that was cut out from the mill was welded to a bigger flat plate of 2 mm thickness to serve as the cover of the feed/discharge opening of the mill (Fig. 13). A hinge was attached to this plate to assist the opening and closing of the mill without removing the cover entirely.

Motor Seating

The motor seating (Fig. 14) was made through the following steps:

- Points for tightening the motor were marked on the 250 x 115 mm plate. These points were punched and drilled using a 9 mm diameter drill bit. A slot was made on one part of the plate and the end closed by welding a plate piece to it (i.e. the slot for the threaded M16 shaft);
- Small pipes and shaft were used to make a hinge carrying the threaded M16 shaft on the other 170 x 60 mm plate. This was done in order to assist in the tensioning of the belt between the motor and the mill when connected;
- These plates with their components were welded to the leg of the mill stand.

Completed Mill Assembly

Shown in Fig. 15 is the complete mill assembly (without the drive belt) after construction of the mill.

e) Grinding Test

The aim of the grinding test is to determine the performance or efficiency of the designed and constructed laboratory ball mill. Since the mill was designed to operate at P_{80} of 100 microns, efficiency can be achieved if the product of the mill has a particle size of which 80% is 100 microns. If the product particle size is > 100 microns, the mill is said to be inefficient.

To carry out the grinding test, the inner chamber of the mill was cleaned to remove foreign particles that would act as impurity in the required product. The as received limestone ore was manually crushed into particles within the size range of 2 mm. A representative sample of the crushed limestone (270 g) was fed into the ball mill with the required amount of steel balls, after which the grinding operation was performed for about 30 mins. After grinding, the ground ore was discharged from the mill together with the steel balls. The ground product from the mill was then analysed to determine its particle size distribution. The results obtained are presented in the next section of this work.

III. Results and Discussion

a) Laboratory Ball Mill

As can be seen from Fig. 15, the constructed laboratory ball mill met all the specifications required in the design. The mill has a mill diameter of 210 mm, a length of 375 mm, a speed of 81.914 rpm and a 0.5 hp motor to drive the mill. The ball mill also has three lifters, an opening for ore feeding and discharging of ground products, and a solid stand to counter wobbling during operation.

b) Grinding and Particle Size Analysis Results

Shown in Fig. 16 is the picture of the crushed limestone that was fed into the fabricated ball mill for the grinding test. As can be seen in Fig. 17, the picture of the limestone after the grinding test shows that a very fine ground product was obtained after the test.

i. *Feed Particle Size Analysis Results*

The results (weight retained in grams for each sieve size, % weight retained for each sieve size, and cumulative weight % passing for each sieve size) of the particle size analysis of the feed ore or limestone are shown in Table 3. These results were used in plotting the particle size distribution curve of the feed material (Fig. 18). As can be seen from Fig. 18, the plot of the cumulative % passing of the feed limestone against particle size (in microns), the values of F_{50} and F_{80} of the feed are 650 microns and 1950 microns respectively.

This means that about 50% of the feed limestone passes through a sieve size of 650 microns while 80% of the feed material passes through a sieve size of 1950 microns. It is also important to note that the value of F_{80} from the particle size analysis of the feed is almost the same as the value assumed for F_{80} in the ball mill specific power design (F_{80} = 2000 microns).

ii. *Product Particle Size Analysis Results*

The results (weight retained in grams for each sieve size, % weight retained for each sieve size, and cumulative weight % passing for each sieve size) of the particle size analysis of the limestone product from the grinding test are shown in Table 4. These results were used to plot the particle size distribution curve of the ground product (Fig. 19). As can be seen from Fig. 19, the plot of the cumulative % passing of the product limestone against particle size (in microns), the values of P_{50} and P_{80} of the ground product are 47.5 microns and 85 microns respectively. This means that about 50% of the ground limestone passes through a sieve size of 47.5 microns while 80% of the ground product passes through a sieve size of 85 microns. Since P_{80} is 85 microns, which is less than 100 microns (the value of P_{80} used in designing the mill), it means the laboratory ball mill is working within the required size reduction and thus is efficient.

IV. Conclusion

Based on the results of the design, fabrication, grinding test and performance check of the produced laboratory ball mill, the following conclusions have been drawn:

1. The fabricated ball mill met all the specifications required in the design. It has a mill diameter of 210 mm, length of 375 mm, and a speed of 81.914 rpm.
2. The minimum shaft power required to drive the laboratory ball mill when filled with ore and grinding media is 0.2025 horsepower.

3. The minimum shaft dimensions for the ball mill are: 30 mm for diameter and 712.2 mm for the length of the shaft.
4. The performance of the laboratory ball is effective as the P_{80} of the products from the mill is less than the P_{80} (100 microns) of the design. The ball mill is efficient for grinding limestone.
5. The laboratory ball mill can also be used to grind other ores.

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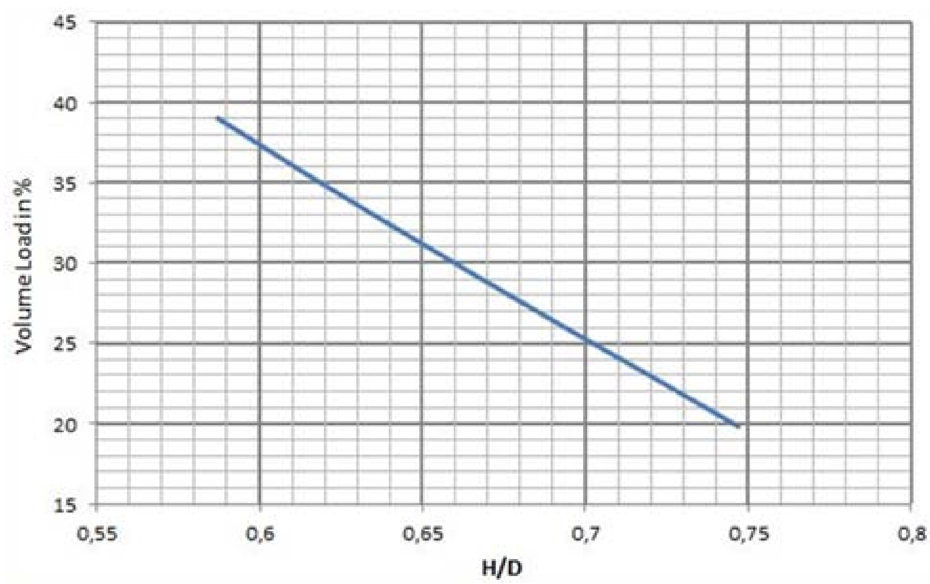

Fig.1: Filling degree as a function of H/D ratio (The Cement Grinding Office, 2012)

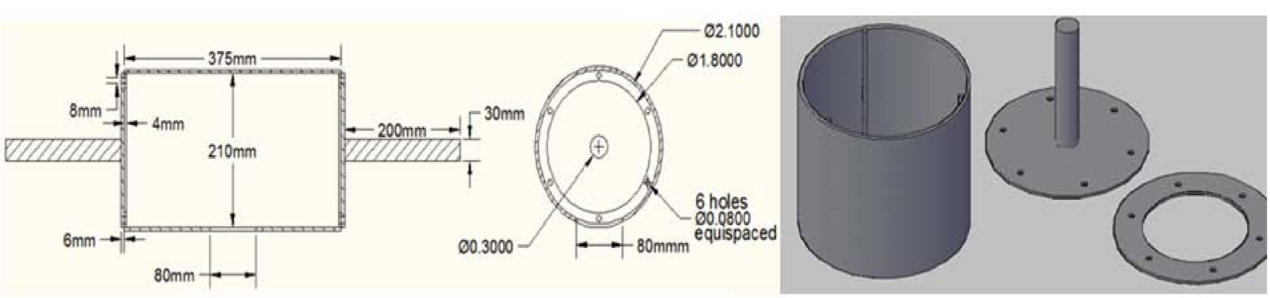

Fig. 2: Detailed working drawing of the vessel for the mill

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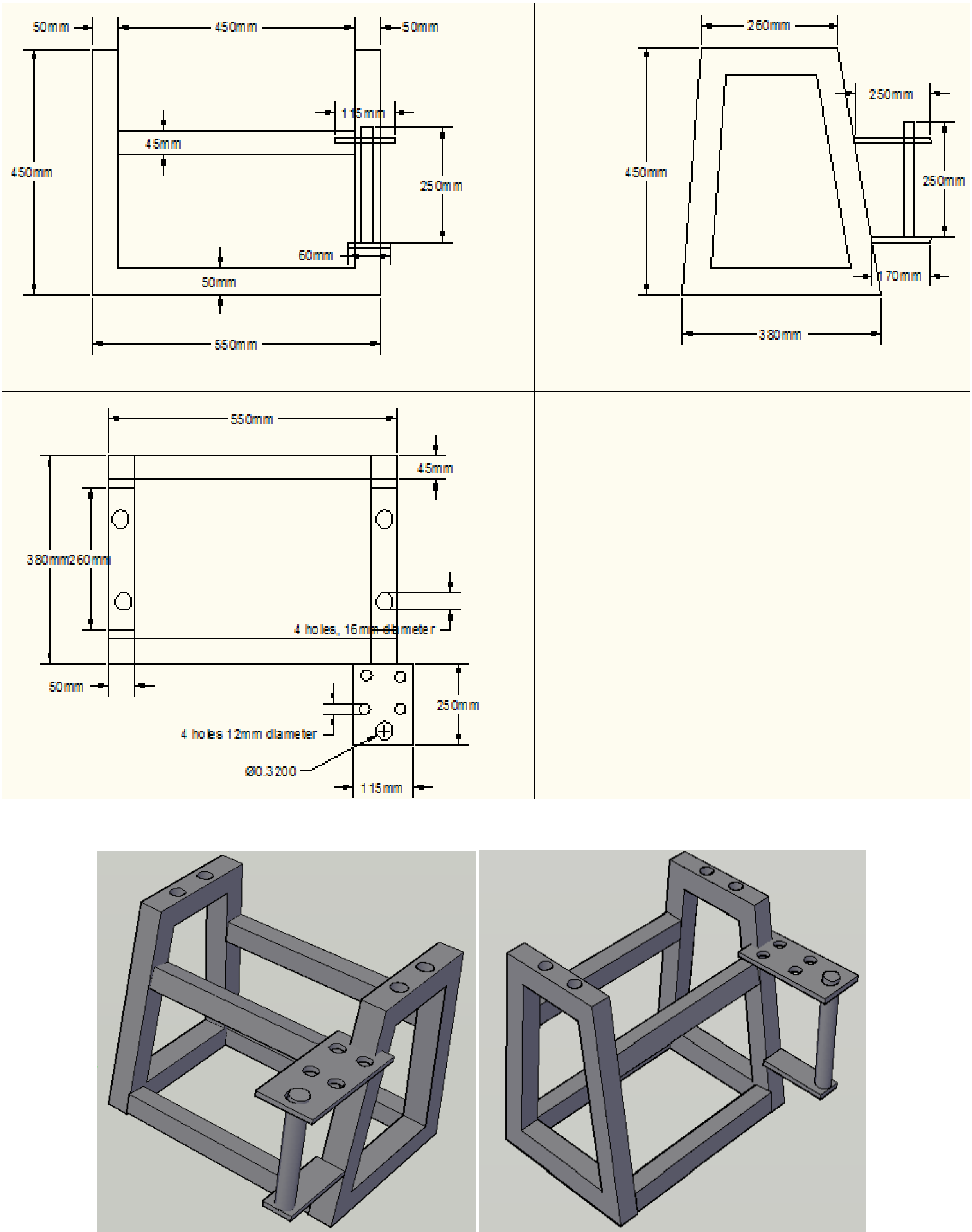

Fig. 3: Detailed working drawing of the stand to the mill

Fig. 4: The steel pipe cut to 375mm and the welded lifters

Fig. 5: Marking the rings using the dividing head; machined rings welded to the pipe

Fig. 6: Shafts welded to the round plates to make the flanges

Fig. 7: Registers made on the flanges

Fig. 8: Flanges fastened to the pipe using M8 bolts

Fig. 9: Different views on how the pipe and flange assembly were mounted on the lathe machine and the scribing of the mounted assembly

