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By Mr Kishan Choudhuri & Dr Prasun Chakraborti
National Institute of Technology, Agartala.

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A COMPUTATIONAL APPROACHON THEPOSITION OFLOAD CENTRE OFASLIPPER BEARING

Strictly as per the compliance and regulations of:

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Mr Kishan Choudhuri [α] & Dr Prasun Chakraborti [σ]

Abstract - The slipper bearing is an integrated part of an axial piston pump. Proper lubrication is important for successful operation of the slipper bearing. This type of bearing is a type of hydrostatic thrust bearing. Many works have been done in the recent past on this type of bearing. This current work is based on the theoretical investigation of the locus of the load centre of this type of bearing. The leakage losses and the slipper drag are two important factors on which this type of bearing is designed. The load carrying capacity has a direct impact on those two factors. On the other hand the stability of the bearing depends upon the position of the load centre. There are many input factors on which the position of load centre is varied. These input factors thus play an important role on the smooth operation of such bearing. Such input variable are slipper tilt, applied pressure on the slipper, slipper speed, slipper non flatness angle or slipper land size. On the variation of these input variables, the nature of the position of load centre is plotted in this work. Based on the results the reasonable conclusions are made.

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I. Introduction

Axial piston swash-plate type hydrostatic pumps are being used extensively in aircraft, industrial and agricultural systems since they can transmit large specific power and the flow rate from them can be varied. A basic difference in the design of various models of axial piston pumps is how the pistons contact the swash plate. Many design use a bronze slipper positioned between the piston and the swash plate. With this design, hydraulic fluid is fed through internal passages to the piston/slipper and slipper/swash plate interfaces to supply lubrication at these surfaces. Some axial do not use a slipper, but rather finish each piston with a case-hardened spherical dome. The spherical dome contacts the swash plate in such a fashion, much like the contact that occurs in ball bearings. Elimination of the slipper reduces costs and eliminates the disadvantages of the slipper design, but unfortunately, it creates other problems. One of these is wear at the spherical dome/swash plate interface. The fig. 1 shows a typical slipper-piston assembly. The slipper is pivoted on the ball at the end of the piston to allow it to adjust to the swash plate angle and to rotate relative to the piston. High pressure fluid from the piston is connected via the control orifices in the piston and slipper to the central slipper pool allowing covered the influence of the orifice size on the performance of the bearing. Koc and Hooke [1] examined the effect of the tilting couples on the behavior of the slippers experimentally. Wang and Yamaguchi [2], [3] clarified experimentally and theoretically the effects of nozzle and thermoplastic materials on the characteristics of hydrostatic bearing/seal parts in water hydraulic axial pumps and motors. Manring [4] investigated the effects of pressure-induced deformations on the characteristics of hydrostatic thrust bearing. Manring [5] investigated experimentally, the effect of different socket geometry in the performance of slipper bearing. They found the effect on the leakage flow, load carrying capacity and the film thickness of the slipper bearing. In the work of Nie S. L. [6], the characteristic equation of the hydrostatic slipper bearing with an annular orifice damper is formulated, where the effects of various geometric parameters (e.g. damping length, supporting length, and clearance between the piston and the cylinder bore) are reflected. S. Kumar, J.M. Bergada, J. Watton [7] presented static and dynamic characteristics of a piston pump slipper with a groove. Three dimensional Navier Stokes equations in cylindrical coordinates have been applied to the slipper/plate gap, including the groove. In the work of M. Borghi, E. Specchia and B. Zardin [8] a numerical procedure is used to solve the Reynolds equation, written here with respect to the slipper-swash plate gap, whose height is considered variable in a two dimensional field and with time. In the work of Hong Liu, Zeng Xiong Peng, Chu Jing Shen [9] the calculation of film shape is simplified as a single objective optimization problem with two decision variables. A genetic algorithm is used to investigate about the film shape of the entire slipper bearing In the work of Fazil Canbulut, Erdem Koç, Cem Sinanoglu [10], the slipper geometry and working conditions affected on the slipper performance have been analyzed experimentally. The model of the slipper system has been established by original neural network (NN) method. The objective of the present work is theoretical investigation of the position of the load centre of the slipper bearing which is not studied extensively by the previous authors.

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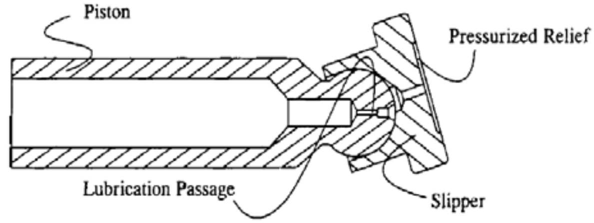

Figure 1 : Piston-slipper assembly

List of Symbols

a	Conical angle of the slipper.
$\bar{a}$	Non-dimensional value of a
a^*	Another non-dimensional form of a
d	A dimension for a conical slipper
$\bar{d}$	Non-dimensional value of d
e	A measure of slipper tilt
G	Non dimensional hydrodynamic parameter.
h	A variable defining film thickness
h_a	Average film thickness.
$\bar{h}$	Non-dimensional value of h
$\bar{h}_c$	The non dimensional film thickness at the mid radius of the land
$\bar{h}_o$	Non dimensional film thickness at middle land for no tilt
O	Orifice size coefficient
O_f	Orifice coefficient of the orifice between piston cylinder and slipper pocket.
p	Variable defining pressure in the slipper land
p_s	Pressure in slipper pocket
$\bar{p}_s$	Non-dimensional value of p_s
$\bar{p}$	Non-dimensional value of p
Q	Drain flow through the conical and tilted slipper
$\bar{Q}$	Non dimensional form of Q
r	Radius of any point on the slipper land measured from slipper center.
$\bar{r}$	Non-dimensional value of r
r_c	Mid-land radius
$\bar{r}_c$	Non dimensional mid land radius
r_i	Inner radius of slipper
$\bar{r}_i$	Non-dimensional value of r_i
r_o	Outer radius of slipper.
$\bar{r}_o$	Non-dimensional value of r_o
t	Slipper tilt in radian
$\bar{t}$	Non-dimensional value of t
t^*	Another non-dimensional form of t
u	Slipper velocity
W	Load carrying capacity for the slipper
$\bar{W}$	Non-dimensional value of W
$\bar{w}$	Non dimensional width of the slipper land
θ	Angle measured from trailing edge of the slipper
θ_d	Angle measured from the position of maximum clearance
θ_m	Angle of maximum clearance.

II. Mathematical Model

The following assumptions are taken into account to derive all the equations:

- Body forces acting on the lubricant such as gravitational, magnetic or electrical are neglected
- The pressure induced flow in the circumferential direction is neglected
- The pressure is assumed to constant through the thickness of the lubricating fluid.
- The lubricant is Newtonian.
- Viscosity is considered to be constant through the thickness of the lubricating film.
- The flow is laminar.
- Surface velocities are considered to be constant in direction.
- The lands is approximately conical.

Slipper is having a circular pocket, which is surrounded by a land as shown in figure. 1. The orifice connects the slipper pocket to the piston bore which feeds it with oil thus establishing a pressure in the slipper pocket which is approximately equal to piston pressure. The oil inside the slipper pocket lubricates the total slipper area. Referring to the Figure 2 the clearance between the land of an untilted slipper and the swash plate can be expressed as

$h = h_a - d + az + tr$. When slipper is tilted (Figure.3) this clearance becomes $h = h_a - d + az + tr\cos(\theta_d)$

And in non-dimensional form $\bar{h} = 1 - \bar{d} + \bar{a}\bar{z} + \bar{t}\bar{r}\cos(\theta_d)$

Pressure distribution over a slipper land must satisfy Reynold's equation, which is expressed in polar coordinate by:

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{rh^3}{12\mu}\frac{\partial p}{\partial r}+\frac{1}{r^2}\frac{\partial}{\partial \theta}\frac{h^3}{12\mu}\frac{\partial p}{\partial \theta}=$$

$$\frac{u}{2}\left[\frac{\partial h}{\partial r}\cos\theta-\frac{1}{r}\frac{\partial h}{\partial \theta}\sin\theta\right]$$

Making Non-dimensional form and introducing the non-dimensional group

$$G=\frac{\mu u r_o}{h_a^2 p_p}$$

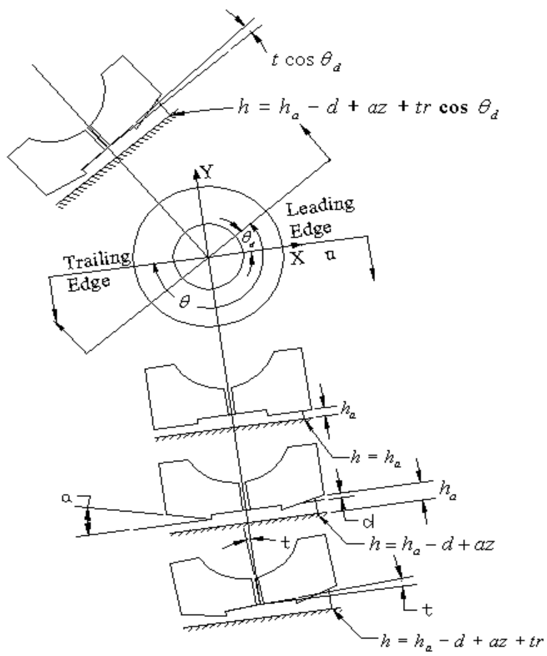

Figure 2 : The geometry of slipper bearing

$$\bar{p}=A+\frac{6G}{\bar{r}_c\bar{h}_c^3}$$

$$\left\{C\bar{z}+\left[\bar{r}_c\left(\bar{a}\cos\theta+\bar{t}\cos\theta_m\right)-\frac{C}{\bar{r}_c}-\frac{3C}{\bar{h}_c}\left(\bar{a}+\bar{t}\cos\theta_d\right)\right]\frac{\bar{z}^2}{2}\right\}$$

where $\bar{h}_c=1-\bar{d}+\bar{t}\bar{r}_c\cos\theta_d$ is the non-dimensional film thickness at the mid radius of the land. Constants A and C can be found out from the boundary conditions. The boundary conditions are

At $r=r_i$, $p=p_s$ and at $r=r_o$, $p=0$

This leads to a pressure distribution:

$$\bar{p}=\bar{p}_s\left[\frac{1}{2}-\frac{\bar{z}}{\bar{w}}+\frac{\left(\bar{z}^2-\bar{w}^2/4\right)}{2\bar{w}\bar{r}_c}\right]+\frac{3\bar{p}_s}{2\bar{w}\bar{h}_c}\left(\bar{a}+\bar{t}\cos\theta_d\right)\left(\bar{z}^2-\bar{w}^2/4\right)$$

$$+\frac{3G}{\bar{h}_c^3}\left(\bar{a}\cos\theta+\bar{t}\cos\theta_m\right)\left(\bar{z}^2-\bar{w}^2/4\right) \qquad (1)$$

where, $\bar{w}=\frac{r_o-r_i}{r_o}$ is the non-dimensional width of the slipper land.

The first group of the equation (1) corresponds the hydrostatic pressure distribution for flat and untilted slipper and the second group corresponds the hydrostatic pressure distribution produced by coning of the land and the tilt of the slipper. The final group represents the hydrodynamic effects due to conical shape of the land, slipper tilt and the slipper velocity.

The first group of the equation (1) can be replaced by an analytical solution of pressure for flat and untilt slipper which is derived in Appendix A. That analytical solution can be found out as $p=\frac{\ln(r/r_o)}{\ln(r_i/r_o)}p_s$.

Thus ultimately the equation of pressure distribution over the land of the slipper can be written as

$$\bar{p}=\bar{p}_s\frac{\ln\left(\bar{r}/\bar{r}_o\right)}{\ln\left(\bar{r}_i/\bar{r}_o\right)}+\frac{3\bar{p}_s}{2\bar{w}\bar{h}_c}\left(\bar{a}+\bar{t}\cos\theta_d\right)\left(\bar{z}^2-\frac{\bar{w}^2}{4}\right)+$$

$$\frac{3G}{\bar{h}_c^3}\left(\bar{a}\cos\theta+\bar{t}\cos\theta_m\right)\left(\bar{z}^2-\frac{\bar{w}^2}{4}\right).$$

Non-dimensional load is given as

$$\bar{W}=\int_0^{2\pi}\int_{-\bar{w}/2}^{+\bar{w}/2}\bar{p}\left(\bar{r}_c+\bar{z}\right)d\bar{z}\,d\theta$$

Putting the non-dimensional pressure the load carrying capacity can be derived as

$$\bar{W}=\frac{\pi\bar{p}_s\left(\bar{r}_o^2-\bar{r}_i^2\right)}{2\ln\left(\bar{r}_o/\bar{r}_i\right)}-\frac{2\pi\bar{p}_s\bar{r}_c\bar{w}^2}{4\bar{h}_o}\left[\frac{\bar{a}}{\sqrt{1-e^2}}+\frac{\bar{t}}{e}\left(1-\frac{1}{\sqrt{1-e^2}}\right)\right]$$

$$-\frac{G\bar{r}_c\bar{w}^3}{2\bar{h}_o^3}\cdot\frac{\pi\cos\theta_m}{\left(1-e^2\right)^{2.5}}\left[\bar{t}\left(2+e^2\right)-3e\bar{a}\right] \qquad (2)$$

Where

$\bar{h}_o=\frac{h_a-d}{h_a}$ and $e=\frac{\bar{t}\bar{r}_c}{1-\bar{d}}$

In equation (2) the first group is load carrying capacity for flat and untilted slipper. The second group is its modification for conical shape of the land and slipper tilt. The third group is the hydrodynamic effect on the load carrying capacity.