Fig.10: Different views of the welded legs of the stand

Fig. 11: Mill mounted on the stand

Fig. 12: Feed and discharge hole cut on the vessel

Fig. 13: Square cut out part welded to a curved plate to serve as feed hole cover

Fig. 14: The different views of the assembled stand and a clearer view of the motor seating

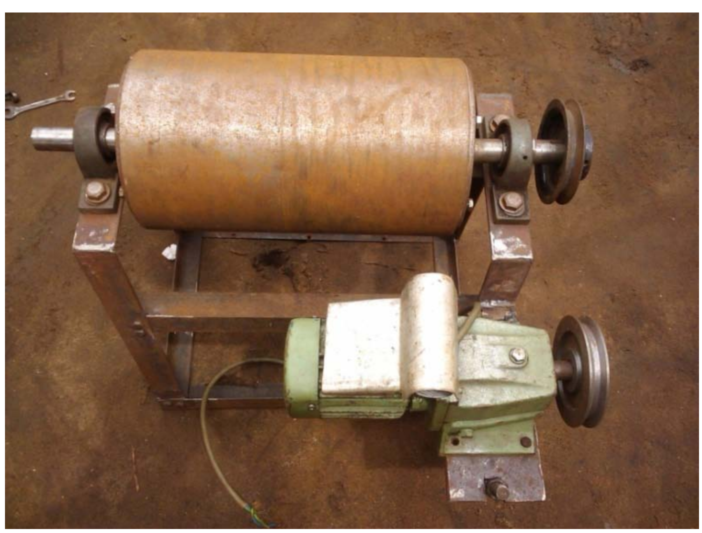

Fig. 15: Complete mill assembly without drive belt

Fig. 16: Feed material

Fig. 17: Limestone product (a) after grinding (b) after sieving

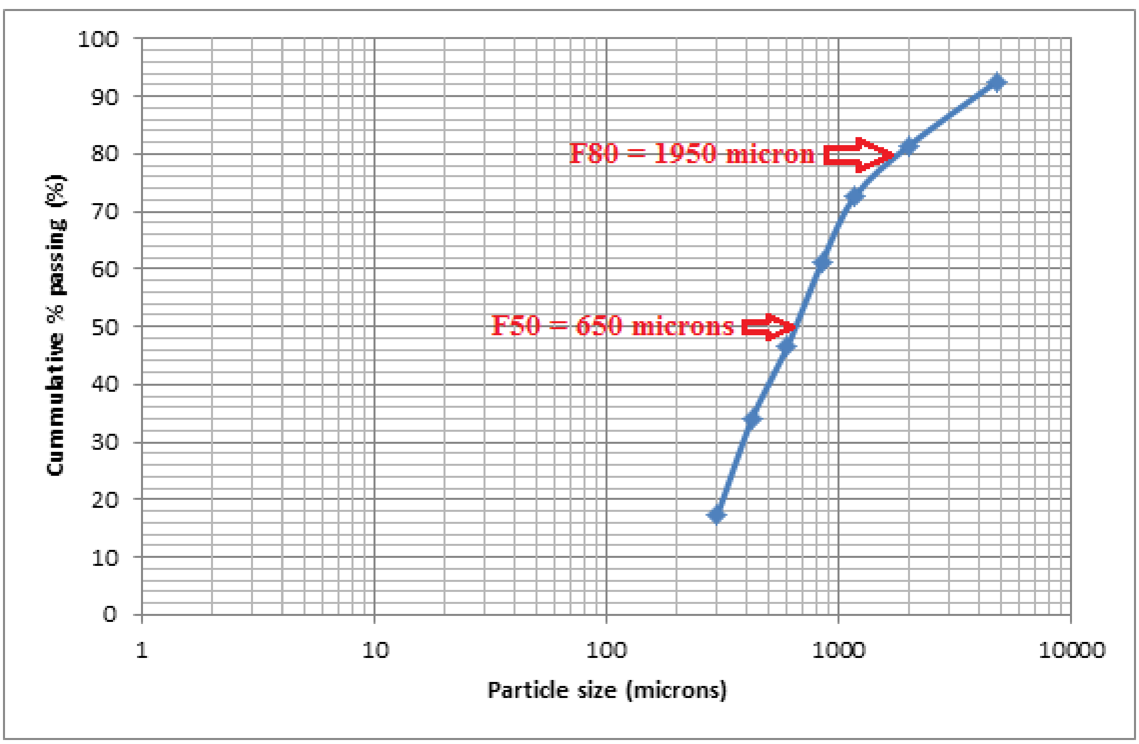

Fig. 18: Graph of Cumulative % passing to Particle size for feed size

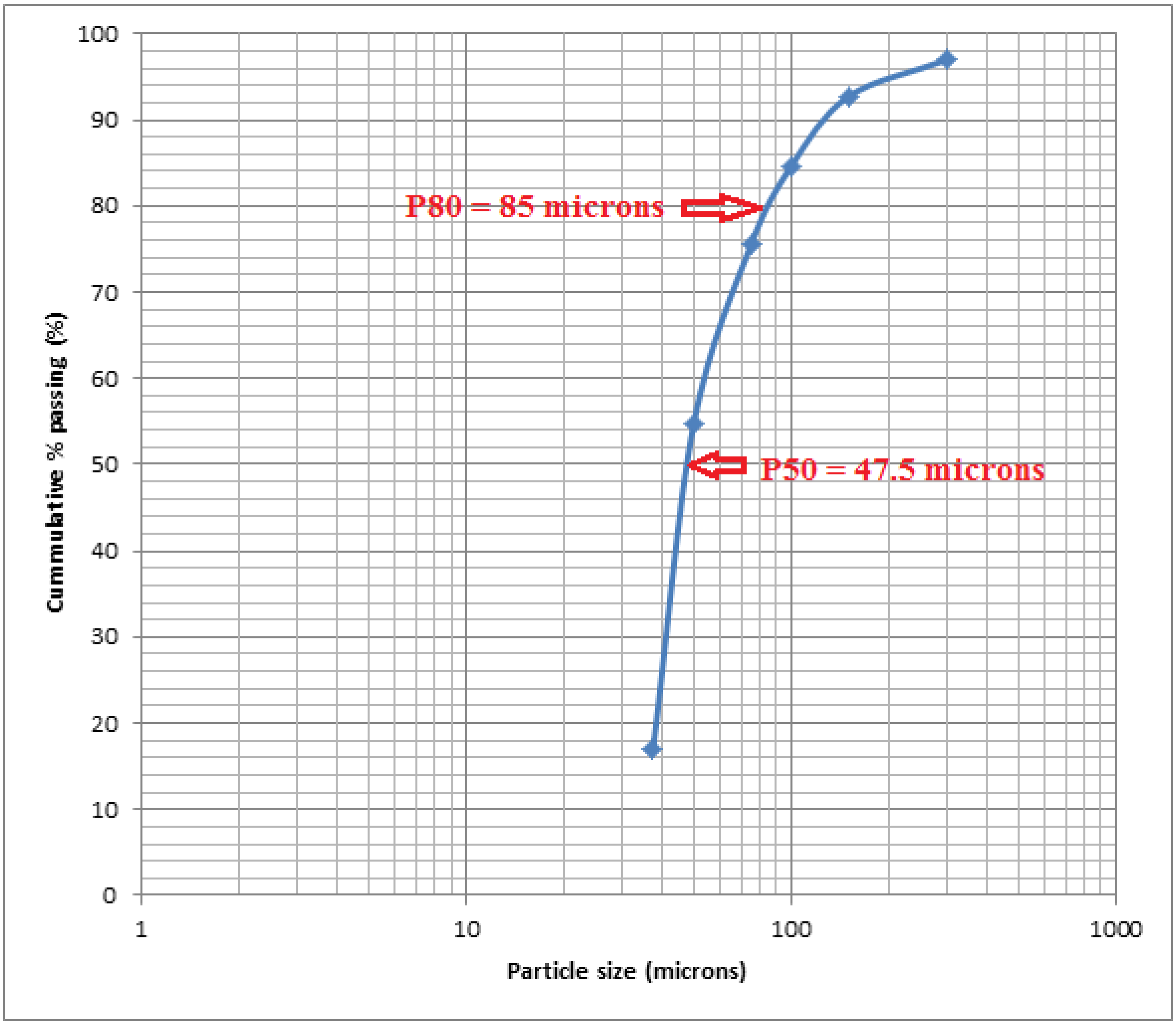

Fig.19: Graph of Cumulative % passing to Particle size for product size

Table 1: Correction factors for open circuit (Schlanz, 1987)

Product passing size	Reference C2
50	1.035
60	1.05
70	1.10
80	1.20
90	1.40
95	1.57
98	1.70

Table 2: Work pieces

SN	Part of machine	Item description	Quantity	Picture
1.	Mill chamber	Steel pipe – diameter, 210 x 400 mm.	1	
		Flat bar – 5x10x370 mm.		
		Steel balls – diameter, 25mm	3 20	
2.	Flanges	Round plate – diameter, 210 x 8 mm.	2	
		Round rings – diameter, 210 x 6 mm.	2	
		Steel shaft – diameter, 35 x 350 mm.	1	
		Pillow block – 30mm inner race	2	
3.	Electric motor	Electric gear motor – single phase, 0.5hp, 70rpm.	1	
		Pulleys – 125mm diameter; 62.5mm diameter, both with B belt groove	2 ; 1	
		Key – Gib-head key of 7x6x50 mm.		

4.	Motor seating	Flat plate - _______ Threaded shaft __mm M16 nuts Hinges Short pipes Shaft	2 1 2 2 2 1	
5.	Mill stand	Angle iron, 76.2x76.2 mm (3" x 3"). Angle iron, 50.8x50.8 mm (2" x 2").	5 6	
6.	Fasteners	M8 bolts and nuts M16 bolts and nuts Electrodes	24 4 ½ pack	

Table 3: Feed particle size analysis with the cumulative percent passing

Sieve size(microns)	Weight retained(g)	% weight retained	Cumulative% passing
4750	20.210	7.485	92.515
2000	29.956	11.095	81.420
1180	23.275	8.617	72.803
850	31.085	11.513	61.290
600	40.050	14.274	46.457
425	33.140	12.274	34.183
300	45.510	16.855	17.328
pan	46.784	17.327	0.000
	270.00	100.000	

Table 4: Product particle size analysis with the cumulative percent passing

Sieve size(microns)	Weight retained(g)	% weight retained	Cumulative% passing
300	8.077	3.04	96.96
150	11.289	4.24	92.72
100	21.515	8.09	84.64
75	24.360	9.16	75.48
50	54.922	20.64	54.84
37.5	100.565	37.80	17.04
Pan	45.338	17.04	0.000
	266.070	100.00	

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Response Surface Optimization of Rolling Process Parameters in Hot Rolling of St60mn Steel

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Abstract- In hot rolled process, the yield strength, tensile strength and toughness play major roll in the structural reliability of the hot rolled steel. Hot rolled St60Mn steel rebars are used for the manufacture of steel for use in construction and other industries. Improved yield strength and toughness of the steel used in construction are often desired to avoid fracture failure and promote impact loading. In this study, Response Surface Methodology was used to study the behaviour of the tensile properties and toughness of the hot rolled St60Mn steel when hot rolled at various finish rolling temperatures and rolling strain rates. The Response Surface Methodology (RSM) was used to investigate the individual and interaction effect of finish rolling temperature and rolling strain rate as independent variables on the yield strength, tensile strength and toughness properties of the hot rolled steel.

Keywords: hotrolled, steel; finish rolling temperature; rolling strainrate; yield strength; tensile strength; toughness; optimization; rsm, model.

GJRE-A Classification: FOR Code: 091399p

RESPONSESURFACEOPTIMIZATIONOFROLLINGPROCESSPARAMETERSINHOTROLLINGOFST60MNSTEEL

Strictly as per the compliance and regulations of:

Response Surface Optimization of Rolling Process Parameters in Hot Rolling of St60mn Steel

Peter U. Nwachukwu [α] & Oluleke O. Oluwole [σ]

Abstract- In hot rolled process, the yield strength, tensile strength and toughness play major roll in the structural reliability of the hot rolled steel. Hot rolled St60Mn steel rebars are used for the manufacture of steel for use in construction and other industries. Improved yield strength and toughness of the steel used in construction are often desired to avoid fracture failure and promote impact loading. In this study, Response Surface Methodology was used to study the behaviour of the tensile properties and toughness of the hot rolled St60Mn steel when hot rolled at various finish rolling temperatures and rolling strain rates. The Response Surface Methodology (RSM) was used to investigate the individual and interaction effect of finish rolling temperature and rolling strain rate as independent variables on the yield strength, tensile strength and toughness properties of the hot rolled steel. The St60Mn steel was hot rolled at various finish rolling temperature between 915°C-923°C for rolling strain rates of between 5 x $10^3 s^{-1}$- 7 x $10^3 s^{-1}$. The influence of the finish rolling temperature and rolling strain rates on the yield strength, tensile strength and toughness were investigated by modelling the relationship using cubic order polynomial to develop the response surface plots and their respective contour plots. The RSM proposes models describing the influence of the rolling process parameters on the properties of the hot rolled steel. The model was able to account for the curvature of the response and the interaction of the independent variables in the response surface. There spone surface methodology (RSM) was applied to optimize the rolling process parameters to attain the optimal values of the properties. The optimized values for the yield strength, tensile strength and toughness for the hot rolled St60Mn steel were obtained as 470.13 MPa,701.63 MPa and 0.458042 joules/mm² respectively. The optimization was achieved within the 95% confidence interval.

Keywords: hotrolled, steel;finish rolling temperature ;rolling strainrate; yield strength; tensile strength; toughness; optimization; rsm, model.

I. Introduction

When a piece of metal is rolled between two rolls, the metal piece experiences both vertical and horizontal stresses caused by the compressive load from the rolls and the restrains by the portions of the metal piece before and after the material in contact with the roll respectively (Dutta ,1986).

As the rolls exert a vertical stress on the metal piece, the latter exerts the same amount of stress back onto the rolls itself. As such the rolls are subjected to stresses exerted by the rolls and it is treated as a two-dimensional % total deformation in the thickness in length directions or changes its cross sectional area. This deformation influences the mechanical properties of the hot-rolled steel (Ashrafi *et al*,2015).In the deformation zone the thickness of the input metal gets reduced and it elongates. This increases the linear speed of the work piece at the exit.

The contour of the roll gap controls the geometry of the product (Dutta,1986).

"Draft", also known as draugth, is a term meant to express the reduction in cross section height / area or reduction in height in a vertical direction when compressed between two rolls.

Draft is either direct or indirect.

Indirect draft results when the rolls exert on the stock in non-vertical direction. Basically it is a grinding action between the collars of two rolls rotating in opposite direction.

When part of the pass profile is inclined in between the vertical and horizontal, the % total deformation is caused by a combination of direct as well as indirect drafting.

Up to an inclination of 45°with the horizontal direct drafting predominates. However, above 45° inclinations the effects of indirect drafting comes in to play. Near 90° the % total deformation depends almost entirely on indirect draft (Dutta,1986).This reducing ratio or draft also affect the mechanical properties and microstructure of rolled products (Aoda*et al*,2012,Song *et al*,2004).

"Elongation"in stock length is associated with reduction in area, as volume of metal that leaves the rolls and the one that enters them is equal. Elongation factor, i.e., the ratio of the final length to the initial length is always greater than unity (Dutta, 1986); and this enlongation decreases as the deformation increases(Hutchinson *et al*,2015)."Spread": When steel stock is compressed between two rolls, it obviously moves in the direction of least resistance. There is not only a longitudinal flow but also some lateral flow, which is called 'Spread' (Dutta,1986).

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Rolling signifies one action but two reactions. The rolls apply a 'reduction' (vertically); this reduction produces an 'elongation' and 'spread' (sideways).

The stock under vertical compression meets some longitudinal resistance to free elongation which assists in causing sideways spread.

Spread is the flow of material at right angles to the directions of compression and elongation.

The coefficient of spread is the ratio between exit and entry width.

The higher the coefficient of friction, higher is the resistance to lengthwise flow and more is the spread.

The quantum of spread can never be worked out analytically. Neither any formula nor any method of computation is available to quantify spread.

Roll Designers only rely on guess estimate to overcome the problem, but accuracy of such guess work is not only extremely necessary but is needed.
In practice it is found that the following factors affect the amount of spread.

Rolling temperature of the work piece influences spread appreciably. Lower the rolling temperature of steel input, greater is the spread, as well as the strength of the hot-rolled steel. Similarly, higher the rolling temperature, lesser is the spread, as well as the strength of the steel. Also the higher the rolling strain rate, the greater is the spread and the strength of the steel and the lower the enlongation of the hot-rolled steel. The lower the rolling strain rate, the lesser is the spread and vice versa (Sierakowski, 1997;Fahker *et* al,2014; Mihalikova *et al*,2007;Song *et al*,2004).Lesser speed of rolling results in greater spread and vice-versa.

Diameter of the working rolls plays a significant role in the guess estimation of spread. Higher the diameter of the working rolls, lesser is the spread. Similarly, lower diameter results in higher spread.

Surface roughness, i.e., friction of the working rolls plays a note worthy part in determining spread. Rougher the roll surface lesser is the spread and smoother the roll surface more is the spread. Stock height and width play influences spread. Higher draft and wider stock signifies greater spread. When rectangular stock passes through plain rolls then the spread is "free" or "unrestricted".

However, if the stock passes through grooved rolls, then the form of the pass keeps the spread within certain limits. This is known "restricted" spread.
Because of this restricted spread the width of an entering stock is smaller than the width of the pass groove.

It is accepted that beyond a ratio width / height = 5, spread becomes negligible (Dutta,1986).

An investigation on the optimization of hot-rolling process parameters in bar and rod rolling of Fe-500 and high alloy steels using gleeble temperature profile, strain, strain rates and temperature in roughing and finishing stands lead to defect free rolling (Kumar *et al.,*2012).

A mathematical model which consists of sub models for static and metadynamic recrystallisation, grain growth and the transformed ferrite grain size that were characterised for a wide range of C-Mn and HSLA steels, has been developed. It predicts the final mechanical properties of hot rolled steels, and is suitable for the evaluation of new steel grades and the development of optimised thermo mechanical processing routes (Hodgson *et al*,1992).

In this present study, the combined influence of the finish rolling temperature and rolling strain rates of the hot rolled St60Mn steel is discussed. The yield strength, tensile strength and toughness of the hot rolled St60Mn steel are developed as functions of the finish rolling temperature and rolling strain rates using the response surface methodology (RSM).It is desired to investigate how much of influence the finish rolling temperature and rolling strain rates affect the property response of the hot rolled St60Mn steel and to find the combination of these rolling process parameters that will provide the optimal response of the properties.

II. Methodology

Rolling cycles of St60Mn steel billets which were charged into the furnace and heated to the rolling temperatures in the range 1150°C -1250°C and later rolled into 12mm,14mm,16mm and 25mm diameters of rebars were investigated at finish rolling temperature of 915°C,917°C,918°C,920°C,922°C,923°C,keeping the % total deformations constant at 99%,while changing rolling strain rates to $7 \times 10^3 s^{-1}$,$6 \times 10^3 s^{-1}$,$5 \times 10^3 s^{-1}$.

Mechanical tests were performed on the hot-rolled samples at room temperature of 27°C on UPD 100s Universal Materials Testing Machine and PSW Pendulum Impact Testing Machine, respectively. The optimum finish rolling temperature,% total deformation and rolling strain rates were evaluated using the Response Surface Methodology. The yield strength, tensile strength and toughness were obtained from the mechanical test.

Table 2.1: Chemical composition of the as received St60Mn steel specimen used.

STEEL GRADE	CHEMICAL COMPOSITION %								
	C	Si	Mn	P	S	Cr	Ni	Cu	N
ST60Mn	0.41	0.24	1.12	0.021	0.008	0.02	0.03	0.03	0.010

a) Response Surface Modeling Technique

Response surface methodology was used for the optimization of the yield strength, tensile strength and toughness of the hot rolled St60Mn steel. Actual values from the experimental data were used directly for the RSM experimental design. The behaviour of the yield strength σ_y, tensile strength σ_T ,and toughness $E_{ImT,}$ as obtained in the experimental data were modelled as functions of the finish rolling temperature and rolling strain rate using the Response Surface Methodology (RSM).The response surface methodology was obtained from the design expert software version 6.0.8.Response surface methodology usually aim at determining the optimum settings for the variables and to see how the variables perform over the whole experimental domain, including any interactions such as the simultaneous influence of the rolling process parameters on the properties of the hot rolled St60Mn steel. The finish rolling temperature and rolling strain rate were taken as two independent variables which determine the response of the yield strength σ_y, tensile strength σ_T ,and toughness E_{ImT}, of the steel to the hot rolling process parameters. The experimental design and statistical analysis were performed according to the response surface analysis method using Design Expert 6.0.8 software. Historical data obtained from the experiments was employed to study the combined effect of the finish rolling temperature (x_1) and rolling strain rate (x_2).The dependent variables (y) measured were the yield strength σ_y, tensile strength σ_T and toughness E_{ImT}, of the hot rolled St60Mn steel. These dependent variables were expressed individually as a function of the independent variables known as response function.

The cubic order three dimensional surface model was determined to describe the relationship between each of the properties y, and the two independent variables (finish rolling temperature;x_1, and rolling strain rate;x_2).The model was able to account for the curvature of the response and the interaction of the independent variables in the response surface. The data point (y,x_i,x_j) defines a curved surface in 3D space represented by the following polynomial (Karuppaiya et al.,2010;Lazic,2004;Man et al,2010).

$$y = \beta_0 + \Sigma^q_{j=1}\beta_j x_j + \Sigma^q_{j=}1\beta_{jj}x_j^2 + \Sigma^q_{j=1}\beta_{jj}x_j^3 + \Sigma_{i<}j\Sigma\beta_{ij}x_ix_j + e$$

The parameters β_i are constant coefficients known as the regression coefficients. These coefficients measure the expected change in the response y per unit increase in x_i when the x_j is held constant and vice versa and are established by regression analysis in the RSM programme.

$\Sigma\beta_j x_j$ is the main effect.$\Sigma\beta_{jj}x_j^2$ are the curvature,$\Sigma_{i<j}\Sigma\beta_{ij}x_ix_j$ is the interaction and e is the error.All the coefficients were obtained by the use of the Design Expert software package. The goodness of fit for each property model was confirmed by the R^2 values and the probability obtained from the analysis of variance (ANOVA).The optimum values of the rolling process parameters and the properties were obtained from the numerical analysis of the RSM package .Experiments were conducted at the optimal condition to validate the values obtained.

III. RESULTS AND DISCUSSION

a) Influence of finish rolling temperature on the mechanical properties at constant % total deformation of 99%, changing rolling strain rates to 7 x 10^3s^{-1},6 x 10^3s^{-1} and 5 x 10^3s^{-1}.

The results obtained from the mechanical test experiments were used to describe the behavioural pattern of the yield strength σ_y, tensile strength σ_T and toughness E_{ImT}, properties with the finish rolling temperature and rolling strain rates as shown in Figures 1.1,1.2 and 1.3.

The figures expose the influence of the finish rolling temperature and rolling strain rate on each of the properties. As shown in the figures, the tensile strength and yield strength decrease as the finish rolling temperature increases but increase as the rolling strain rates increase. But the toughness on the other hand, increases as the finish rolling temperature increases but decreases as the rolling strain rates increase.