Finding out the appropriate G value is the main issue to solve the slipper equations. This is done from load equilibrium conditions. This analysis is different from Hook's analysis only by the equation of load equilibrium. The hydrodynamic parameter

$$G=\frac{\mu u r_o}{h_a^2 p_p}$$

which is dependent on h_a and

$$h_a = \left[6\mu r_o \sqrt{\frac{2}{\rho p_s}} \ln(r_o / r_i) \right]^{\frac{1}{2}}$$

The moment of the load with respect to x and y axis can be found out by integrating the load of small strip abut x and y axis. These moments are given by

$$\overline{M}_x = -\frac{\overline{p}_s}{4\overline{h}_o}\left(\overline{r}_c^{\,2}\,\overline{w}^{2} + \frac{\overline{w}^{4}}{20}\right)\left[\frac{2\pi \sin\theta_m}{e}\left(1 - \frac{1}{\sqrt{1-e^2}}\right)\left(\overline{a} - \frac{\overline{t}}{e}\right)\right]$$

$$-\frac{G}{2\overline{h}_o^{3}}\left(\overline{r}_c^{\,2}\,\overline{w}^{3} + \frac{\overline{w}^{5}}{20}\right)\left[\frac{3\pi e \sin\theta_m \cos\theta_m}{(1-e^2)^{2.5}}\left(\overline{a}e - \overline{t}\right)\right]$$

and

$$\overline{M}_y = -\frac{\overline{p}_s}{4\overline{h}_o}\left(\overline{r}_c^{\,2}\,\overline{w}^{2} + \frac{\overline{w}^{4}}{20}\right)\left[\frac{2\pi \cos\theta_m}{e}\left(1 - \frac{1}{\sqrt{1-e^2}}\right)\left(\overline{a} - \frac{\overline{t}}{e}\right)\right]$$

$$-\frac{G}{2\overline{h}_o^{3}}\left(\overline{r}_c^{\,2}\,\overline{w}^{3} + \frac{\overline{w}^{5}}{20}\right)\left[\frac{\pi \overline{a}(1+2e^2)\cos^2\theta_m}{(1-e^2)^{2.5}} + \frac{\pi \overline{a} \sin^2\theta_m}{(1-e^2)^{1.5}} - \frac{3\pi e\overline{t} \cos^2\theta_m}{(1-e^2)^{2.5}}\right]$$

From these two moments the load centre of the load can be found out by dividing the moment with the load carrying capacity. The derivations of the moments are given in Appendix C. Now the dimensional moments are given by

$M_x = \overline{M}_x.(r_o^3 p_p)$ and $M_y = \overline{M}_y.(r_o^3 p_p)$

The total moment on the land is given by

$$M = \sqrt{M_x^2 + M_y^2}$$

The polar arm of the load centre can be found out by

$$j = \frac{M}{W} = \frac{r_o \sqrt{\overline{M}_x^2 + \overline{M}_y^2}}{\overline{W}}$$

The angle between polar arm with the X axis is given by

$$\theta' = \tan^{-1}\frac{M_x}{M_y} - \frac{\pi}{2}$$

The abscissa and the ordinate of the load centre is given by

$j_x = j\cos\theta'$ and $j_y = j\sin\theta'$

III. Results

As the solution is directly got from the analytical method, the plotting can be done using MATLAB programming window. All the equation are set in the programming environment of the MATLAB software and the solutions are plotted. Generally the maximum clearance occurs very near to the leading edge. In the analysis of theoretical slipper drag, programming is developed with the fact that in the leading edge maximum clearance occurs. The position of the load centre is plotted against the slipper tilt. the slipper are considered as perfectly flat. For the figure 3, the slipper speed is kept constant at 1500 rpm and the plot is drawn for different pressure. It can be seen from the graph that after some point of tilt angle the position of load centre goes out of the slipper land area. This prove that slipper runs with very small tilt angle. For figure 4 the pressure is kept constant at 120 bar and the plot is drawn for different speeds. It is observed for a higher theoretical tilt the slipper does not work. Apparently the fluid film breaks after a maximum angle of tilt.

It can be observed from figure 3 through figure 6, that the slipper center stays in the center line of motion or X axis for small tilt angles. For small tilt angle the center of load moves firstly towards the negative X axis. More tilt brings the center of load on the positive side of X axis. A little more tilt bring the centre of load to the actual centre of slipper. But for more tilt angle the centre of tilt angle the load goes outside the area of slipper which is not possible. Therefore a higher tilt is not possible to occur in actual slipper operation. Moreover the variation of pressure, speed, slipper area and non flatness angle put different response to the position of load centre. It can be observed that higher pressure in the slipper pocket tries to keep the slipper load centre in the actual centre of slipper and lower pressure tries to deflect the load centre away from actual slipper centre. In the same way higher speed of slipper tries to keep the slipper load centre in the actual centre of slipper and lower speed tries to deflect the load centre away from actual slipper centre. From figure 5, it can be observed that a particular amount of non-flatness angle tries to keep the load centre in the actual slipper centre.

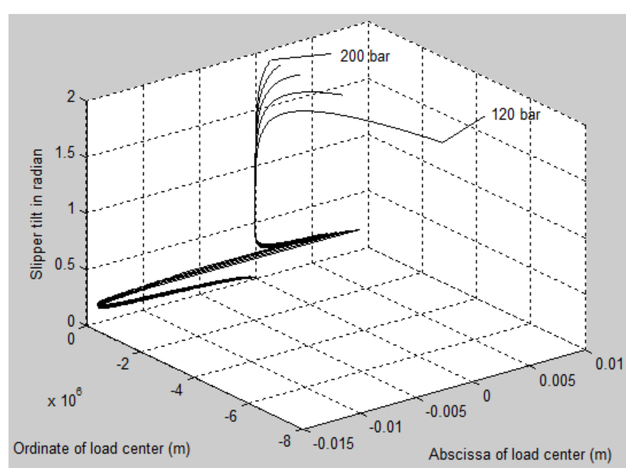

Figure 3 : Position of load centre with slipper tilt for different pressure

From figure 6, it can be observed that a more amount of slipper are tries to keep the load centre in the actual slipper centre and hence stabilize the bearing fast.

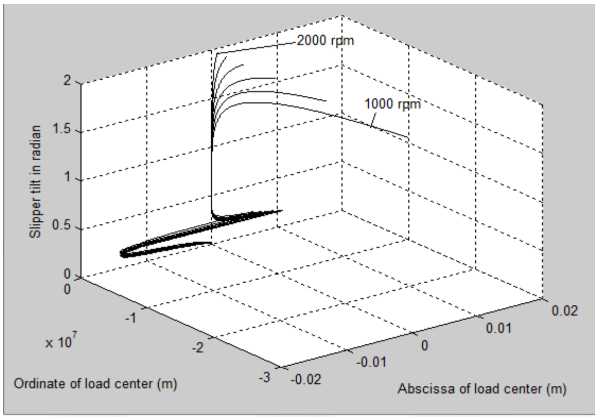

Figure 4 : Position of load centre with slipper tilt for different slipper area

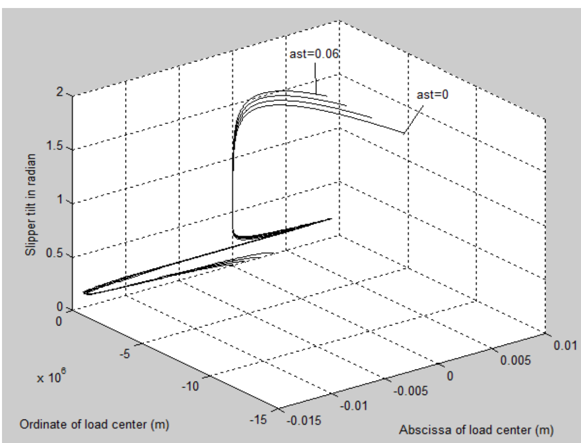

Figure 5 : Position of load centre with slipper tilt for different non flatness angle

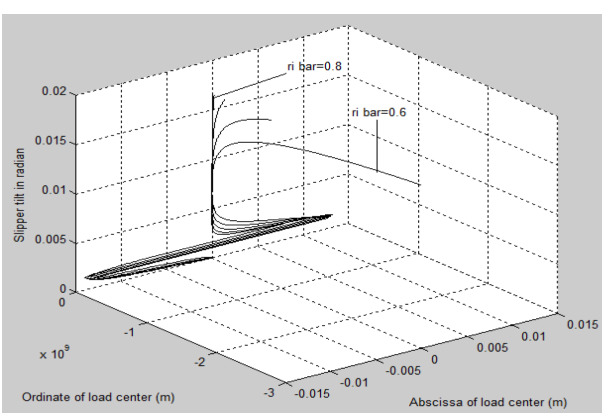

Figure 6 : Position of load centre with slipper tilt for different slipper area

IV. Conclusion

From the results of the computation of the position of load centre, it can observed that higher tilt angle gives irrelevant results. It may happen the fluid film breaks at higher tilt angles. The stability of slipper increases with increase of slipper pressure (vide figure 3). The stability increases with increase of slipper speed (vide figure 4). The stability of slipper increases with increase of slipper non flatness angle (vide figure 5). The stability increases with increase of slipper land size (vide figure 6). For more practicality of this tilt angle more computation is required.

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CFD Analysis of Intake Valve for Port Petrol Injection SI Engine

By K.M Pandey & Bidesh Roy
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Abstract - The air standard efficiency for SI engine is approximately 60% under full load condition but the actual brake thermal efficiency under full load condition is approximately 32.6% which is due to the various losses that occur. One of the primary lose is burning time loss which is approximately 4% and occur due to finite time combustion of the charge. This lose can be reduced to some extend by generation of a higher degree of swirl which will increase turbulence intensity with in the engine cylinder. The production of turbulence of higher intensity is one of the most important factors for stabilizing the ignition process, fast propagation of flame, especially in case of lean-burn combustion In general, two type of vortices are utilized in order to generated and preserve the turbulence flows efficiently. These vortices are usually known as swirl and tumble flows, which are organized rotations in the horizontal and vertical plane of the engine cylinder, respectively.

Keywords : *Swirl, turbulence intensity, swirl ratio.*

GJRE-A Classification : *FOR Code : 091399*

CFD ANALYSIS OF INTAKE VALVE FOR PORT PETROL INJECTION SI ENGINE

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CFD Analysis of Intake Valve for Port Petrol Injection SI Engine

K.M Pandey [α] & Bidesh Roy [σ]

Abstract - The air standard efficiency for SI engine is approximately 60% under full load condition but the actual brake thermal efficiency under full load condition is approximately 32.6% which is due to the various losses that occur. One of the primary lose is burning time loss which is approximately 4% and occur due to finite time combustion of the charge. This lose can be reduced to some extend by generation of a higher degree of swirl which will increase turbulence intensity with in the engine cylinder. The production of turbulence of higher intensity is one of the most important factors for stabilizing the ignition process, fast propagation of flame, especially in case of lean-burn combustion In general, two type of vortices are utilized in order to generated and preserve the turbulence flows efficiently. These vortices are usually known as swirl and tumble flows, which are organized rotations in the horizontal and vertical plane of the engine cylinder, respectively. They contribute to the improvement of engine performance. Hence, it is indispensable for the development of an ICE with high compression ratio to realize high turbulence intensity and lean burn combustion. Swirl can be generated during intake stroke as well as compression stroke of the engine. Intake generated swirl usually persists through the compression, combustion, and expansion stroke and it can greatly enhances the mixing of air and fuel to give a homogeneous mixture in the very short time. This is done by shaping and contouring the intake manifold, valve ports, and by use of shrouded intake valve.

Keeping the above point in view, in this paper, an analysis is performed in a port fuel injection SI engine using computational fluid dynamic (CFD) code FLUENT to determine the level of intake swirl induced by poppet intake valve and its reduction along the length of the cylinder. From the study it was found that intensity of intake swirl reduces along the length of the engine cylinder.