Finish Rolling Temperature Versus Mechanical Properties At Constant Deformations Of 99%, Changing Rolling Strain Rates

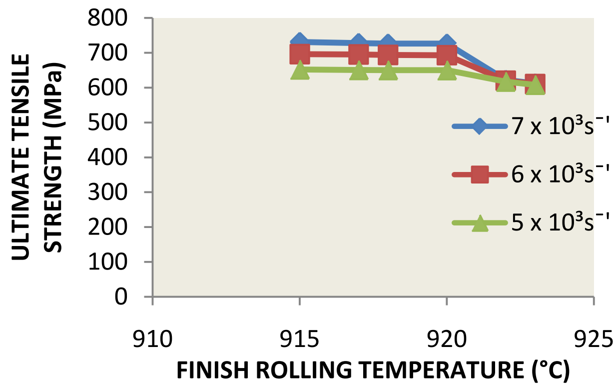

Figure 3.1: Finish rolling temperature versus tensile strength at constant deformation of 99%,changing rolling strain rates

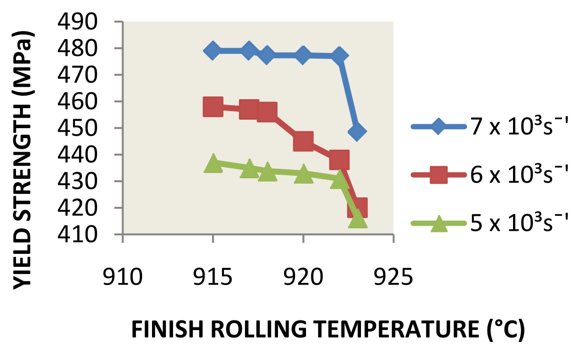

Figure 3.2: Finish rolling temperature versus yield strength at constant deformation of 99%,changing rolling strain rates

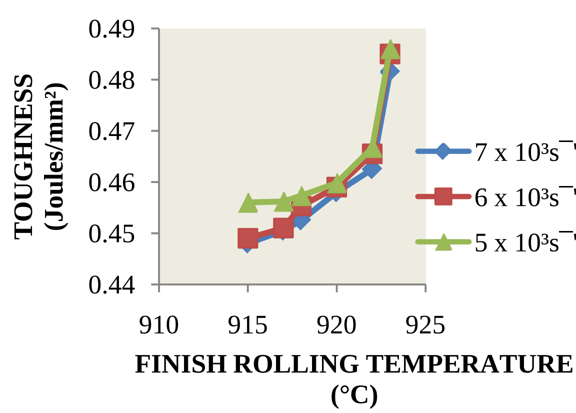

Figure 3.3: Finish rolling temperature versus toughness at constant deformation of 99%,changing rolling strain rates

b) Response Surface Analysis

The properties parameters as obtained from the rolling data are shown in Tables below.

Table 3.1: Actual data from the effect of finish rolling temperature on the mechanical properties of St60Mn steel at 99% constant deformation, changing rolling strain rates.

Mechanical properties of hot-rolled St60Mn steel																		
Rolling strain rate (s^{-1})	Finish rolling temperature (°C)																	
	915			917			918			920			922			923		
	σ_T	σ_y	E_{lmT}	σ_T	σ_y	E_{lmT}	σ_T	σ_y	E_{lmT}	σ_T	σ_y	E_{lmT}	σ_T	σ_y	E_{lmT}	σ_T	σ_y	E_{lmT}
7×10^3	731	479	0.44	728	479	0.45	726.2	477.3	0.45	726.2	477.3	0.45	622	477	0.46	611.8	448	0.48
6×10^3	696	458	0.44	695	457	0.45	693.5	456	0.45	693	445	0.45	620	438	0.46	610	420	0.48
5×10^3	652	437	0.45	650.5	435	0.45	650.2	433	0.45	650	433	0.45	617	431	0.46	608	416.2	0.48

Table 3.1 show the dependency of the yield strength, tensile strength and toughness on the finish rolling temperature for different rolling strain rates and % total deformations. The data in the tables were populated in the RSM actual-design value frame for the 18 observations obtained. The RSM capable of developing model fits for the data was used to develop the models describing the relationship of each of the properties with the hot-rolling parameters. Tables 3.2,3.3 and 3.4 below show the results of the model fit for the three mechanical properties under consideration as analysed using the RSM.

Table 3.2: Response surface model for tensile strength relationship with finish rolling temperature at 99% deformation, changing rolling strain rates

Model Summary Statistics for Tensile strength of hot rolled St60Mn steel at 99% deformation,changing rolling strain rates						
Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	25.61	0.8002	0.7559	0.6345	10803.59	
2FI	22.03	0.8689	0.8194	0.7536	7283.71	
Quadratic	8.92	0.9839	0.9704	0.9151	2510.19	suggested
Cubic	0.89	0.9999	0.9997	0.9924	223.61	Aliased

Table 3.3: Response surface model for yield strength relationship with finish rolling temperature at 99% deformation, changing rolling strain rates

Model Summary Statistics for Yensile strength of hot rolled St60Mn steel at 99% deformation,changing rolling strain rates						
Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	6.52	0.9364	0.9223	0.8979	614.21	
2FI	6.62	0.9417	0.9199	0.9044	575.00	
Quadratic	3.83	0.9854	0.9732	0.9367	380.79	Suggest d
Cubic	1.35	0.9988	0.9966	0.9131	522.66	Aliased

Table 3.4: Response surface model for toughness relationship with finish rolling temperature at 99% deformation, changing rolling strain rates

Model Summary Statistics for Toughness of hot rolled St60Mn steel at 99% deformation,changing rolling strain rates						
Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	6.227E-003	0.9031	0.8815	0.8250	6.299E-004	
2FI	6.440E-003	0.9078	0.8733	0.7365	9.484E-004	
Quadratic	1.852E-003	0.9943	0.9895	0.9536	1.670E-004	Suggested
Cubic	8.513E-004	0.9992	0.9978	0.9426	2.067E-004	Aliased

The results suggest Quadratic order for the description of the mechanical properties relationship with the hot-rolling parameters as indicated in the tables. These are obtained by focusing on the model that maximizes the adjusted and predicted R-square values for each of the properties and the lowest level of uncertainty. The quadratic order compared to the other models has moderate standard deviation, high R^2 values and low predicted residual sum of squares for the three properties indicating that the quadratic model is the most suitable for describing each of the steel properties relationship with the process parameters.

The Analysis of Variance (ANOVA) for the response surface cubic models of the yield strength, tensile strength and toughness are shown in Tables below respectively with estimated values of the regression coefficients for 99%,98%,96% total deformation variables. The ANOVA is employed inorder to determine which of the variables in the rolling process parameters are significant in describing the behaviours of the mechanical properties.TheR^2 values were determined from the F-test.The significant parameters are shown in Tables below. Parameters with '' Prob> F''-values less than 0.0001 are significant to the description of the properties relationship to the rolling process parameters.

Table3. 5: ANOVA for tensile strength relationship with finish rolling temperature at 99% deformation, changing rolling strain rates

ANOVA for Tensile strength of hot-rolled St60Mn steel at 99% deformation, changing rolling strain rates.										
ANOVA for Response Surface Cubic Model										
Analysis of Variance table [Partial sum of squares]										
Source	Sum of Squares	Coefficient Estimate	Mean Squares	F Value	Prob>F	DF	95% CL Low	Standard Error	95% CL High	VIF
Model	29558.33		4222.62	5387.59	<0.0001	7				
X_1	3698.00	−43.00	3698.00	4718.23	<0.0001	1	−44.74	0.63	−41.26	4.46
X_2	2903.22	38.10	2903.22	3704.18	<0.0001	1	36.36	0.63	39.84	4.46
X_1^2	3194.98	−38.19	3194.98	4076.43	<0.0001	1	−39.85	0.60	−36.53	1.03
X_2^2	20.93	−3.09	20.93	26.71	0.006	1	−4.75	0.60	−1.43	1.03
x_1x_2	2277.69	−18.84	2277.69	2906.08	<0.0001	1	−19.81	0.35	−17.87	1.08
X_1^3	0.000 0									
X_1^3	0.000 0									
$X_2^2x_2$	459.67	−17.36	459.67	586.49	<0.0001	1	−19.35	0.72	−15.37	4.54
$X_1x_2^2$	7.64	2.24	9.74	0.0355			0.25	0.72	4.23	4.54
Residual	3.14		0.78			4				
Lack of fit	3.14		3.14			1				
Pure error	0.000		0.000			3				
Cor Total	29561.47					11				
Intercept		691.79				1	685.99	0.65	693.59	

Std.Dev.	0.89	R-Squared	0.9999
Mean	660.73	Adj R-Squared	0.9997
C.V.	0.13	Pred R-Squared	0.9924
PRESS	223.61	Adeq Precision	170.160

Table 3.6: ANOVA for Yield strength relationship with finish rolling temperature at 99% deformation, changing rolling strain rates

ANOVA for Yield strength of hot-rolled St60Mn steel at 99% deformation,changing rolling strain rates.										
ANOVA for Response Surface Cubic Model										
Analysis of Variance table [Partial sum of squares]										
Source	Sum of Squares	Coefficient Estimate	Mean Squares	F Value	Prob>F	DF	95% CL Low	Standard Error	95% CL High	VIF
Model	5926.69		1185	80.93	<0.0001	5				
X_1	1708.51	−14.20	1708.51	116.66	<0.0001	1	−17.41	1.31	−10.98	1.05
X_2	3110.89	19.15	3110.89	212.41	<0.0001	1	15.94	1.31	22.37	1.05
X_1^2	165.78	−8.69	165.78	11.32	0.0151	1	−15.00	2.58	−2.37	1.05
X_2^2	122.39	7.46	122.39	8.36	0.0277	1	1.15	2.58	13.78	1.02
X_1X_2	33.26	−2.26	33.26	2.27	0.1826	1	−5.92	1.50	1.41	1.06
X_1^3	0.000 0									
X_2^3	0.000 0									
$X_1^2X_2$	20.12	−3.63	20.12	10.98	0.0295	1	−6.68	1.10	−0.59	4.54
$X_1X_2^2$	57.06	6.12	57.06	31.15	0.0051		3.07	1.10	9.16	4.54
Residual	87.86		16.45			6				
Lack of fit	87.86		29.29			3				
Pure error	0.000		0.000			3				
Cor Total	6014.56					11				
Intercept		446.79				1	439.94	2.80	453.64	

Std.Dev.	3.83	R-Squared	0.9854
Mean	446.47	Adj R-Squared	0.9732
C.V.	0.86	Pred R-Squared	0.9367
PRESS	380.79	Adeq Precision	24.648

Table 3.7: ANOVA for toughness relationship with finish rolling temperature at 99% deformation, changing rolling strain rates.

ANOVA for Toughness of hot-rolled St60Mn steel at 99% deformation,changing rolling strain rates.										
ANOVA for Response Surface Cubic Model Aliased										
Analysis of Variance table [Partial sum of squares]										
Source	Sum of Squares	Coefficient Estimate	Mean Squares	F Value	Prob>F	DF	95% CL Low	Standard Error	95% CL High	VIF
Model	3.579E-003		7.159E-004	208.71	<0.0001	7				
X_1	2.810E-003	0.018	2.810E-003	819.31	<0.0001	1	0.017	6.360E-004	0.020	1.05
X_2	2.729E-005	1.794E-003	2.729E-005	7.96	0.0303	1	−3.351E−003	6.360E-004	−2.379E−004	1.05
X_1^2	2.948E-004	0.012	2.946E-004	85.94	<0.0001	1	8.526E-003	1.249E-003	0.015	1.02
X_2^2	5.506E-006	1.583E-003	5.506E-006	1.61	0.2521	1	−1.474E−003	1.249E-003	4.640E-003	1.02
X_1X_2	3.287E-005	2.243E-003	3.287E-005	9.58	0.0212	1	4.699E-004	7.245E-004	4.016E-003	1.06
						1				

Residual	2.058E-005		3.430E-006	6			
Lack of fit	2.058E-005		6.860E-006	3			
Pure error	0.000		0.000	3			
Cor Total	3.600E-003			11			
Intercept		0.45		1	0.45	1.355E-003	0.45

Std.Dev.	1.852E-003	R-Squared	0.9943
Mean	0.46	Adj R-Squared	0.9895
C.V.	0.40	Pred R-Squared	0.9536
PRESS	1.670E-004	Adeq Precision	31.229

The F- values for the properties less than < 0.0001 implies that such models are significant. This means that there is only 0.01% chance that the model F-values as large as obtained could occur due to noise. The model terms with ''prob>F'' value < 0.0001 are considered to be significant and influence the responses considerably. Considering the finish rolling temperature relationship with the mechanical properties of hot rolled st60Mn steel at 99% deformation while changing rolling strain rates, the rolling parameter having the most significant influence on the properties was the finish rolling temperature (x_1) main effect with F-values of 4718.23,116.66 and 819.31,for tensile strength, yield strength and toughness respectively. This is followed by rolling strain rate (x_2) with F-values of 3704.18 ,212.41 and 7.96,both having ''prob>F''< 0.0001.This implies that the finish rolling temperature has much more influence on the tensile strength and toughness with ''prob>F'' <0.0001,whereas the rolling strain rate has much more influence on the yield strength than the other two,with ''prob>F''value <0.0001.The model terms having ''prob>F''value >0.0001 indicates that the terms are not significant.