Keyword : *Swirl, turbulence intensity, swirl ratio.*

I. Introduction

The engine cycle of typical internal combustion engines consist of four consecutive processes as intake, compression, expansion (including combustion) and exhaust. Of these four processes, the intake and compression stroke is one of the most important processes which influences the pattern of air flow structure coming inside cylinder during intake stroke and generates the condition needed for the fuel injection during the compression stroke. As a result of the high velocity inside the internal combustion engine (ICE) during operation, all in cylinder flows are typically turbulent. The exception to this is the flows in the corners and small crevices of the combustion chamber where the close distance of the walls diminished out turbulence. Heat transfer, evaporation, mixing and combustion rates all increase as engine speed increases. This increases the time rate of fuel evaporation, the mixing of the fuel vapor and air as well as combustion process. Fluid motion within the engine cylinder is one of the major factors that control the fuel-air mixing and combustion process in spark ignition engines. It also has a significant impact on heat transfer. Both the bulk fluid motion and the turbulence characteristics of the flow are essential to produce the homogeneity structure of air flow come into cylinder. Generally, the initial in-cylinder flow pattern is set up by the intake process and then be substantially modified during compression process. The small-scale mixing of turbulence with compressible flows is represented by the turbulence kinetic energy and turbulence kinematic viscosity .Turbulence inside the cylinder is high during the intake and then decreases as the flow rate slows near bottom dead centre (BDC). It increases again during the compression stroke as swirl, squish and tumble increase near top dead centre (TDC) [1]. Intake generated swirl usually persists through the compression, combustion, and expansion stroke and it can greatly enhances the mixing of air and fuel to give a homogeneous mixture in the very short time. It is also a main mechanism for very rapid spreading of the flame front during the combustion process [2]. Many researchers worked in this area via experimental as well as computational to explorer the phenomenon of the in-cylinder flow of Internal Combustion Engine. Some of them are cited here. B. Reveille and A. Duparchy [3] worked on 3D CFD analysis of an abnormally rapid Combustion phenomenon in downsized gasoline engines. This paper has focused on a particular abnormally rapid, yet non destructive and seemingly stable combustion phenomena which have been identified on low speed mid to high load operating points when performing aggressive downsizings on various engines. Franz X. Tanner & Seshasai Srinivasan [4] worked on CFD-based optimization of fuel injection strategies in a diesel engine using an adaptive gradient method. A gradient-based optimization tool has been developed and, in conjunction with a CFD code, utilized in the search of new optimal fuel injection strategies. The approach taken uses a steepest descent method with an adaptive cost function, where the line search is

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performed with a backtracking algorithm. Vijaya Kumar Cheeda, R. Vinod Kumar, G. Nagarajan [5] worked on design and CFD analysis of a regenerator for a turboshaft helicopter engine. In this paper a continuous heat transfer regenerator for a turboshaft helicopter engine is designed suitably. The regenerator effectiveness is assessed by the CFD tool CFX and evaluated the effectiveness and the pressure drop. The predicted CFD results are in good agreement with experimental results. L. Li, X.F. Peng, and T. Liu [6] worked on combustion and cooling performance in an aero-engine annular combustor. The investigation was conducted to understand the characteristics of the flow, combustion, cooling performance and their interaction in an aero-engine combustor. The conservation equations and Eddy-dissipation combustion model were employed for solving the flow, heat transfer, and combustion in the entire combustor. The reliability of the simulation was demonstrated by comparing calculated combustor exit temperature distributions with profiles of the rig-test measurements. Christian Hasse, Volker Sohm, and Bodo Durst [7] worked on Numerical investigation of cyclic variations in gasoline engines using a hybrid URANS/LES modeling approach. The study investigates the feasibility of using the SST DES model to predict cycle to cycle variations in internal combustion engines and the effect of cyclic variations in engines and their root causes including the major flow patterns. Wendy Hardyono Kumiawan, Shahrir Abdullah and Azhari Shamsudeen [8] worked on CFD study of cold-flow analysis for mixture preparation in a motored four-stroke direct injection engine. In this study, the CFD simulation to investigate the effect of piston crown to the fluid flow field inside the combustion chamber of a four-stroke direct injection automobile engine under the motoring condition is presented. The analysis is focused on study of the effect of the piston shape to the fluid flow characteristics the result obtained from the analysis could be employed to examine the homogeneity of air-fuel mixture structure for better combustion process and engine performance. Andras Kadocsa, Reinhard Tatschl and Gergely Kristof [9] worked on analysis of spray evolution in internal combustion engines using numerical simulation. This paper summarizes results of research about a new approach of spray formation calculations. Using a primary breakup model for separately describing the initial liquid disintegration of injected liquid based on the flow properties stemming from a previous calculation of injector nozzle flow gives a better prediction capability and suits the new needs of advanced combustion systems such as HCCI engines or various forms of split injection. Toyoshige Shibata Hideo Matsui, Masao Tsubouchi and Minoru Katsurada [10] worked on Evaluation of CFD Tools Applied to Engine Coolant Flow Analysis. This paper presents the results of test application of some automatic mesh generation tools to the CFD calculation of coolant flow, and compares the functional characteristics and features of these tools. The paper also discusses coolant flow items that can be evaluated by CFD analysis and the merits of applying CFD to these items. Semin, N.M.I.N. Ibrahim, Rosli A. Bakar and Abdul R. Ismail [11] worked on In-Cylinder Flow through Piston-Port Engines Modeling using Dynamic Mesh. This paper presents numerical study of three-dimensional analysis of two-stroke spark-ignition cross loop-scavenged port. The objective of this study is to investigate the in-cylinder characteristics at motored transient condition. The pressure on in-cylinder and intake port were collected and applied for validation with numerical results for 1400 rpm. The three-dimensional modeling analysis was performed utilizing dynamic mesh method. The prediction of distribution of in-cylinder pressure and mass fraction of gases function of crank angle were discussed. The results shown that the relative error between experimental and numerical less that 2 %. Helmut Doleisch [12] worked on simvis: interactive visual analysis of large and time-dependent 3d simulation data. In this paper the major new technological concepts of the SimVis approach are presented and real-world application examples are given. SimVis is a system for the graphical analysis of simulation data, built on a new, cutting-edge technological approach for interactive visual analysis of large, multi-dimensional, and time-dependent data sets resulting from CFD simulation. S. M. Jameel Basha, P. Issac Prasad and K. Rajagopal [13] worked on simulation of in-cylinder processes in a DI diesel engine with various injection timings. In this paper an attempt has been made to study the combustion processes in a compression ignition engine and simulation was done using computational fluid dynamic (CFD) code Fluent. An Axisymmetric turbulent combustion flow with heat transfer is to be modeled for a flat piston 4-stroke diesel engine. The unsteady compressible conservation equations for mass (Continuity), axial and radial momentum, energy, species concentration equations can express the flow field and combustion in axisymmetric engine cylinder. Turbulent flow modeling and combustion modeling was analyzed in formulating and developing a model for combustion process. R. Rezaei, S. Pischinger, P. Adomeit and J. Ewald [14] worked on Evaluation of CI In-Cylinder Flow using optical and numerical techniques. In this paper different port concepts for modern Compression-Ignition engines, usually quantities as the swirl level and the flow coefficient are evaluated, which are measured on a stationary flow test bench. As additional criterion, in this work, the homogeneity of the swirl flow is introduced and defined quantitatively. Different valve lift strategies are evaluated using three-dimensional Particle Imaging Velocimetry in a stationary flow configuration and transient In-Cylinder CFD simulation using both the Reynolds Averaged Navier Stokes equation and the

Large Eddy simulation approach. M.M.Noor1, K.Kadirgama1, R.Devarajan, M.R.M.Rejab, N.M.Zuki N.M. and T.F.Yusaf [15] worked on Development of a High Pressure Compressed Natural Gas Mixer for A 1.5 Litre CNG-Diesel Dual Engine. In this paper Computational Fluid Dynamics (CFD) analysis software was used to study the flow behavior of compressed natural gas (CNG) and air in a CNG-air mixer to be introduced through the air inlet of a CNG-Diesel dual fuel stationary engine. Yasar Deger, Burkhard Simperl and Luis P. Jimenez [16] worked on Coupled CFD-FE-Analysis for the Exhaust Manifold of a Diesel Engine. This paper aims to investigate the thermo-mechanical behaviour of an exhaust manifold which has an active cooling system, the full water flow, partial water flow (by 50% reduced cooling flow) and Vapour flow three cases of cooling analyzed. Fluid flow, thermal heat transfer and stress analysis are coupled for each case using a one-way coupling approach. Selected results given in form of temperature, stress and displacement distribution plots in this paper. The investigation was focusing on potential structural optimization measures. Therefore some suggestions for design improvements are presented also, which are presumably effective to reduce the temperature peaks and temperature gradients and to ensure a longer service life for the exhaust manifold. Kihyung Lee, Choongsik Bae, and Kernyong Kang [17] worked on the effects of tumble and swirl flows on flame propagation in a four-valve S.I. engine. The effects of in-cylinder flow patterns, such as tumble and swirl flows, on combustion were experimentally investigated in a four valve S.I. engine. Tumble flows were generated by intake ports with entry angles of 25˚, 20˚ and 15˚. Inclined tumble (swirl) flows were induced by two different swirl control valves. The initial flame propagation was visualized by an ICCD camera, the images of which were analyzed to compare the enflamed area and the displacement of initial flames. The combustion duration was also calculated by the heat release analysis. B. Murali Krishna and J. M. Mallikarjuna [18] worked on Tumble flow analysis in an unfired engine using particle image velocimetry. This paper deals with the experimental investigations of the in-cylinder tumble flows in an unfired internal combustion engine with a flat piston at the engine speeds ranging from 400 to 1000 rev/min., and also with the dome and dome-cavity pistons at an engine speed of 1000 rev/min., using particle image velocimetry and It is suggested in the paper to use the flat piston rather than dome, dome-cavity pistons which are rather difficult to manufacture as far as tumble flows are concerned. B. Khalighi worked on Study of the intake tumble motion by flow visualization and PTV [19].The purpose of this work is to characterize the in-cylinder tumbling flow generated by an engine head during the induction process using flow visualization and PTV. The study was carried out for a 4-valve engine head with shrouded intake valves in special single cylinder transient water analog. This shrouded intake valve configuration was used to obtain a prototypical "pure tumble" flow suitable for fundamental combustion studies. K.M Pandey, S.N Pandey, and Bidesh Roy [20] worked on numerical analysis to determine the effect of temperature on the intake generated swirl for port fuel injection SI engine. Hence, for computational investigation for intake swirl within the engine, cold flow simulation will provide faster computational result. In this study it was concluded that the temperature on various part of the engine produces a very negligible effect on the intake swirl generation. Thus, we can see that very few works have been done in field of determining the behavior of intake swirl red along the length of the engine cylinder.

II. Specification of the Si Engine

The engine considered for the computation analysis is a single-cylinder continuous type port fuel injection four stroke SI engine with cylindrical combustion chamber and single intake port and exhaust port. The computation analysis is performed at WOT maximum power condition. The specification of engine is listed in Table 1.

Table 1 : Engine specifications and calculation conditions

Bore x stroke	95mm x 99mm.
Compression ratio	9:1
Piston cavity	Flat.
Max power at WOT	13.2 BHP at 4950 RPM.
Intake valve diameter	42mm
Maximum intake valve lift	12mm.
Exhaust valve opening	64˚ BBDC.
Exhaust valve closure	5˚ ATDC.
Intake valve opening	5˚ BTDC.
Intake valve closure	60˚ ABDC.
Fuel	C_8h_{18}

III. Poppet Intake Valve

A Poppet intake valve is used in the SI engine in which the computational analysis is performed. The dimensions of the Poppet intake valve are shown in the figure below:

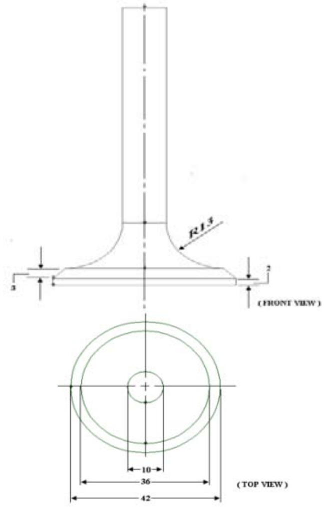

Figure 1 : Dimensions of Poppet intake valve (All dimensions are in mm)

IV. Computational Domain and Boundary Conditions

The numerical formulation of the problem is incomplete without prescribing boundary conditions, which correspond to the specific physical model. The specification of mathematically correct boundary conditions that ensure the uniqueness of the solution, while being compatible with the physics at the boundaries, is not always straightforward. Before arriving at the boundary conditions at various boundaries, we have to first identify the solution/computational domain of the problem. The physical domain and computational domain usually differ. However, the computational domain largely depends on the geometry of physical domain. The computational domain boundary (truncated from the real boundary) along with appropriate boundary conditions should be chosen in such a way that there is negligible change in the results with further increase in its size.

The computational domain shown in the figure 2 is a generalized one since, the analysis is performed at different crank angle during the suction stroke of the engine as result the distance of the piston from the engine head shown in the figure 2 by "B" also varies corresponding to the engine crank angle.

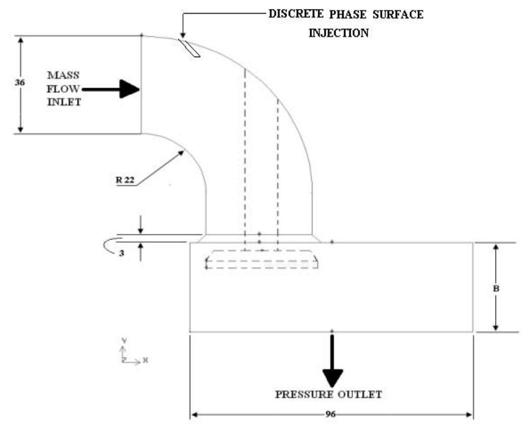

Figure 2 : Computational domain and boundary conditions (All dimension in mm)

The boundary conditions shown in figure 5 are as follows:

I. *Inlet boundary on the inlet port of the engine: -* The inlet boundary condition is assigned as mass flow inlet. Since the investigation is performed at 72 degree of the crank angle and at that instant the mass flow inlet of air is 0.01319 kg/sec for the computation.