Similar trends were observed for the other variables of 98%,96%, for the hot-rolled St60Mn steel. The determination coefficient R^2 values show a good response between the predicted values and the data for the properties at various variables of the parameters. This gives the confidence that the models describing the response of the properties are good fits of the model data. The adequate precision which measures the signal to noise ratios for the relationships describing the yield strength surface response, tensile strength surface response and the toughness surface response for all the variables of the rolling process parameters indicates adequate signals having been determined to be greater than 4.00 as shown in the Tables. It is required that this ratio greater than 4 is desirable. These models can therefore be used to navigate the design space for the three properties.

The satisfactory correlation between the data and the RSM predicted values is also evident as shown in the figures below, in which the plotted points are observed to be spaced out on the fit line as shown for the three properties respectively for 99%,98%,96% rolling process variables.

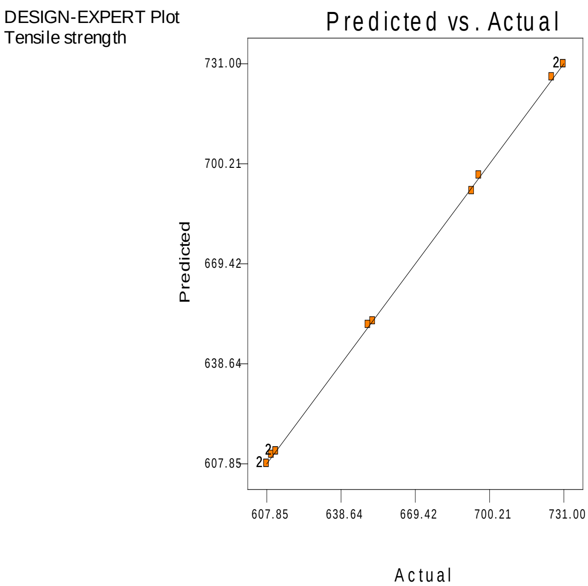

Fig. i: Tensilestrength

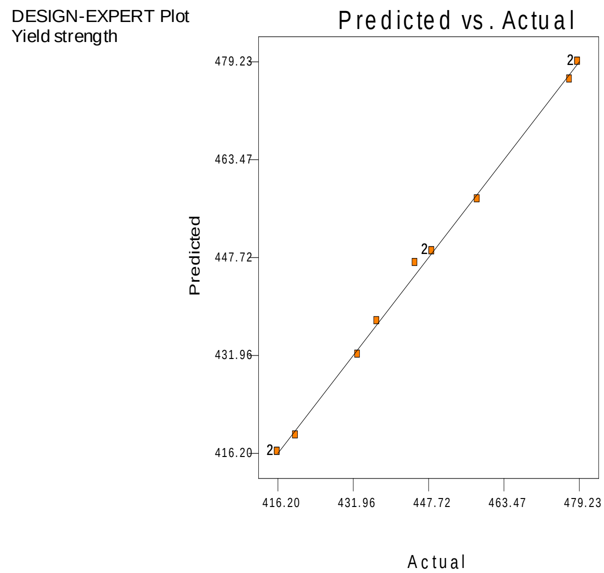

Fig. ii: Yield strength

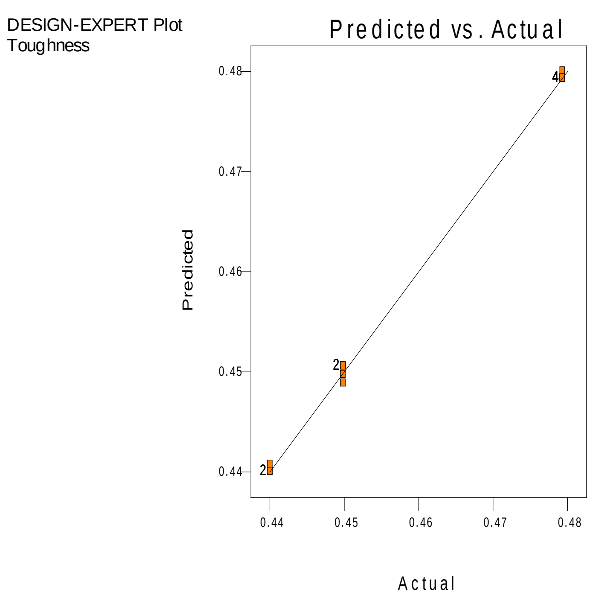

Fig. iii : Toughness

Fig. 3.4: Parity plot for mechanical properties relationship with finish rolling temperature at 99% deformation , changing rolling strain rates

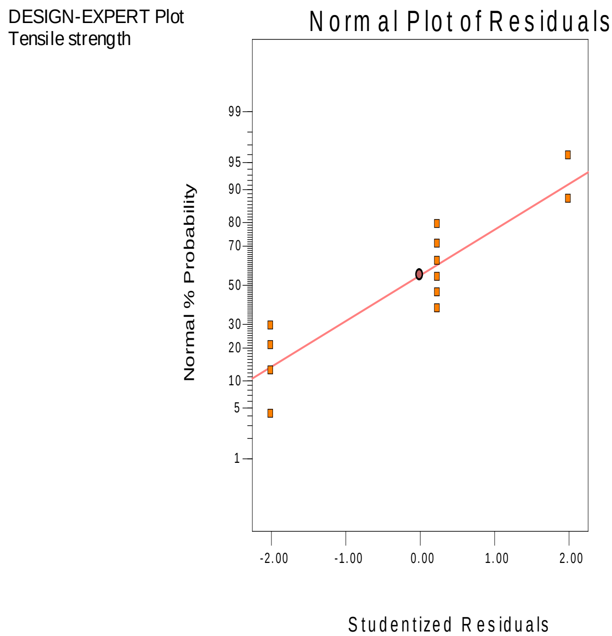

Fig. i: Tensile strength

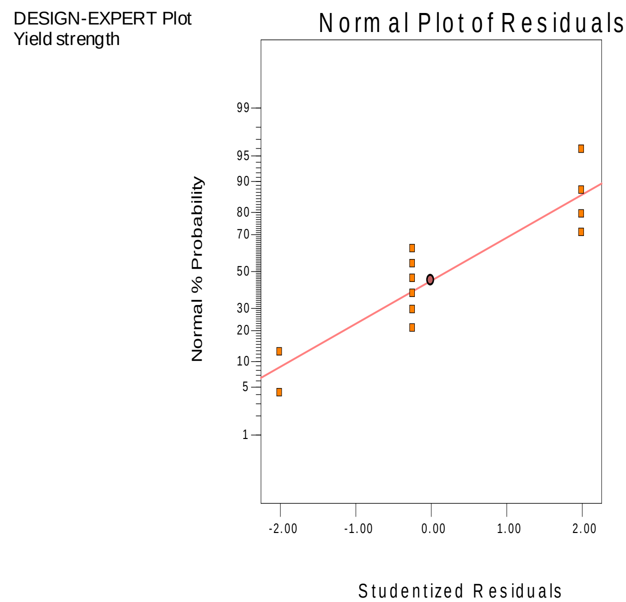

Fig. ii: Yield strength

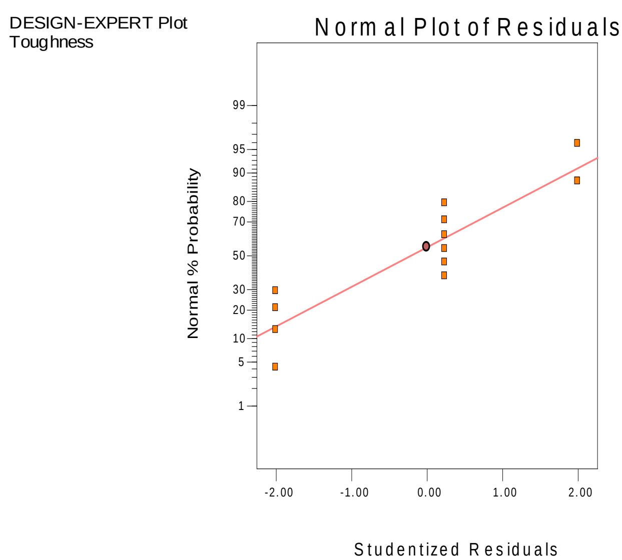

Fig. iii: Toughness

Fig 3.5: Normal plot for mechanical properties relationship with finish rolling temperature at 99% deformation, changing rolling strain rates

It was observed that the residuals tend to be aligned with the normal distribution assumptions as defined by the straight lines. This implies that the errors are normally distributed. The predicted values for the properties as function of the process parameters could therefore be considered useful for getting information from the experiments.

The relative equations describing the response of each of the properties with the process parameters as obtained from the Response Surface Method are as follows:

Tensile strength for finish rolling temperature at 99% deformation, changing rolling strain rates

$$\sigma_T = \text{Tensile strength} = +691.79 - 43.00 * x_1 + 38.10 * x_2 - 38.19 * x_1 2 - 3.09 * x_2 2 - 18.84 * x_1 * x_2 - 17.36 * x_1 2 * x_2 + 2.24 * x_1 * x_2 2 \quad \ldots\ldots 3.1$$

Yield strength for finish rolling temperature at 99% deformation,changing rolling strain rates,in terms of actual factors.

$$\sigma_y = -4.57768E+005 + 997.70178 * x_1 + 0.44789 * x_2 - 0.54291 * x_1 2 + 7.46346E-006 * x_2 2 - 5.63984E-004 * x_1 * x_2 \quad \ldots\ldots 3.2$$

Toughness for finish rolling temperature at 99% deformation,changing rolling strain rates,in terms of actual factors.

$$E_{ImT} = +610.84091 - 1.32942 * x_1 - 5.36062E-004 * x_2 + 7.23945E-004 * x_1^2 + 1.58311E-009 * x_2^2 + 5.60686E-007 * x_1 * x_2 \quad \ldots\ldots 3.3$$

Where x_1 is the finish rolling temperature (deg C) and x_2 is the rolling strain rate (s^{-1}).The contour of the responses as obtained in equations are calculated and was used to plot the surface response and the contour plots of the properties as shown below.