II. *Solid surface of the cylinder of the engine: -* It is assigned wall boundary condition i.e. no slip condition on the solid surface of the cylinder. The computation is performed with solid surface of the cylinder at a temperature of 300°K for faster computational result [20].

III. *Outlet Boundary on the piston of the engine: -* Outlet boundary is assigned the pressure outlet boundary condition. For the investigation outlet pressure is taken as a static pressure of 0:935 bar.

IV. *Discrete phase surface injection for injector: -* In the computation domain the injector of the valve is assign as discrete phase surface injection with fuel flow rate of 0.0011 kg/sec for the engine considered.

V. Grid Independence Study

The resolution of the grid has a great quantitative impact over the results obtained. There exists a level of refining of a computational domain beyond which there is no significant quantitative changes in the results achieved. The computational domain at this level of refinement is said to enter the regime of grid independence. In the present work maximum tangential velocity at a surface 9.18mm from engine cylinder head has been taken as the criteria and the number of grid is refined until the required value is gained. For the simulation grid independence was reached for 384876 cells and 82377 nodes as shown in table 2.

Table 2 : Grid independence study			
Refining Level	No. of Nodes	No. of cells	Max. Tangential velocity at a surface 9.18mm from engine cylinder head
1)	53307	254668	10 m/sec
2)	52208	244537	10 m/sec
3)	82377	384876	8.8 m/sec

VI. Result and Discussion

Computational result at 72 ˚ crank angle for the specified SI engine at various locations along the length of the engine cylinder is shown below:-

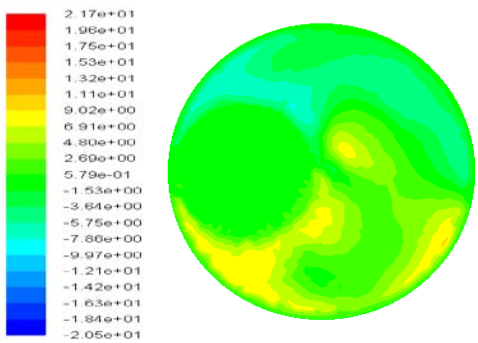

Figure 3 : Contour plot of tangential velocity (m/sec) for surface located at 9.18mm from Engine cylinder head.

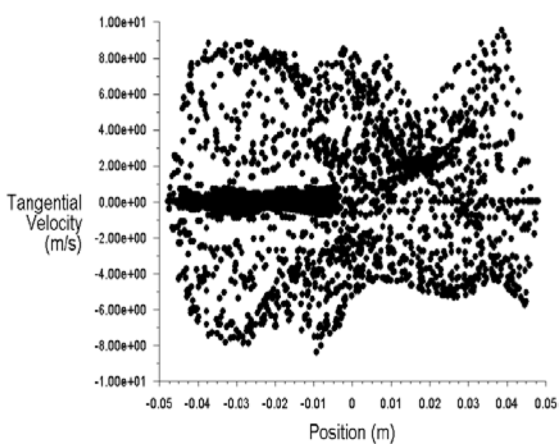

Figure 4 : X-Y plot of tangential velocity (m/sec) for surface located at 9.18mm mm from Engine cylinder head.

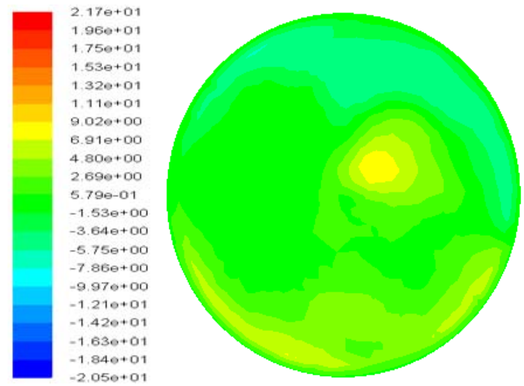

Figure 5 : Contour plot of tangential velocity (m/sec) for surface located at 18.1mm mm from Engine cylinder head.

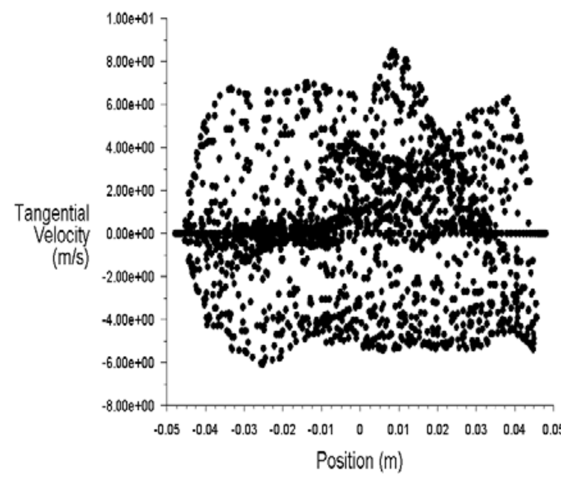

Figure 6 : X-Y plot of tangential velocity (m/sec) for surface located at 18.1mm mm from Engine cylinder head.

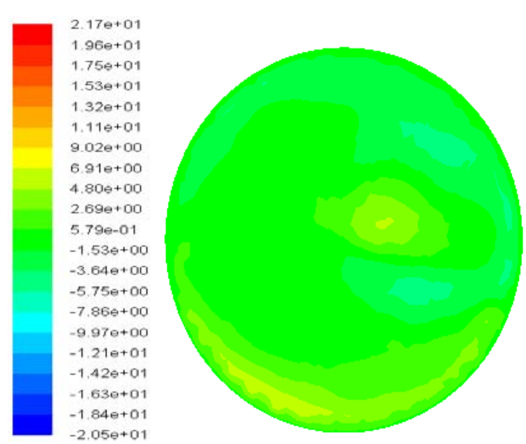

Figure 7 : Contour plot of tangential velocity (m/sec) for surface located at 28.8mm mm from Engine cylinder head.

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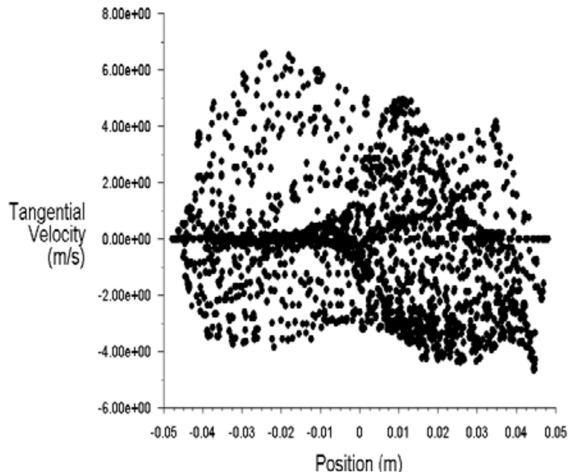

Figure 8 : X-Y plot of tangential velocity (m/sec) for surface located at 28.8mm mm from Engine cylinder head

The nature of swirling flow in actual operating engine is very difficult to determine. Swirl ratio is a dimensionless parameter used to quantify swirling flow within the cylinder as shown by the equation below

$$SR(\Theta) = \left| \frac{v(\Theta) \times 60}{2\Pi nr} \right| \qquad (1)$$

From the equation 1, it is clear that tangential velocity plays a vital role in determining the intensity of swirl within the engine.

From the results of the computation analysis carried out at 72 ° crank angle with poppet intake valve, for the specified SI engine it is seen that the surface at 9.18mm from engine cylinder head which is closer to the valve shows higher tangential velocity at various location compared to the surface at 18.1mm and 28.8mm from engine cylinder head which is at higher distance from the intake valve.

VII. Conclusion

From this study the following it can be concluded that the surface which is closer to the poppet intake valve shows higher tangential velocity at various locations compared to the surfaces which are at higher distance from the intake valve i.e. the intensity of swirl decreases along the stroke length of the engine cylinder.

NOMENCLATURE	
Θ	crank angle (degrees)
r	radial coordinate (m)
v	tangential velocity (m/s)
n	engine speed (rpm)
BTDC	before top dead center
BBDC	before bottom dead center
ATDC	after top dead center
ABDC	after bottom dead center
SR	Swirl ratio

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Productivity Enhancement by Reducing Setup Time - SMED: Case study in the Automobile factory

By M. S. Desai

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Abstract - The Single Minute Exchange of Die (SMED) is one important lean tool to reduce waste and improve flexibility in manufacturing processes allowing lot size reduction and manufacturing flow improvements. SMED reduces the non-productive time by streamlining and standardizing the operations for exchange tools, using simple techniques and easy applications. However the process doesn't give the specific actions to implement which can result in overlooking improvements. To overcome this, common statistical and industrial engineering tools can be integrated in the SMED approach to improve SMED implementation results.

Keywords : Lean Manufacturing, SMED, Changeover. Internal and external setups.

GJRE-A Classification : FOR Code : 091399

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Productivity Enhancement by Reducing Setup Time - SMED: Case study in the Automobile factory

M. S. Desai

Abstract - The Single Minute Exchange of Die (SMED) is one important lean tool to reduce waste and improve flexibility in manufacturing processes allowing lot size reduction and manufacturing flow improvements. SMED reduces the non-productive time by streamlining and standardizing the operations for exchange tools, using simple techniques and easy applications. However the process doesn't give the specific actions to implement which can result in overlooking improvements. To overcome this, common statistical and industrial engineering tools can be integrated in the SMED approach to improve SMED implementation results.

In the present work, experiments were carried out to reduce the setup time and tool change time this are important factors which will take lot of time of the production in an automobile factory. The applicability of the proposed SMED approach was tested for shaping machines changeovers in the automotive industry. The implementation has enabled reduction in setup time, through company's internal resources reorganizations without the need for significant investment.

Keywords : Lean Manufacturing, SMED, Changeover. Internal and external setups.

I. Introduction

The SMED system is a theory and set of techniques that make it possible to perform equipment setup and changeover operations in under 10 min. SMED improves setup process and provide a setup time reduction up to 90% with moderate investments. Setup operation is the preparation or after adjustment that is performed once before and once after each lot is processed [1]. Shingo divides the setup operation into two parts: Internal setup and external setup. Internal setup is that setup operation that can be done only when the machine is shut down (attaching or removing the dies). External setup is that setup operation that can be done when the machine is still running. These operations can be performed either before or after the machine is shut down. For example getting the equipment ready for the setup operation before the machine is shut down. The setup period is constituted by internal setup and external setup. During the internal setup there is no production. In the run-up period re-adjustments and trial productions are taking place. This period terminates when full output capacity is reached. SMED system includes three main steps. These steps are as follows:

a) Separating Internal and External Setup

At this step an important question must be asked for each setup activity. "Do I have to shut the machine down to perform this activity?" The answer helps us in distinguishing between internal and external setup. This step can reduce the setup time by as much as 30 to 50 percent. The three techniques that SMED uses at this step are: Check lists, function checks, and improved transport of dies and other parts.

b) Converting Internal Setup to External Setup

In order to achieve the single digit setup time objective SMED introduces this step. At this step internal setup activities tried to be converted to external activities. So the total time that the machine is shut down will be reduced. Advance preparation of operating conditions, function standardization, and use of intermediary jigs are the techniques to support the second step.

c) Streamlining all Aspects of the Setup Operation

At this step "specific principles" are applied to shorten the setup times. Implementing parallel operations, using functional clamps, eliminating adjustment and mechanization techniques are used to further setup time reduction.[1].

II. Methodology

The researcher observed three complete set-ups, in addition to the one in the manufacturing cell, and several partial set-ups. The set-ups have been evaluated to examine the type of improvements which can be made using the SMED methodology. The observations were undertaken using manual means employing a standardized recording and analysis sheet. The Factory had not used video techniques to record set-ups and a decision was taken not to employ this method as it was considered this would prevent operators from co-operating in the study. The first step in the implementation of SMED is to separate internal

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(activities which can only be carried out when the machine is stopped) and external (activities which can be carried out when the machine is operating) setup activities.

Once the internal and external activities are identified and separated a checklist can be made of all the parts and steps which should be carried out externally during the current and preceding operations. The checklist of the set-up procedure which has been developed for the CNC shaping machine is given in Table 1, saving an estimated 30-35 minutes. Based on the set-ups observed, there are numerous other activities that need to be eliminated, which are contributing to longer set-up times. For example, as changeover time was not regarded as a lost production opportunity there was a very relaxed approach by operational personnel to the changeover operation. Operators were also keeping tools and fixtures in their personal lockers so that they would be close to hand when needed. It was also observed that the grinding of cutting tool tips was not carried out on time. In addition, the computer program was not updated and this could potentially lead to an incorrect set-up and therefore delays. Another problem was that the machines used metric measurements whereas the schedules used imperial figures; this meant that operators had to convert the imperial figures into metric, thus increasing the set-up procedure. It is estimated that by tackling these types of problems an extra 10-15 minutes would be saved on the total set-up times.

The second stage in Shingo's SMED methodology is to convert internal to external set-up activities. The height of the machine tables could be fixed and the distance to the cutting tip set at the appropriate level. The dimensions of the various components and jig could be determined and contact jigs, compensating for height, could be mounted and set on the table so that the Cutting surface would be at the appropriate level. The horizontal and vertical dimensions of the contact jigs could be standardized by locating them against stops set into the table, enabling the operators to centre the component more easily. These improvements would not only make the set-ups easier for the machine operators but they will also reduce the set-up times by up to 15 minutes. To facilitate these improvements spacer jigs would have to be made. They are thinner than the main jig plates, making them easier to transport. Another option for the smaller components is to use intermediary jigs, which involve the use of two standardized jig plates of the appropriate size and shape. When the component attached to one of the plates is being processed, the next component can be centered and attached to the other jig. When the first component is finished, this second jig, together with the attached component, can be mounted on the machine. From the set-ups observed it was found that operators spend considerable time attaching and fastening jigs and components, and undertaking the necessary checks, and in some cases these fastenings were problematic.