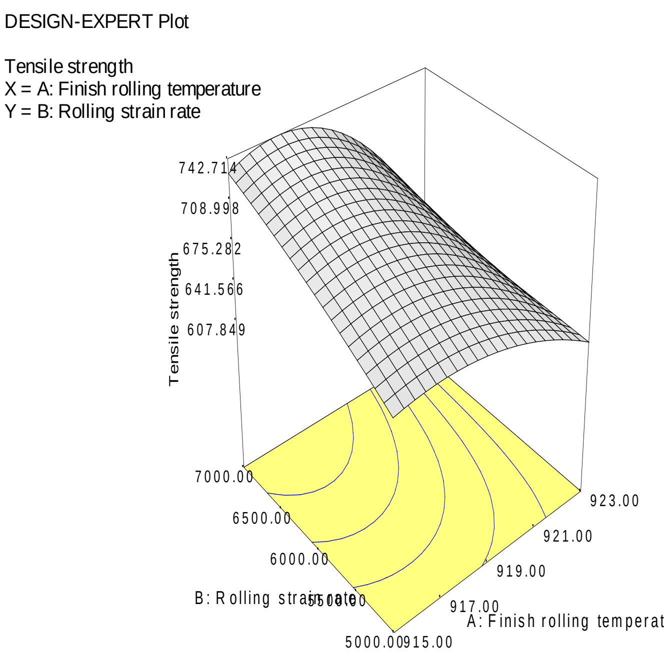

Fig i.: Surface plot for tensile strength

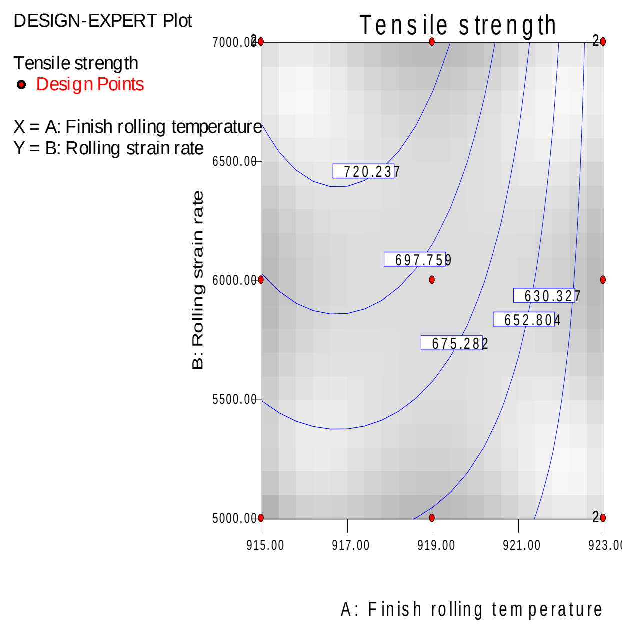

Fig ii.: Contour plot for tensile strength

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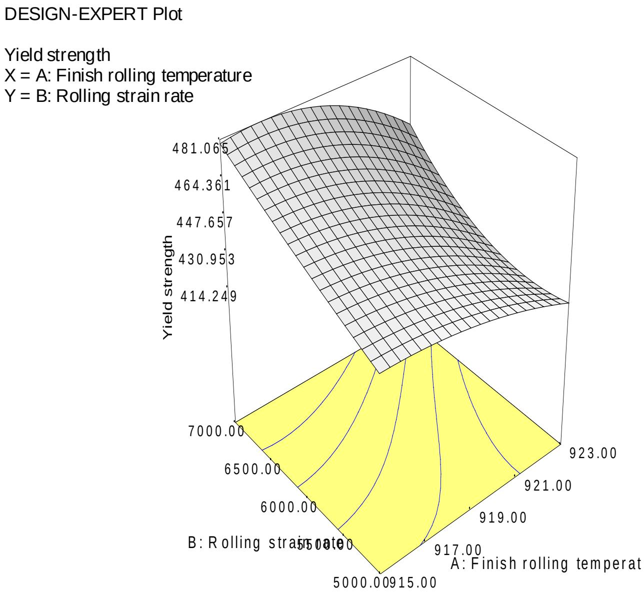

Fig. iii: Surface plot for yield strength

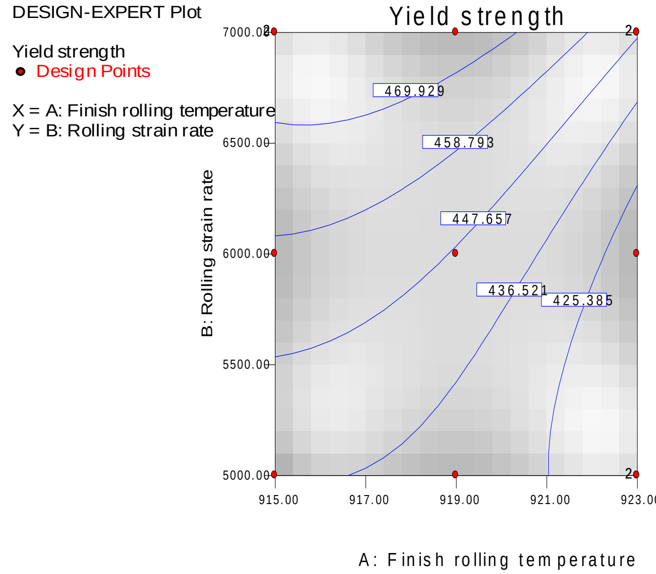

Fig. vi: Contour plot for toughness

Fig. 3.6: Surface and contour plot for tensile strength relationship with finish rolling temperature at 99% deformation, changing rolling strain rates.

The plots show the combined influence of the rolling process parameters on the yield strength, tensile strength and toughness of the hot rolled St60Mn steel samples for all the variables observed. The contour plots of the yield strength for all the variables observed showed similar curve shapes where yield strength decreases with increasing finish rolling temperature and increases with increasing rolling strain rates. Both rolling strain rate and finish rolling temperature shows a strong positive effect on the yield strength for all the variables observed. The characteristics of the contour plots for tensile strength are similar to that of the yield strength. The contour plots of the toughness for all the variables observed showed similar curve shapes where toughness increases with increasing finish rolling temperature and increases with decreasing rolling strain rates. The maximum achievable responses of the properties are well exposed on the contour plots. It is clear from the plots that the tensile strength and yield strength the hot rolled St60Mn steel decrease with increasing finish rolling temperature and increase with increasing rolling strain rates; whereas the toughness increases with increasing finish rolling temperature and increases with decreasing rolling strain rates. So these indicate that the maximum values of tensile and yield strength could be obtained at lower finish rolling temperature and higher rolling strain rates respectively, whearas the maximum values of toughness could be obtained at higher finish rolling temperature and lower rolling strain rates respectively; indicating considerable improvement of the properties at the respective parameters. The independent influence of the rolling process parameters is obtained on the surface plots. It was observed that the three parameters had equal influence on the properties at the variables observed. This influence is well exposed in the contour plots for the three properties. The improved yield strength is good for steel bars used in construction which tends to prevent failure of the steel when subjected to impact load. Therefore the yield and tensile strength should be maximized. The combined effect of the rolling process parameters is responsible for the curvatures of the plots. The implication is that the effect of the three parameters should be considered simultaneously for a global emergence of optimal process parameters for improved properties of the hot rolled St60Mn steel.

The effect of the finish rolling temperature,% total deformation and rolling strain rates on these properties could be optimized to avoid full recrystallization of the all the sample grains beyond the temperature range of 923°C.The criteria for optimization of the rolling process parameters were selected to maximize the yield strength, tensile strength and toughness for improved properties as required of the steel. The combined influence of the rolling process parameters on the simultaneous responses of the yield strength, tensile strength and toughness of the steel are presented in the Tables. The achievable optimal yield strength, tensile strength and toughness values were found as predicted in the tables with 95% confidence interval which ensures that the probability of the effectiveness of the optimization procedure is greater than 0.05.The corresponding parameters that yielded these optimal values were also shown in the tables for the various degrees of cold drawn deformation.

Table 3.8: Optimal values for tensile strength and finish rolling temperature at 99% deformation, changing rolling strain rates

Factor	Name	Level	Low Level	High level	Std.Dev.
X_1	Finish rolling temperature	920.30	915.00	923.00	0.000
X_2	Rolling strain rate	7000.00	7000.00	7000.00	0.000

Response	Prediction	Actual	SE Mean	95% CI low	95% CI high
Tensile strength	701.63	701.915	0.76	669.51	703.75
Yield strength	470.128	470.198	1.17	466.89	473.37
Toughness	0.458042	0.457964	7.334E-004	0.46	0.46

IV. Conclusion

The yield strength, tensile strength and toughness of hot-rolled St60Mn steel were evaluated when subjected to rolling process parameters towards obtaining the rolling process parameters that will be suitable for improving these properties of hot-rolled St60Mn steel to prevent the steel from the influence of poor mechanical properties which results in fracture failure when the steel is subjected to impact loads. The finish rolling temperature and rolling strain rate are found to influence these properties to a large extent as exposed in the Response Surface Analysis of the properties. The model developed by the RSM describing the experimental data shows that conclusion could be drawn from the model of the individual and combined interaction influence of the rolling parameters on the yield strength, tensile strength and toughness of the hot-rolled steel. The RSM was able to obtain the optimal values of the properties. The optimal yield strength ,tensile strength and toughness of the steel were obtained to be 470.13 MPa,701.63 MPa and 0.458042 joules/mm² respectively for the hot-rolled St60Mn steel.The RSM could be useful to obtain desired properties of hot-rolled St60Mn steel by controlling the rolling process parameters during hot-rolling.

Compliance with ethical standards:
Funding: This study was funded by the corresponding author (there was no grant received from any company).
Conflict of interest:we have no conflict of interest.

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Effect of Particle Concentration and Sliding Velocity in Magnetic Abrasive Finishing of Brass Pipe

By Saurav Arora & Jasgurpreet Singh Chohan
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Abstract- The present study investigates the influence of magnetic field on the internal surface finish of Brass UNS C26800 pipe. The input parameters such as sliding velocity of electromagnets, concentration ratio (castor oil and magnetic abrasive particles) and number of cycles were varied in the selected range and their effect was comprehended in terms of percentage change in surface finish (%ΔRa). The remaining process parameters were kept constant throughout the experimentation. According to the results, % ΔRa initially increases and afterwards decreases with an increase in sliding velocity of electromagnets in case of concentration ratio 7:3 and 8:2. But, in case of concentration ratio 9:1, there is uniform increase in %ΔRa with an increase in sliding velocity. Also, at low sliding velocities (0.62 mm/sec and 1.23 mm/sec), the %ΔRa decreases with an increase in concentration ratio but at 2.46 mm/sec, the %ΔRa increases with increase in amount of oil added.

Keywords: magnetic abrasive finishing, magnetic abrasive particles, surface roughness, magnetorheological finishing.

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EFFECTOFPARTICLECONCENTRATIONANDSLIDINGVELOCITYINMAGNETICABRASIVEFINISHINGOFBRASSPIPE

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I. Introduction

The surface finish has a vital influence on the surface properties such as wear and friction on most of the engineering applications (Boparai et al., 2017). Magnetic abrasive finishing (MAF) is a super finishing process which uses a resilient multi point cutting tool to finish the work pieces (Kala and Pandey, 2014). A mixture of abrasive powder and ferromagnetic powder form the polishing tool called flexible magnetic abrasive brush (Givi et al., 2012). An internal magnetic abrasive finishing process was proposed for producing highly finished inner surfaces of tubes used in critical applications including clean gas or liquid piping systems (Yamaguchi and Shinmura, 1999). By varying various process factors, the finishing force and torque acting on the workpiece can be varied and thus, surface finish can be improved.

The various analytical parameters such as spindle speed, type of abrasives, electromagnet - workpiece gap, percentage weight of abrasives, magnetic flux density, no. of cycles, processing time etc. were studied by many researchers for optimization. Most of the researchers have concentrated on surface finishing at single location in the pipe. But, for practical applications, it is required to finish the whole internal surface of pipe. The present research work has explored the effect of varying sliding velocity of electromagnets on surface finish and material removal rate.

Magnetorheological Finishing uses the Magnetorheological (MR) polishing fluid for the precise finishing of components (Bedi and Singh, 2015). The magnetic abrasives particles mixed oil provides better and controlled internal finishing of pipes (Jha and Jain, 2004). But, hitherto no study has been performed to evaluate the impact of variable concentration ratio of oil and abrasives. Thus, castor oil is mixed with Magnetic Abrasive Particles (MAP) to gain better control over the nano finishing for the present work.

Also, as cited by many researches, number of cycles plays a crucial role in MAF process (Kala and Pandey, 2014; Givi et al., 2012). Hence, number of cycles has been varied in order to achieve controlled and efficient surface finish. The full factorial experimental design has been considered to study the influence of analytical parameters such as sliding velocity of electromagnet, concentration ratio (castor oil to abrasive mixture) and number of cycles of electromagnet on the surface finish. The remaining parameters were kept constant throughout the experimentation.

II. Experimentation

The workpiece material Brass UNS C26800 was taken and two types of abrasive materials i.e. Iron (Fe) and Iron Oxide (Fe_3O_4) were used throughout the experimentation. The average particle size of nano abrasives was 30-40 nm whereas for micro abrasives it was 350-450μm. The specialized designed experimental apparatus (Figure 1) has been used which facilitates the variation in sliding velocity of electromagnets along the horizontal axis of brass pipe.