Setup time of shaping machine for the part no 2 01 3 150

Name of Machine: BA 4156; LORENZ GEAR **Name of Fixture:** RE 332

Sr.No	Activities	Time (Sec) On 21.12.09	Time (Sec) On 03.01.10	Time (Sec) On 17.01.10	Internal Activity	External Activity	Modification	Remark	Time After 21.03.10	Time After 28.03.10	Time After 11.04.10
1	To prepared trolley for setup	120	120	110		External			0	0	0
2	Take a Allan key	10	10	10	Internal				02	02	02
3	Rotate the fixture	30	30	34	Internal			Repeated activity	20	20	18
4	Remove the tie rod	25	20	22	Internal		By automatic Spanner		05	05	05
5	Remove the burrs with the help of Allan key	65	60	66	Internal		By compressed Air (Air run)	Repeated activity	05	05	06
6	Remove the fixtures bolts	40	35	38	Internal		By automatic Spanner		15	15	17
7	**Remove**	200	206	209	Intern		By		45	47	47

	the previous fixture				al		automatic Spanner				
8	Remove the burrs from fixture	35	30	28	Internal		By compressed Air (Air run)		05	07	07
9	Remove the insert rod of fixture	20	25	28	Internal		By automatic Spanner		10	10	13
10	Clean the hole or Remove the burrs from base plate	68	50	56	Internal		By compressed Air (Air run)		10	12	09
11	Take new fixture	10	10	8		External			05	05	05
12	Rotate the base plate	20	20	22	Internal				15	16	15
13	To clean the new fixture by compressed air	20	20	18		External	By compressed Air (Air run)		00	00	00
14	Clean the base plate	40	40	37	Internal		By compressed Air (Air run)		10	11	12
15	To take dial indicator with magnetic stand	10	10	7		External		Repeated activity	10	10	08
16	To fixed & adjust the collector	65	60	58	Internal		By compressed Air (Air run)		30	32	29
17	To fixed the new fixture	85	75	74	Internal		By compressed Air (Air run)		60	62	61
18	**To fixed the bolts of fixture**	278	240	247	Internal		By compressed Air (Air run)		30	32	33
19	To rotate, tight & adjust the fixture	120	100	116	Internal		By compressed Air (Air run)		30	29	27
20	To fixed the stand of dial indicator	10	10	07	Internal				12	10	11

21	To check the run-out of tie rod	100	100	103	Internal			Repeated activity	50	49	48
22	To rotate, tight & adjust the fixtures bolts w.r.to run out	245	240	243	Internal		By compressed Air (Air run)		20	22	23
23	To remove the dial indicator	20	20	18	Internal				10	10	09
24	To fix the bottom bolts of fixture	20	25	27	Internal		By automatic Spanner		10	10	12
25	**To fixed and adjust the height of tie rod**	800	940	955	Internal		**Design the fixed/ dedicated tie rod**	**Very Critical Activity**	40	43	44
26	To fix the job & fix the cap	45	50	52	Internal				25	24	25
27	To set the machine parameter	150	100	120	Internal			External activity	00	00	00
	Total time (sec)	**2651**	**2636**	**2733**					**474**	**478**	**486**
	Total time (Min)	**45**	**44**	**46**					**7.9**	**7.96**	**8.1**

Table 2.1 : Worksheet analysis showing the original and improved setup time of Machine BA 4156; Lorenz gear

The following are the type of errors observed during the study which indicate the potential for further mistake proofing:

- Errors due to absentmindedness and those made without knowing how they have happened (e.g. operators using the wrong equipment or tools).
- Errors due to a lack of concentration (e.g. operators overlooking the need to properly tighten clamps, screws, and tools, etc.).
- Errors due to unsuitable instructions or work standards. More than one operator commented that they found it difficult to adhere to rules and standards (e.g. a measurement may be left to an operator's discretion ± the imperial/metric issue mentioned earlier is a case in point).
- Errors which occur due to equipment running differently than expected (e.g. machines malfunctioning without arming).
- Errors arising from operators misjudging a situation.

The supplier could also communicate with the operator to confirm the paperwork is correct. Production control should also proofread the paperwork to identify and eliminate the errors before this is issued to the shop floor. Chase and Stewart (1994) recommended task and tangible poka yokes to mistake-proof services such as these. The management and control of materials is also critical to set-up reduction and the following problems were observed:

(1) Operators were unable to find tools, clamps, etc.

(2) Difficulties were encountered in retrieving jigs from their point of storage. For example:

- sometimes a forklift driver could not be found, which meant that a set-up could not proceed; and
- It was a time-consuming task getting the jig plates off the shelves and putting them away once the operation had been completed.

(3) Tools, jigs, etc. were not put away in the correct place.

(4) Operators felt that there was a lack of desk and storage space on which to put tools, clamps, etc.

(5) Jig plates were misplaced on shelves and as a consequence they were not easy to locate when required.
(6) Raw materials not arriving on time.
(7) Finished components or work-in-progress taking up valuable space.

These types of problems result in longer set-up times and greater opportunity for errors and mistakes.

III. Discussion on Findings

During the interviews the General Manager, production manager and other middle managers indicated that they wanted to reduce set-up times and errors. The interviews undertaken with operators indicate that this interest has not filtered through to the shop floor. The Factory will not be able to achieve single-minute set-ups and zero defects unless awareness of the importance of this is raised. Management must:

- understand and believe in the link between ``doing things right at first time & always'' and the Factory's business strategy;
- understand the practicalities of set-up time reduction and mistake proofing and be able to communicate the principles and techniques to all employees;
- participate in the problem-solving process to reduce set-ups and eliminate errors;
- formulate and maintain a clear idea of what set-up time reduction and mistake proofing means for the organization.

The problem of housekeeping and team working is particularly pertinent to set-up time reductions and the elimination of errors. The poor housekeeping has resulted in the following problems:

- Operators and engineers are unable to quickly find equipment such as tools, fixtures, clamps, etc.
- Unused and scrapped jigs and fixtures are discarded in places which make them a safety hazard.
- Equipment breakdown is accepted as inevitable.

With respect to team working it was frequently observed that operators in the machined controlled cycle of component manufacturing, which involved 30 minutes of cutting time, did nothing to help their colleagues in setting up an adjacent machine. There are currently no incentives/reward/appreciation systems in place for pursing set-up time reductions and mistake proofing. This, coupled with a lack of a team working ethic, means that the Factory is not fully utilizing the talents of their workforce. The Factory has an adequate training and education Programme, recognized by recent Investors in People award. In the last financial year each person, on average, received the equivalent of six days of training; however this training has not covered SMED and mistake proofing methodologies.

IV. Conclusions

In this study, SMED methodology is applied to prepare an optimal standard procedure for changeover operations on defined machine. Ergonomics and safety issues were also taken into consideration during setups. Since an ergonomic workplace makes operations easier for the operators, simple however crucial changes are suggested. Further studies in the facility may include 5S and Kaizen studies for internal setup. Alternative ways to shorten internal setups can be searched in detail. In order to eliminate adjustment steps, trial and errors should be minimized. Settings must be used for changeover operations instead of adjustments.

Therefore, a design of experiments study can be done to determine parameters of the machine. It should be kept in mind that successful implementation of new production methods requires sustainability and permanent solutions and the key of sustainability is the standardization of that optimal solution.

As a conclusion, it can be stated that SMED "single –minute exchange of die" in other words "Quick Changeover" is still a suitable method not only for manufacturing improvement but also for equipment/ die design development.

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Numerical Modeling of Surface Roughness in Grinding under Minimum Quantity Lubricants (MQL) using Response Surface Method (RSM)

By Mamun A A & Dhar N R
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Abstract - Grinding is primarily a finishing operation where high temperature at the wheel-work interface adversely affects the physical properties of the ground surface in terms of induced surface and sub surface residual stress, surface roughness, micro cracks and dimensional deviation. Conventional application of cutting fluid often cannot control the high temperature generated especially during high speed grinding. Besides, environmental pollution, effect on human health and higher cost has been a great concern of researchers and industries. One of the possible solutions of such problems is the Minimum Quantity Lubricants (MQL) technique which has both economical and environmental advantages. The present investigation is to evaluate the influence of MQL on chip formation mode and surface roughness in grinding AISI 1045 steel with CBN wheel at different level of process parameters. The result indicated that, MQL enables the reduction in surface roughness and more favorable chip formation mode compared to dry grinding.

Keywords : Grinding, Temperature, MQL.

GJRE-A Classification : FOR Code : 091306, 091307

NUMERICAL MODELING OF SURFACE ROUGHNESS IN GRINDING UNDER MINIMUM QUANTITY LUBRICANTS MQLUSING RESPONSE SURFACE METHOD RSM

Strictly as per the compliance and regulations of:

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Abstract - Grinding is primarily a finishing operation where high temperature at the wheel-work interface adversely affects the physical properties of the ground surface in terms of induced surface and sub surface residual stress, surface roughness, micro cracks and dimensional deviation. Conventional application of cutting fluid often cannot control the high temperature generated especially during high speed grinding. Besides, environmental pollution, effect on human health and higher cost has been a great concern of researchers and industries. One of the possible solutions of such problems is the Minimum Quantity Lubricants (MQL) technique which has both economical and environmental advantages. The present investigation is to evaluate the influence of MQL on chip formation mode and surface roughness in grinding AISI 1045 steel with CBN wheel at different level of process parameters. The result indicated that, MQL enables the reduction in surface roughness and more favorable chip formation mode compared to dry grinding. The whole experiment has been repeated with Alumina wheel under same experimental conditions to assess the performance of CBN wheel. A Response Surface model has been developed to predict the surface roughness while grinding AISI 1045 steel with CBN wheel under MQL technique. The model is then checked and validated by comparing with experimental results and found reasonably accurate.

Keyword : Grinding, Temperature, MQL.

I. Introduction

Grinding is a manufacturing process widely used in manufacture of parts and components requiring smooth surface and fine tolerance. Abrasive processes like grinding are the natural choice for machining very hard materials. In grinding operation a wheel containing the abrasive particles rotate at a specified velocity and a table below the wheel moves with reciprocal motion. As the abrasive particle come in contact with the workpiece surface they rub against the surface and removes a chunk of metal from it. This rigorous process on the metal surface produces ridges and valleys which can be quantified by the term surface roughness.

In high speed machining, conventional cutting fluid application fails to penetrate the chip-tool interface and thus cannot remove heat effectively [1], [2], [3]. Addition of extreme pressure additives in the cutting fluids does not ensure penetration of coolant at the chip-tool interface to provide lubrication and cooling [4]. However, high-pressure jet of soluble oil, when applied at the chip-tool interface, could reduce cutting temperature and improve tool life to some extent [5], [6]. Grinding becomes an environmentally unfriendly manufacturing process when a large of amount of cutting fluid is used. Now-a-days efforts are being made to minimize the use of cutting fluid for its detrimental effect on human health and environment and for covering a large percentage of total manufacturing cost (around 17%). Cutting fluids are difficult and expensive to recycle. They can cause skin diseases like dermatitis and have fatal effect on respiratory and dietary system of the machine operator [7], [8], [9]. Inappropriately handled and poorly disposed cutting fluid may have great environmental impact [10]. As the result of these consequences significant pressure is needed to adopt toward stricter standard and rigid regulations. In today's manufacturing industry cost effectiveness depends largely upon the high production rate which entails the need of high speed machining. The use of MQL is of great significance in conjunction between large cutting fluids application and dry machining. Minimum quantity lubrication (MQL) also known as Near Dry Machining (NDM) or semi dry machining is an alternative to traditional use of cutting fluids. As the name implies, MQL uses a very small quantity of lubricant delivered precisely to the cutting surface. Often the quantity used is so small that no lubricant is recovered from the piece.

Minimum quantity lubricants (MQL) systems employ mainly cutting fluids that are nonsoluble in water, especially mineral oils. These oils, inhaled in the form of aerosol, reduce the health hazard factor [11]. It is found that the MQL technique provides efficient lubrication, reducing the grinding power and the specific energy to a level of performance comparable or superior to that obtained from conventional soluble oil, while at the same time it significantly reduces grinding wheel wear [12]. Another characteristic of this technology is that when properly applied, both parts and chips remain dry and are easier to handle [13]. Better cutting performance can be obtained with Minimum Quantity lubrication (MQL) than dry and flood cooling [3]. In MQL a mixture of pressurized air and oil micro-droplets are

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applied directly into the interface between the tool and the chip [14].