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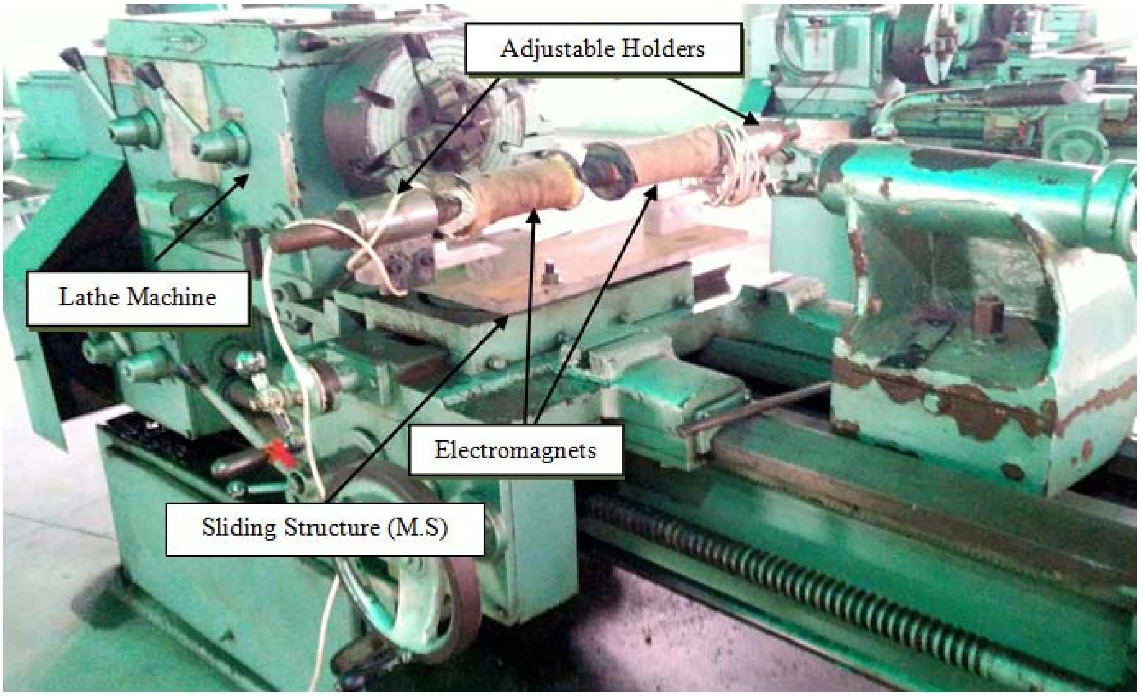


Figure 1: Schematic of experimental setup

The variable and fixed input parameters have been shown in Table 1 and 2 respectively. The range of variable input parameters has been worked out based on pilot experiments and previous studies carried out in case of conventional lathe machines (Boparai et al., 2017).

Table 1: Variable input parameters

S.No.	Input Parameters	Range
1.	Sliding velocity of electromagnets (mm/s)	0.62, 1.23, 2.46
2.	Concentration Ratio (castor oil to MAP) (vol.)	7:3, 8:2, 9:1
3.	No. of cycles	1, 2

The Magnetic abrasive particle (MAP) ratio has been fixed as 3:1 against magnetic flux density of 0.2 Tesla. The effect of selected process parameters was studied on the surface finish and material removal rate (MRR) of magnetic abrasive finishing.

Table 2: Fixed input parameters

	Input Parameters	Range
1.	Workpiece material	Brass UNS C26800
2.	Type of Abrasive	Fe_3O_4
3.	Magnetic flux density	0.2 Tesla
4.	Voltage	220 – 230 V
5.	Current	4 A
6.	Rotational speed	600 rpm
7.	Workpiece gap	2 mm
8.	MAP ratio	3:1

The surface roughness was measured at eight different locations at both ends of brass pipe workpiece with the digital "Surftest SJ 210" roughness tester having stylus tip radius 2µm and tip angle 60°C with measuring force 0.75mN. The measurements were taken employing Gaussian filter, cut-off length 0.25 mm and 2.5 mm exploratory length as per ISO-4287 regulations. Surface roughness (Ra) average values was calculated from mean of eight measurements and percentage improvement in roughness was estimated as:

$$\%\Delta Ra = \frac{(\text{Initial Roughness} - \text{Final Roughness})}{\text{Initial Roughness}} \times 100$$

III. Results and Discussions

The impact of sliding velocity on percentage improvement in surface finish varied due to blunting of abrasive particles in case of concentration ratio 7:3. As shown in Figure 2, initially the %ΔRa increases but upto a certain limit and then starts decreasing at high velocity of particles. Mishra et al., 2013 stated that rubbing action of magnetic abrasive particles with the work surface resulted in the generation of high frictional forces between them and causes wear of abrasives. With the increase in linear velocity of electromagnets, frictional force increases followed by the high spindle speed which causes blunting of abrasives. Due to blunting of abrasives, the cutting ability of abrasives is reduced which further decreases %ΔRa. Djavanroodi (2013) also found that the blunting of abrasive particles resulted in the slow improvement in surface finish.

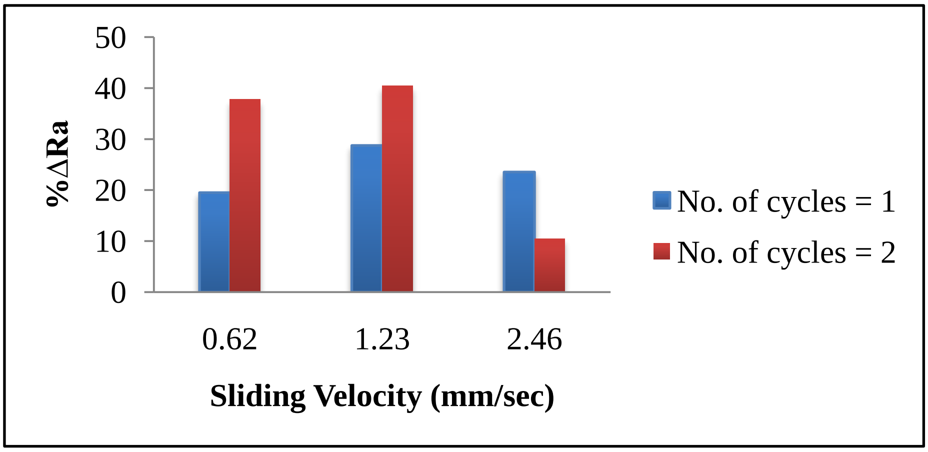


Figure 2: Effect of sliding velocity on surface finish with concentration ratio 7:3

The impact of sliding velocity in case of concentration ratio 8:2 has been plotted in Figure 3 which shows similar results as discussed earlier., As the sliding velocity increases, the surface finish increases but upto a certain limit and then starts decreasing. As rubbing action increases, more amount of lubricant (8:3) could not recompense the blunting of abrasives at very high sliding velocity.

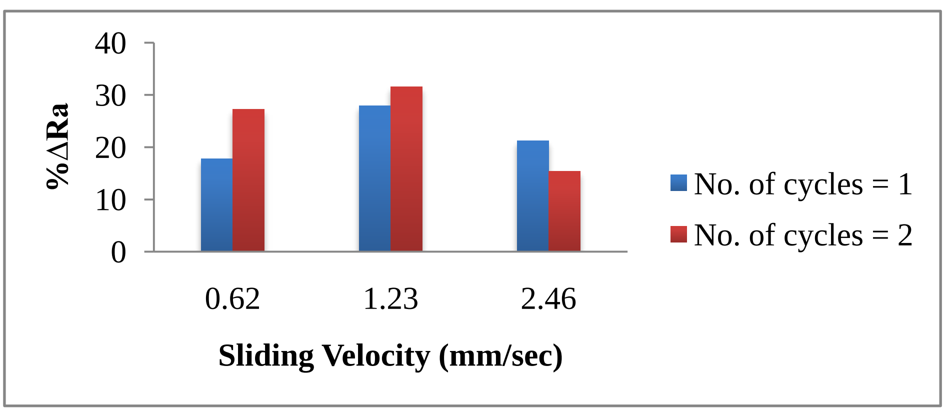


Figure 3: Effect of sliding velocity on surface finish with concentration ratio 8:2

However, the results are different at concentration ratio 9:1where uniform increase in %ΔRa is noted with an increase in the sliding velocity (Figure 4). At higher concentration ratio, the findings are relatively different than 7:3 and 8:2. The higher concentration of castor oil ensures the smooth cutting action and thus blunting of abrasives is prevented as castor oil also acts as lubricating agent. However, in this case the phenomenon of material embrittlement dominates the blunting of abrasives. As the sliding velocity increases, the surface undergo work hardening and thus surface profiles become brittle which can be fragmented easily by the sharp abrasives. Singh et al. (2008) suggested that the amount of material removal and %ΔRa for a particular setting of the process parameters depends upon the ability of the work surface to undergo work hardening and subsequent embrittlement. In present case (concentration ratio 9:1), the phenomenon of which improves cutting action at high velocity.

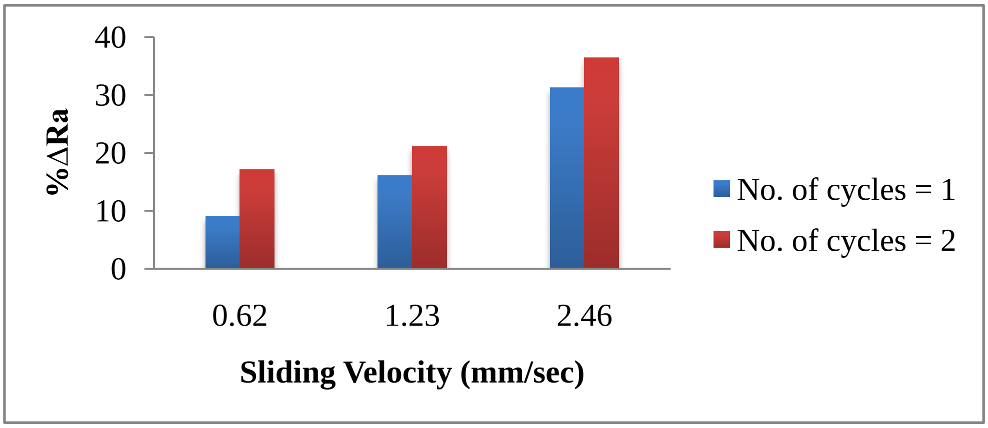


Figure 4: Effect of sliding velocity on surface finish with concentration ratio 9:1

The percentage improvement in surface finish (Figure 5) decreases with the increase in amount of castor oil added in magnetic abrasive particles at sliding velocity 0.62 mm/sec. This might be due to the reasons that with higher concentration of oil, the abrasive mixture become thick. Patil et al. (2012) explained that the oversupply of lubricant could either cause fluid lubrication between the abrasives and the workpiece or wash away the abrasives from the finishing area. This reduces the number of cutting edges acting on the surface, thereby disturbing the finishing action (Sharma and Singh, 2013).

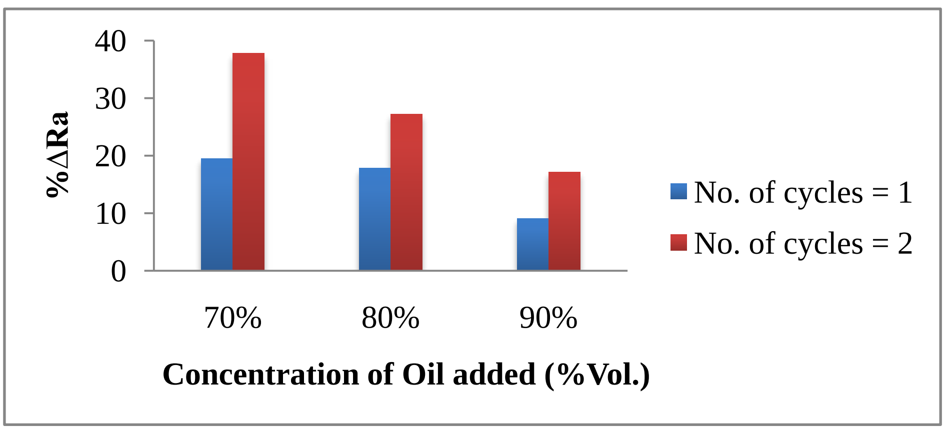


Figure 5: Effect of concentration ratio on surface finish at sliding velocity 0.62 mm/sec

The percentage improvement in surface finish (Figure 6) decreases with the increase in concentration ratio at sliding velocity 1.23 mm/sec. Similar results are found at sliding velocity 0.62 mm/sec.