MQL grinding is still a relatively new research area, and only a few researchers have studied MQL grinding. Dhar et al. [15] investigated the effect of MQL technique to grind 16MnCr5 alloy steel on the cutting performance compared to completely dry cutting and flood cooling with respect to grinding temperature, surface roughness, chip morphology. The results indicated that the use of minimum quantity lubrication (MQL) by cutting oil (VG-68) leads to lower surface roughness compared to dry and wet environments. Silva et al. [16] investigated the performance of MQL system to grind ABNT 4340 steel (HRC 60) with alumina wheel. It was found that, MQL system leads to finer surface finish and higher compressive residual stress compared to dry and conventional cooling. The performance of MQL technique is investigated by Tawakoli et al. [17] for both hard steel 100cr6 and soft steel 42CrMo4. For LB8000 MQL oil with wheel speed 25 m/s and depth of cut 25μm the surface quality improvement in MQL grinding is found to be more significant in comparison to dry and fluid grinding. Barczak [18] studied the machining performance of MQL for mild steel (BS 970 080M40, 32±2 HRC), bearing steel (BS534A99, 62±2 HRC) and tool steel (BS BM2, 52±2 HRC) with alumina wheel. The performance was evaluated in terms of tangential force, surface roughness, force ratio and grinding arc temperature. It has been found that, Low grinding force makes the MQL a low temperature process. But the suitability of MQL is found limited to relatively softer material.

Experimental investigation to assess the surface quality of a ground surface for a specific wheel-work combination is time consuming. Predictive model in this case can give useful insight about the expected value of surface roughness. A probabilistic approach to predict surface roughness in ceramic grinding is depicted in [19] considering the random grit protrusion height and assuming individual grain as spherical.

II. Experimental Conditions and Procedure

The purpose of the experimental investigation in this present research work is to measure the grinding surface roughness under Minimum Quantity Lubrication. The machining tests were carried out by grinding AISI 1045 steel with both alumina wheel and CBN wheel in a rigid surface grinder at different cutting condition under dry and Minimum Quantity Lubrication environment shown in Fig.2. The ranges of cutting conditions chosen in the present investigation are representative of the current industrial practice for the tool-work material combination that has been investigated. The conditions under which the machining tests have been carried out are briefly given in Table 1.

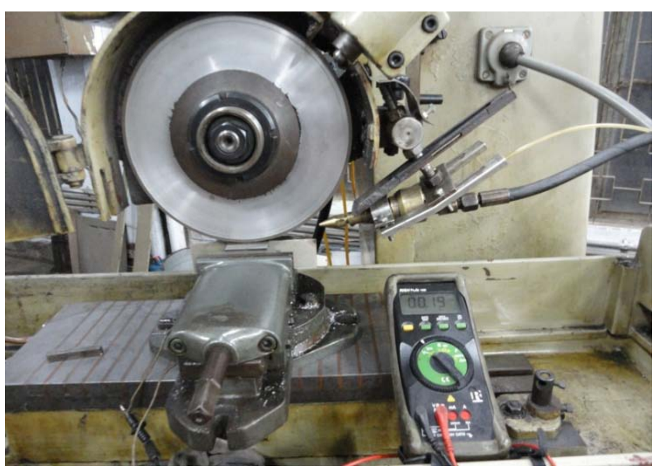


Fig. 2 : Photographic view of the experimental setup

Table 1 : Experimental conditions

Machine tool	:	Surface Grinder, China(2.1/2.8 KW)
Work materials	:	AISI 1045 steel
Grinding Wheel	:	CBN Wheel(Grain Size-107 µm, Grain Concentration-4.4 cts/cm^3, CBN layer thickness-4 mm)
Grinding Mode	:	Down cut
Process parameters		
Spindle Speed	:	1500 rpm, 3000 rpm
Wheel speed, v_s	:	15.21 m/s, 31.42 m/s
Infeed, a_o	:	10, 15, 20, 25, 30, 40, 50 µm
Table Speed, v_w	:	0.08 m/sec, 0.1 m/sec
Minimum Quantity Lubrication (MQL)	:	30 bar, Coolant: 2.0 ml/min through external nozzle
Coolant type	:	VG-68 (ISO grade)
Environment	:	Dry and Minimum Quantity Lubrication (MQL)

After grinding the steel specimen with alumina and CBN wheel the surface was checked rigorously. The surface features include general textures, plastic deformation of asperities, oxidations and cracks. All of them are usually the result of high grinding temperature. A typical parameter that has been used to quantify the quality of a surface is the surface roughness, which is represented by arithmetic mean value, R_a. Here experimental investigation is performed on AISI 1045 steel under dry and MQL condition with different cutting condition. The roughness of the ground specimen is measured in transverse direction by a Taylor Hobson Talysurf Surtonic 3+ roughness checker, UK. The sample length is taken as 0.8 cm. Fig. 3 shows the experimental surface roughness of the ground surface for Alumina wheel with different process parameters for both dry and MQL cooling environment. High roughness value is observed for dry cutting at higher infeed value. Fig.4 shows the roughness values for machining AISI 1045 steel with CBN wheel. From figure it has been found that Surface roughness value is substantially lower for MQL than dry in all conditions. It is also observed that in most of the cases for both dry and MQL condition CBN produced better surface finish than alumina wheel.

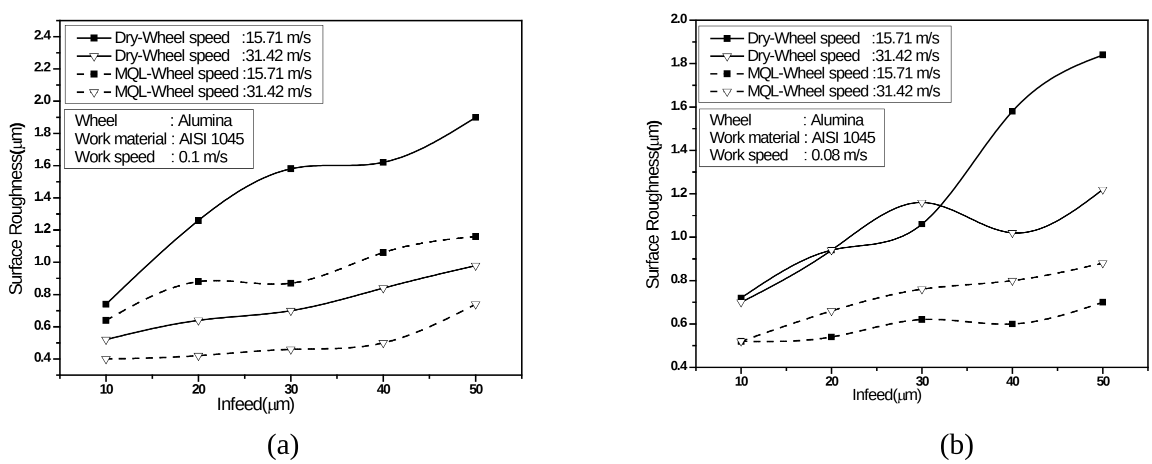


Fig. 3 : Variation of Surface roughness under dry and MQL condition for AISI 1045 steel with Alumina wheel

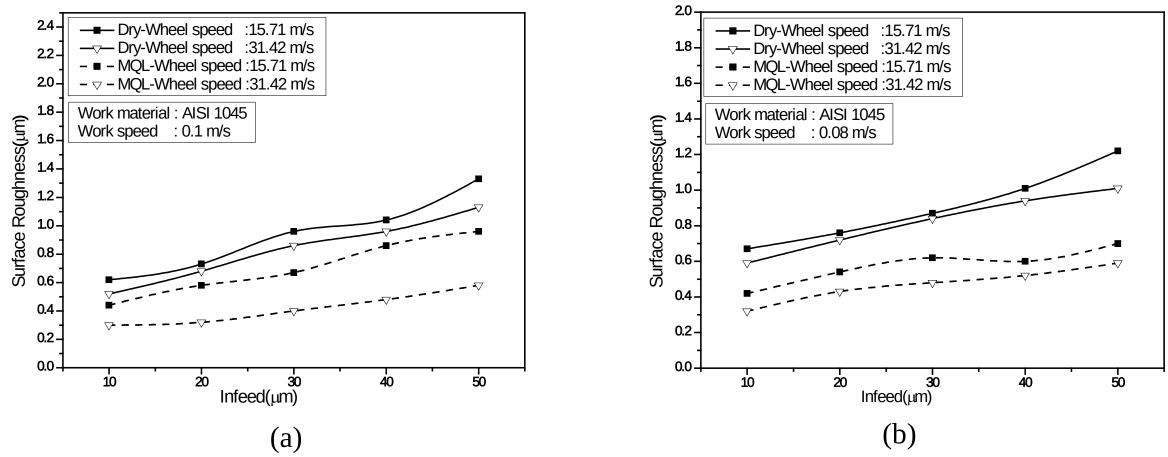
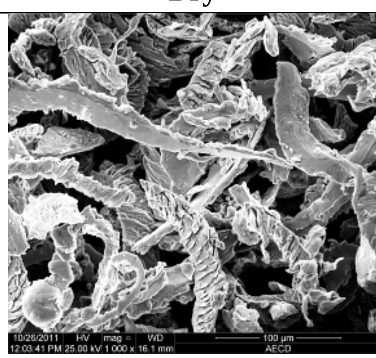
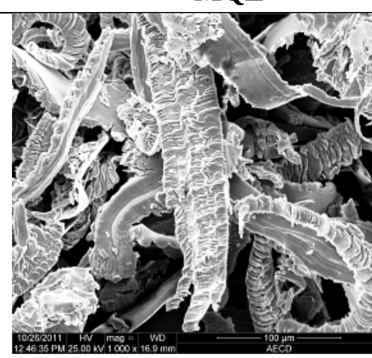
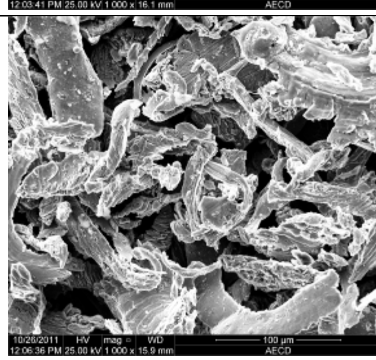
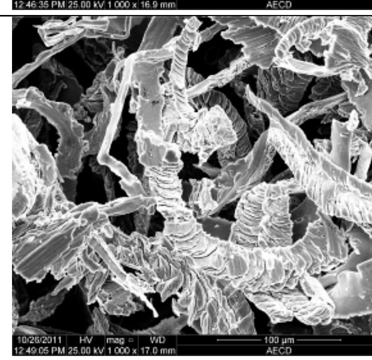


Fig. 4 : Variation of Surface roughness under dry and MQL condition for AISI 1045 steel with CBN wheel

The grinding chips are collected during the experiment by placing a glass coated with lubricating oil. The glass slide is placed near the spark stream after steady state is obtained with no vibration and change in the magnitude of grinding force with the number of passes. The chips are then placed on a clean glass slide and thoroughly washed with acetone, dried and separated from grinding wheel debris. The dried chips are then attached to carbon tape, mounted on a small disk and observed under Scanning Electron Microscope (SEM) to study the morphological characteristics. Fig 5 shows the SEM view of the chips that are obtained for three different infeed with dry and MQL machining environment when grinding AISI 1045 steel with CBN wheel.

	Dry	**MQL**
10 µm		
20 µm		

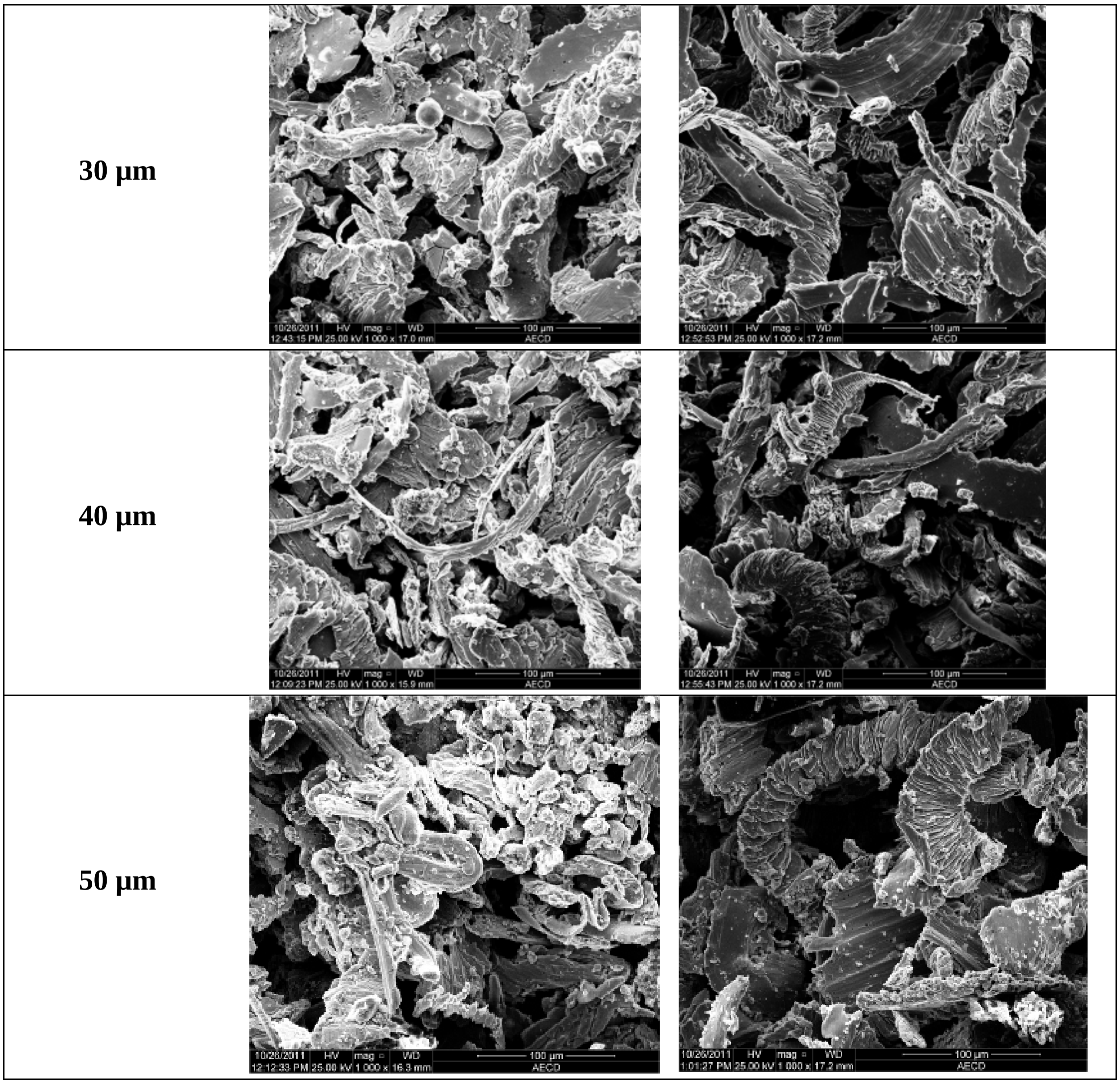


Fig. 5 : SEM photograph of grinding chips at 31.42 m/s wheel speed and 0.1 m/s workspeed while grinding AISI 1045 steel with CBN wheel under dry and MQL condition

III. Surface Roughness Modelling and Validation

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building by careful design of experiments. The objective is to optimize a response (output variable) which is influenced by several independent variables (input variables).

Here a statistical model is developed to make an appropriate approximating relationship between response η and individual variables $\xi_o, \xi_1, \xi_2, \xi_3 \dots \xi_n$ .In general the relationship is,

$$\eta = f\left(\xi_o, \xi_1, \xi_2, \xi_3 \dots \xi_n.\right) + \varepsilon \qquad (1)$$

Here *f* is the true response function which is unknown and perhaps very complicated and ε is a term that represents other sources of variability not accounted for in *f*. usually ε includes effects such as measurement error on the response, background noise, the effect of other variables, and so on. Usually ε is treated as a statistical error, often assuming it to have a normal distribution with mean zero and variance.

In much RSM work it is convenient to transform the natural variables to coded variables $x_o, x_1, x_2, x_3 \dots x_n$, which are usually defined to be dimensionless with mean zero and the same standard deviation. In terms of the coded variables, the response function, which is the expected value of η can be written as,

$$E(\eta) = y = f\left(\xi_o, \xi_1, \xi_2, \xi_3 \dots \xi_n.\right) + E(\varepsilon) = f\left(x_o, x_1, x_2, x_3 \dots x_n.\right) \qquad (2)$$

For the case of two independent variables, the second-order model in terms of the coded variables is,

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^{\ 2} + \beta_{22} x_2^{\ 2} + \beta_{12} x_1 x_2 \tag{3}$$

In general the second order response surface model takes the following form,

$$y = \beta_o + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^{\ 2} + \sum_{i<} \sum_{j=2}^{k} \beta_{ij} x_i x_j \tag{4}$$

Where, f is the response function and a_o, v_s, v_w are the infeed, wheel speed and workspeed and 'ε' is the error which is normally distributed with mean zero.

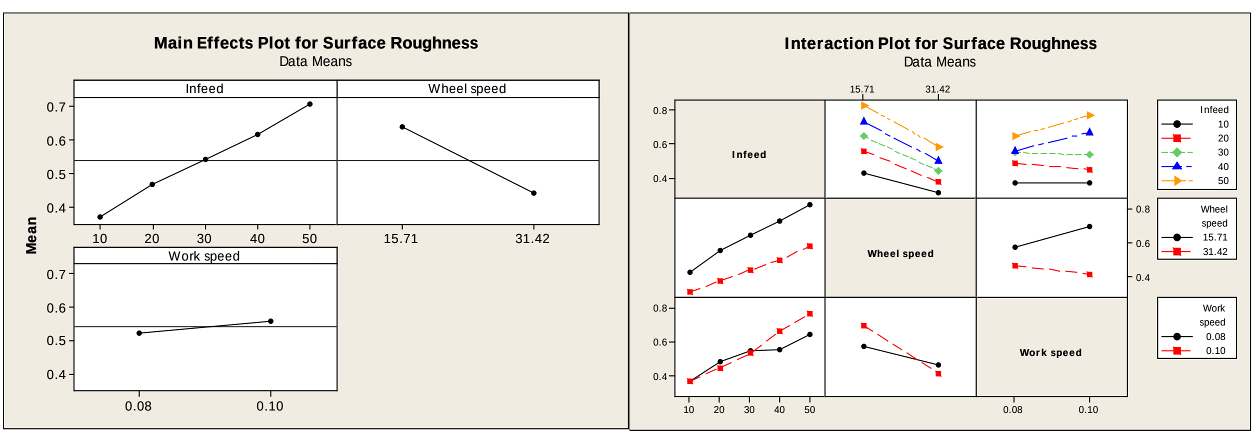
The second order response function for surface roughness R_a as a function of the infeed, wheel speed and workspeed can be written as in Eq. (5).

$$R_a = \beta_o + \beta_1\ a_o + \beta_2\ v_s + \beta_3\ v_w + \beta_{11}\ a_o^{\ 2} + \beta_{22}\ v_s^{\ 2} + \beta_{33}\ v_w^{\ 2} + \beta_{12}\ a_o v_s + \beta_{13} a_o v_w + \beta_{23}\ v_s v_w \tag{5}$$

Where R_a is the response, β_0, β_1, β_2, β_3, β_{11}, β_{22}, β_{33}, β_{12}, β_{13} and β_{23} are the constants.

Here a custom Response Surface Design is created using Minitab 16.1.1 statistical software package and experimental results are used to predict the relationship between three input variables (infeed, wheel speed, work speed) and the response (surface roughness). To assess the influence of the factors to response and interaction between them, the main effect plot and interaction plot is created. The points in the plot are the mean of the response variable at the various levels of each factor, with a reference line drawn at the grand mean of the response data.

Fig. 5(a) show the variation of individual responses with the three parameters i.e. infeed, wheel speed and work speed separately. The plot indicates that, for increasing infeed there is a continuous increase in surface roughness. Roughness decreases with increase of wheel speed but increase a little with increasing work speed. Fig.5(b) shows the interaction plot, that means the variation of main cutting force due to interaction between infeed and wheel speed ($a_o \times v_s$), wheel speed and workspeed ($v_s \times v_w$), infeed and workspeed ($a_o \times v_w$) etc. Interaction effect is highly significant for infeed and wheel speed combination and moderately significant for other two combinations in different degree. For this reason a second order regression model is developed and validated with experimental result to understand the level of effect of order of the equation.



(a) (b)

Fig.5 : (a)Main effect and (b)interaction plot for Surface Roughness

The second order model was postulated in obtaining the relationship between the main cutting force and the machining independent variables. The developed second order mathematical model is given in Eq. (6).

$$R_a = -0.3845 - 0.00459\, a_o + 0.04408\, v_s + 9.275\, v_w - 0.00001\, a_o^2 - 0.00019\, a_o v_s + 0.1975\, a_o v_w - 0.56652\, v_w v_s \quad (6)$$

where,

R_a = Surface Roughness

a_o = Infeed

v_s = Wheel speed

v_w = Work piece

The total analysis was done using uncoded units. The term R^2 is the percentage of response variable variation that is explained by its relationship with one or more predictor variables. The greater the value of R^2 the better the model fits the given data. Here the co-efficient of determination R-Sq = 96.46 % indicate that the equation is able to predict the roughness values with 96.46 % accuracy.

The detailed statistical analysis of the variables that are used in the equation has been given in Table 2.

Table 2 : Regression table for the second order mathematical model

Term	Co-efficient	SE Co-efficient	T	P
Constant	-0.38450	0.31951	-1.203	0.252
a_o	-0.00459	0.00691	-0.664	0.519
v_s	0.04408	0.01071	4.115	0.001
v_w	9.27500	3.44537	2.692	0.020
a_o^2	- 0.00001	0.00005	-0.165	0.872
$a_o \times v_s$	- 0.00019	0.00008	-2.305	0.040
$a_o \times v_w$	0.19750	0.06398	3.087	0.009
$v_w \times v_s$	- 0.56652	0.11519	-4.918	0.000

Here, the P-values are used to determine which of the effects in the model are statistically significant. The α value is assumed as 0.05. From Table 3, it can be clearly stated that, linear and the interaction effects of the cutting process variables are statistically significant since their P-values are less than 0.05.

Analysis of variance (ANOVA) is similar to regression in that it is used to investigate and model the relationship between a response variable and one or more predictor variables.

Table 3 : Analysis of Variance for the second order mathematical model

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	7	0.535447	0.535447	0.076492	46.72	0.000
Linear	3	0.471492	0.471492	0.157164	95.99	0.000
Square	1	0.000045	0.000045	0.000045	0.03	0.872
Interaction	3	0.063910	0.063910	0.021303	13.31	0.000
Residual error	12	0.019648	0.019648	0.001637		
Total	19	0.555095				

The residual is the difference between an observed value (y) and its corresponding fitted value (ŷ). The residual plots are used to check the goodness of the model fit. The residual plots are used to check the goodness of the model fit. The points in this plot should generally form a straight line if the residuals are normally distributed. Here in the **normal probability plot** the data points are fairly close to the fitted line. Small deviation at two ends may be due to the small number of observations. **Residuals versus fits** plot shows the comparison of fitted value against the residuals. This plot should show a random pattern of residuals on both sides of zero. Here the points are random and evenly distributed on both side of zero line moreover, no pattern is detected. . In Fig.6 (c) the **histogram plot** shows nearly a normal distribution with slight evidence of skewness at the right end. This may be due to small number of observations. **Residuals versus order** plot shows all residuals in the order that the data was collected and can be used to find non-random error, especially of time-related effects. No such effect was detected in the current experiment.

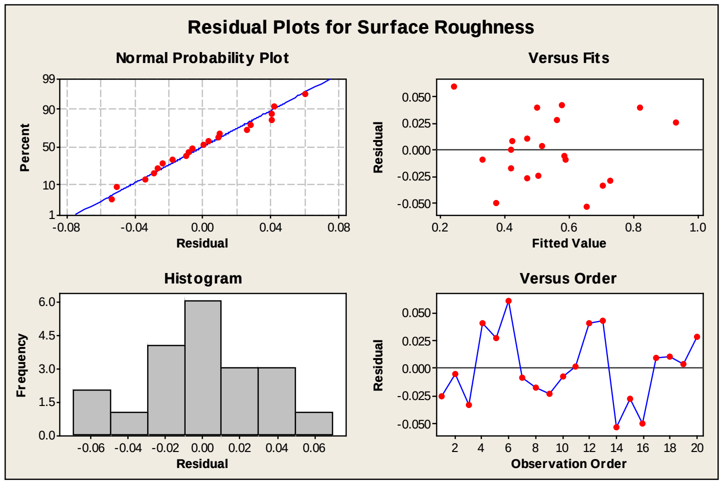


Fig. 6 : Second order mathematical model (a) Normal probability plot for residuals (b) Residual VS fitted value plot (c) Histogram of residuals (d) Residual vs. Order plot

In order to validate the developed model, the experimental surface roughness at different infeed, wheel speed and workspeed has been compared with the predicted value. The pressure and flow rate of the MQL are maintained at 80 bar and 2.0 l/min respectively. In Table 4 the combination of infeed, wheel speed and workspeed for different test have been shown.

Table 4 : Test conditions for Surface roughness validation

Test No.	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Infeed, a_o(μm)	10	20	30	40	50	10	20	30	40	50
Wheelspeed, v_s (m/s)	15.71	15.71	15.71	15.71	15.71	31.42	31.42	31.42	31.42	31.42
Work speed, v_w (m/s)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Test No.	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
Infeed, a_o(μm)	10	20	30	40	50	10	20	30	40	50
Wheelspeed, v_s (m/s)	15.71	15.71	15.71	15.71	15.71	31.42	31.42	31.42	31.42	31.42
Work speed, v_w (m/s)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

The comparison of experimental and predicted value of surface roughness for 20 test samples are illustrated in Fig 7.