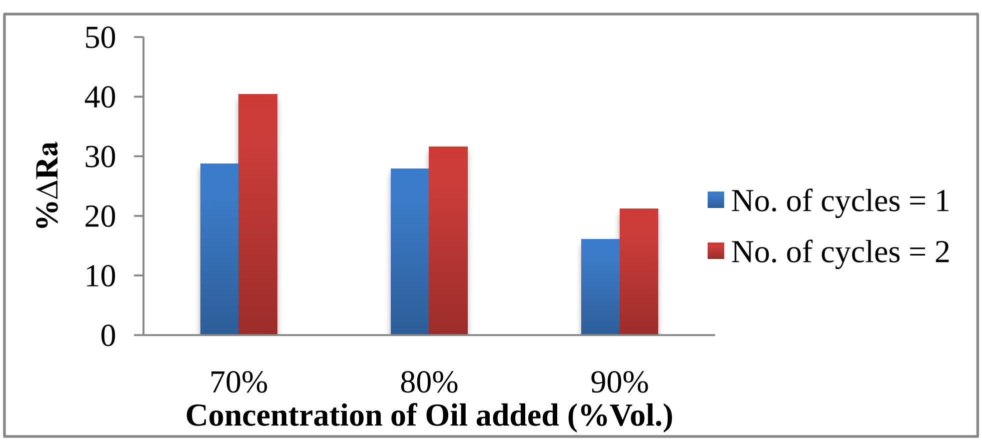


Figure 6: Effect of concentration ratio on surface finish at sliding velocity 1.23 mm/sec

Figure 7 depicts the impact of concentration ratio on percentage improvement in surface finish at sliding velocity 2.46 mm/sec. Results are quite different from sliding velocities 0.62 mm/sec and 1.23 mm/sec. At high sliding velocity of electromagnets, particles move with very high linear speed followed by high spindle speed carrying workpiece (Jain et al., 2001). Thus, the proper lubrication at high velocities provides better and smooth control over the surface.

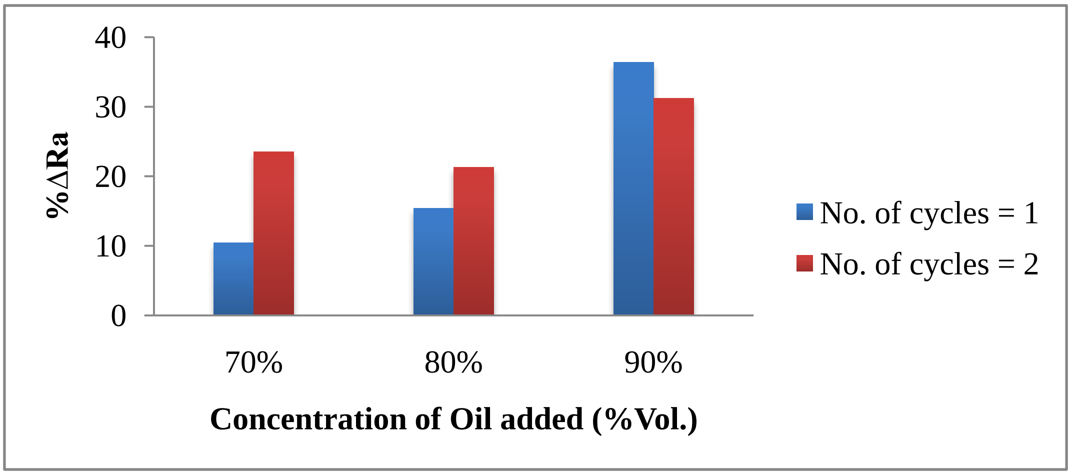
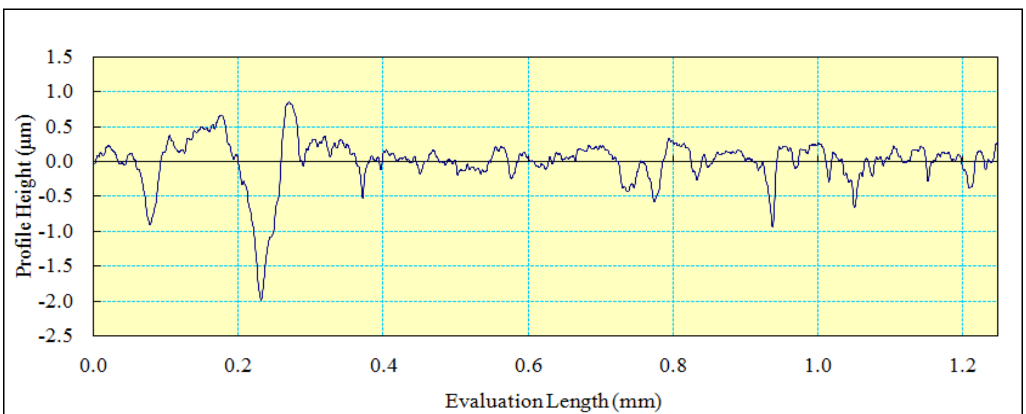


Figure 7: Effect of concentration ratio on surface finish at sliding velocity 2.46 mm/sec

The surface profiles were generated using the surface roughness tester (Mitutoyo Surftest SJ-210) with the help of communication tool during internal surface testing of pipes taken before and after experimentation. The experiments are selected randomly with comparatively different process parameters that offered best results out of the entire practice.

The roughness profiles have been arranged in Figure 8 for experiment performed at 1.23 mm/s, concentration ratio 8:2 and one cycle. The maximum height of profile before finishing is around 2.75 μm and after finishing is around 0.9 μm. This means that magnetic abrasive finishing assisted magnetorheological finishing diminishes the grooves or plows of the surface and smoothen the surface which results in the change in average height of the roughness profile (Verma et al., 2016).



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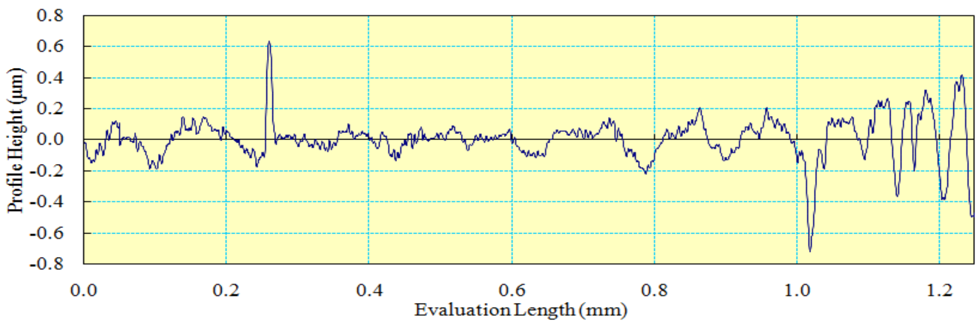
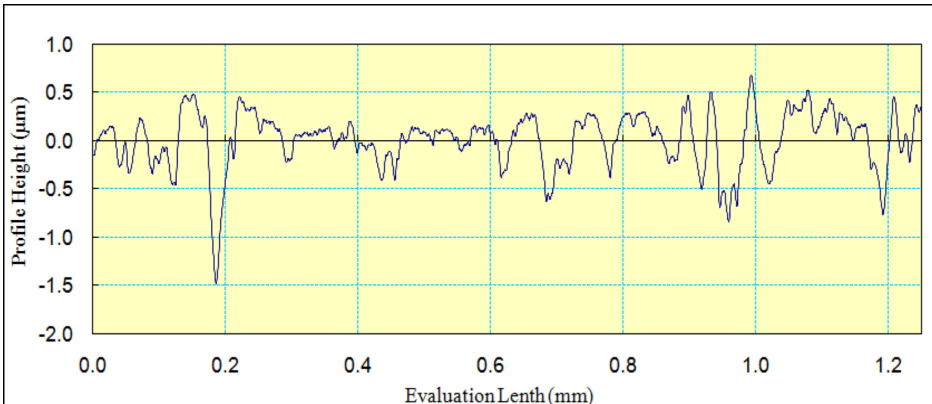


(b)

Figure 8: Roughness profiles (a) Before Finishing (b) After Finishing

The Figure 9 plots the roughness profiles acquired during experimentation at sliding velocity 1.23 mm/s, concentration ratio 7:3 and two cycles. The maximum profile height before finishing is around 2.0 μm and after finishing is around 1.6 μm. So, there is reduction in maximum profile height and also the graph is stable towards the centre line after the finishing process which results in the impressive reduction of average roughness (Ra) throughout the process.



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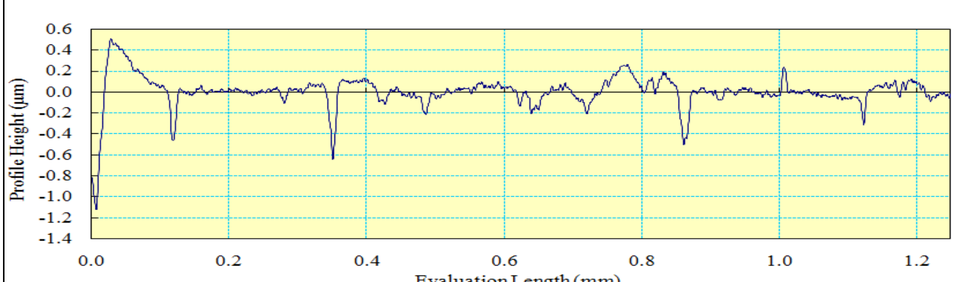

(b)

Figure 9: Roughness profiles (a) Before Finishing (b) After Finishing

IV. Conclusions

The investigative parameters such as sliding velocity, concentration ratio and number of cycles have been analyzed in the present research work using Brass UNS C26800 pipe. The surface finish improves with an increase in number of cycles of electromagnets. The amount of castor oil added in the abrasive mixture has significant effect on the percentage improvement in surface finish (%ΔRa). The surface finish improves with an increase in sliding velocity of electromagnets in case of concentration ratio 9:1 as brass undergoes embrittlement which ensures efficient micro-cutting. However, in ratio 7:3 and 8:3, the surface finish initially increase and afterwards decreases with an increase in sliding velocity which has been attributed to blunting of abrasives. The findings could be beneficial for brass pipe manufacturing industry as the internal finish of thin pipes has significant impact on fluid velocity, losses and turbulence in fluid.

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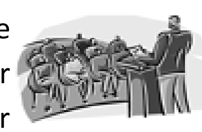

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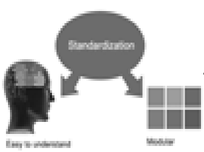

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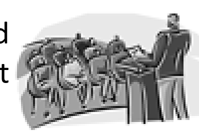

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The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of “Open Association of Research Society, U.S.A (OARS)” so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

Journals Research
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The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.

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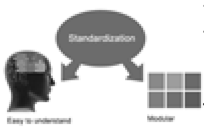

After nomination of your institution as “Institutional Fellow” and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.

The board can also take up the additional allied activities for betterment after our consultation.

The following entitlements are applicable to individual Fellows:

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- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

Note :

"

- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone.

"

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The paper should be in proper format. The format can be downloaded from first page of 'Author Guideline' Menu. The Author is expected to follow the general rules as mentioned in this menu. The paper should be written in MS-Word Format (*.DOC,*.DOCX).

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(II) Choose corresponding Journal.

(III) Click 'Submit Manuscript'. Fill required information and Upload the paper.

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1. General,

2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript's Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

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The recommended size of original research paper is less than seven thousand words, review papers fewer than seven thousands words also.Preparation of research paper or how to write research paper, are major hurdle, while writing manuscript. The research articles and research letters should be fewer than three thousand words, the structure original research paper; sometime review paper should be as follows:

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(c) Up to ten keywords, that precisely identifies the paper's subject, purpose, and focus.

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(e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition; sources of information must be given and numerical methods must be specified by reference, unless non-standard.

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(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

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- One should avoid outdated words.

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Acknowledgements: Please make these as concise as possible.

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27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

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Key points to remember:

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- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

Title Page:

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

Abstract:

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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