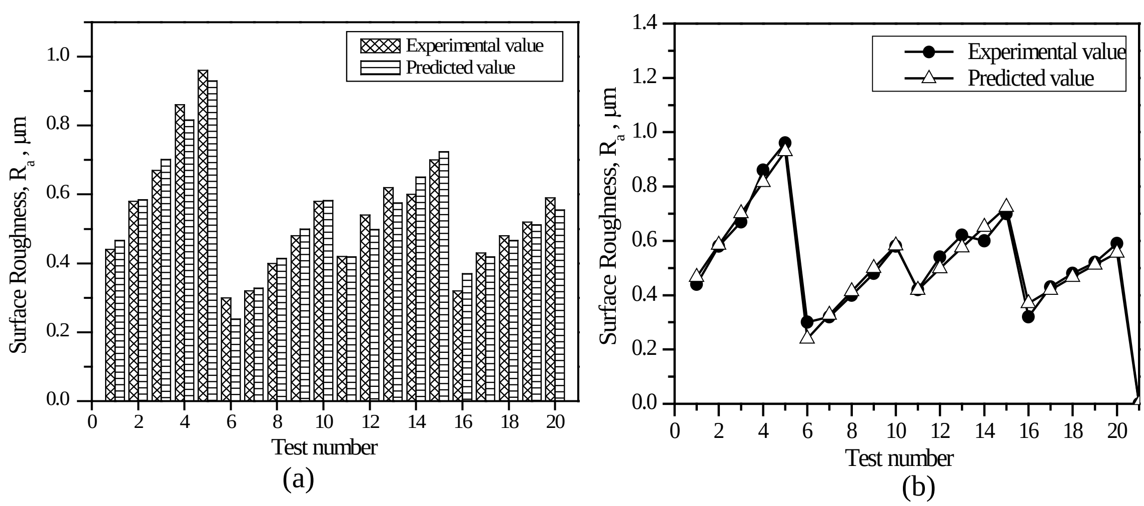


Fig.7 : Comparison of the experimental surface roughness and the predicted surface roughness from the second order mathematical model for different tests for turning AISI 1045 steel with CBN wheel under MQL condition.

IV. Results and Discussion

In this research AISI 1045 steel is ground with alumina and CBN wheel under dry and MQL cooling environment. The surface generated by grinding consists mostly of overlapping scratches produced by the interaction of abrasive grit with the workpiece. Figure 3 and 4 shows the surface roughness of the ground component for two different wheel speed, two different work speed and five different values of infeed consecutively for two different types of wheel. In all cases MQL produces lower values of roughness than dry environment. The lubrication is more effective at lower wheel rotational speed. The lower roughness value is due to more effective lubrication and cooling of the abrasive grains at the workpiece–tool interface. Efficient lubrication allows the chips to slide more easily over the tool surface and results in a better surface finish. Study of the ground surfaces also indicates that in MQL grinding the metal removal takes place mostly by shearing and fracturing, unlike prevalence of plastic deformation, grain pull-out and ploughing in conventional fluid and dry grinding.

Higher rpm of wheel produces lower surface roughness. In higher rpm more abrasive grit come into contact with the work surface thus overlapping cutting remove the surface flaws and smoother surface is obtained. From Fig. 3 it is evident that for higher rpm and higher work speed, MQL environment can produce better surface finish. There are some irregularities in the dry roughness value for 0.08m/s work speed and 30μm infeed. This may be the result of wheel loading and chip clogging. Roughness value increases with increasing infeed as for higher depth of cut, grains penetrate deep in the workpiece and remove bigger chunk of material in each contact. As a result higher peak and valley distance is created which in turn affects the surface roughness. Fig. 4 shows the roughness value with CBN wheel. Here surface roughness for both dry and MQL steadily increased with increasing infeed value.CBN grains are harder than conventional abrasive wheel so they retain their sharpness and can cut through the workpiece smoothly producing lower surface roughness.

The surface burn is observed during grinding under dry condition. The surface becomes burnt blue when machining at 50μm infeed in dry environment. Minimum Quantity Lubrication results burn free surface due to retained grit sharpness and less rubbing and ploughing though at very high infeed the surface become blackish indicating slight sign of surface burn.

The morphology of grinding chips produced by different infeed and cooling environment can be explained with the mechanism of chip formation and material removal. The chips produced during grinding AISI 1045 steel at lower infeed (10 μm and 20μm) have been shown in Fig. 5 under different cooling environment. Both 10μm and 20μm infeed produced different types of chips such as lamellar, flaky and irregular shaped particles with overlapping scratches produced by the interaction of abrasive particles with the workpiece. The flaky shape is produced mainly by rubbing action between abrasive grit and workpiece. At higher infeed (30 μm) some spherical chips are found indicating excessive heating. In all cases MQL produced longer lamellar chips with nearly equal width. The surface of the chips is also less rough in MQL than dry grinding environment. The reason is, in MQL effective lubrication allows the chip to slide more easily over the work surface providing better surface finish. In dry grinding the chip formation particularly involves shearing, ploughing and rubbing. However, the chip formation in MQL is mainly shearing due to low grinding zone temperature. Due to change in infeed no substantial variation in type and length of the chips could be found. In most of the cases wider chips are obtained at higher infeed which indicates higher penetration of abrasive particles into the workpiece.

In real life, application of grinding operation is not limited to these experimental values. Varity of grinding conditions may be used in different industries. So it is necessary to know the roughness value for other experimental conditions and this is where empirical modeling has come into action. The developed model in Eqn. 6 can predict the roughness value with 93.49% accuracy. The statistical conformity of the model is verified by Analysis of Variance (ANOVA) analysis in table 3 and by Residual plots in Figure 6. The model passed the conformity tests with slight variation which may be due to the small number of observations. In Fig.7 predicted values from RSM models have been plotted and compared with the experimental values. From these figures it can be concluded that the RSM can predict the trend of the experimental data and predict the surface roughness with a reasonable amount of error.

V. Conclusions

Based on the research work which is mainly analytical aided with experimental investigation, the following issues can be concluded,

I. Surface roughness of the ground surface is evaluated for AISI 1045 steel under dry and MQL condition with CBN and Alumina wheel. The MQL provided lower value of surface roughness with reduced burn of the surface than dry grinding. The roughness is found to be proportional to infeed and wheel rotational speed. The work speed is also found to have a strong correlation with the roughness value.

II. In all cases CBN wheel produces lower value of surface roughness than Alumina wheel. The increase of roughness value with the increase of infeed is more stable for CBN wheel than Alumina wheel. High thermal conductivity of CBN wheel enhances heat conduction away from the grinding zone to the wheel.

III. In MQL grinding chips are long, lamellar chips compared to the dry grinding where small and more irregular shaped chips are found. Chip formation mode shifted from ploughing, rubbing and shearing to sharp shearing due to retention of sharpness of abrasive grit and lesser ductility of steel under low temperature.

IV. A second order response surface model is developed to predict the surface roughness of AISI 1045 steel with CBN wheel under MQL condition. The model can predict the roughness with 96.46 % accuracy.

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A Fuzzy-Multicritaria Based Approach for Job Sequencing and Routing In Flexible Manufacturing System (Fms)

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Abstract - Flexible manufacturing systems (FMS) are production systems consisting of identical multipurpose numerically controlled machines (workstations), automated material handling system, tools, loading and unloading stations, inspection stations, storage areas and a hierarchical control system. Job sequencing and routing are fundamental components of FMS A flexible manufacturing system (FMS) is a manufacturing system in which there is some flexibility that allows the system to react in the case of changes. Scheduling of an FMS is very complicated, particularly in dynamic environment. A simulation based FMS scheduling system can take into account these uncertainties and perform accordingly. Fuzzy logic based simulation is easy to apply and can consider a number variables with reasonable amount of accuracy. Here the proposed model will prioritize the job and select the best alternative route with multi-criteria scheduling through an approach based on a fuzzy logic. There are three criteria for both the job sequencing and routing with 27 rules. With the help of the rules the sequence of the jobs are done and the best route is selected.

Keywords : Flexible Manufacturing System (FMS), Fuzzy Logic, Scheduling, Job Sequencing, Routing.

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Keywords : Flexible Manufacturing System (FMS), Fuzzy Logic, Scheduling, Job Sequencing, Routing.

I. Introduction

The present industrial trend of manufacturing low cost low-to-medium volumes of modular products with high variability demands manufacturing systems with flexibility and low delivery times. This led to manufacturing systems with small batch productions, low setup times and many decisional degrees of freedom. Those systems are flexible manufacturing systems (FMS). They are highly automated systems with many redundancies, thus allowing for many degrees of freedom in the decision process. Even though there are no universally accepted definitions of FMSs, according to what is proposed by Tempelmeier and Kuhn (1993) and Viswanadham and Narahari(1992) an FMS is composed of:

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- Numerically controlled (NC) multipurpose machine, with automated tool exchange.
- Automated materials and tools handling system (MHS), made by conveyor belts, automatic guided vehicles (AGV), industrial robots, etc.
- Load and unload stations that manage the loading and unloading of parts (loaded parts are fixed on pallets);
- Inspection stations (for quality control);
- Storage areas like input, output and input-output buffers for every machine, or centralized buffers;
- Tools storage areas;
- Hierarchical control system that manages the MHS, all the parts and tools movements and loading and unloading of parts in stations and machines.

A FMS has some built in "hardware" redundancies that should give it the necessary flexibility. These redundancies, although useful, create difficult control problems, i.e. the search for the "best" action to take in a particular situation. The real problem in achieving the desired flexibility presently consists of finding a correct "solution" of the control problem. Such a problem is typically divided into three hierarchical problems characterized by the time frame they refer to long, medium and short-term control. This study will focus on the short term control, or scheduling, problem. The most appropriate control of an FMS requires real time control and state feedback. This way all the dynamic characteristics of the system are taken into account. This means that job schedules cannot be predetermined (i.e., predictive scheduling) but they need to be adapted to the current state and goals during the evolution of the system (i.e., reactive scheduling). Moreover, the best decisions can be taken by using all the available information on the state of the system.

In practice, human experts are the ones that, by using practical rules, make an FMS work to the desired objective. This leads to the idea of a scheduling approach that mimics the behavior of human experts, that is the emerging field of intelligent manufacturing. The literature offers a wide variety of intelligent techniques for the scheduling of manufacturing systems. Namely, fuzzy logic systems (FLS), artificial neural networks (ANN), genetic algorithms (GA), artificial intelligence (AI) and hybrid systems are used in scheduling. AI based systems (i.e., more precisely expert systems) are useful in scheduling because of their ease in using rules captured from human experts, even though presenting some limitations.

Fuzzy logic has the ability to simultaneously consider multiple criteria. Furthermore, the advantage of the fuzzy logic system approach is that it incorporates both numerical and linguistic variables. In this paper, we apply fuzzy logic to simulate FMS. The fuzzy based simulation, in this paper, is designed to solve the problem of determine the job sequence and selecting the best part route. The simulation via a fuzzy model is shown in figure 1.

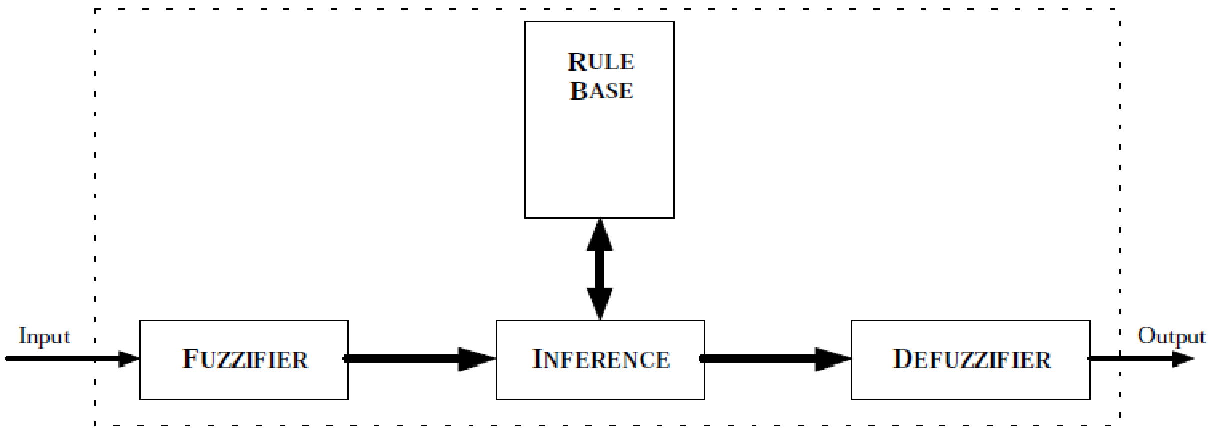

Fig. 1 : Structure of a Fuzzy Logic System

Fuzzy logic, which was introduced by Zadeh (1965), has been applied to various industrial problems. The advantage of the fuzzy logic system approach is that in incorporates both numerical results from previous solutions or simulation and the scheduling expertise from experience or observation or hypothetical data, and it is very easy to implement. Several Fuzzy logic based scheduling systems have recently been developed. Using fuzzy logic to control flexible manufacturing systems seems very appropriate due to its simplicity in dealing with uncertain data, along with the multi-objective nature of the problem.

Hintz and Zimmermann(1989), are probably the first to propose a production planning and control system that uses fuzzy set theory. The interesting part of their work consists in the application of approximate reasoning techniques to both the sequencing and the priority setting problems. The authors develop a hierarchy of elements that are important to make a decision in both cases. Those elements become the antecedents of the fuzzy rules in the scheduling procedure. This methodology is quite general, thus it can be easily modified and extended by changing the antecedents. The consequent of the rules are the next job to be entered into the system (sequencing) or to be processed (priority setting).

Angsana and Passino (1994) seem to be the first to have a more systematic approach to the problem. They present a fuzzy controller for the priority setting problem along with a procedure that can be used for both design and adaptation.

Watanabe et. al (1997) proposed a fuzzy scheduling mechanism for job shops, that they name FUZZY. The only problem that they actually attack is the priority setting problem for a free machine choosing in its buffer the next job to serve. Grabot (1993) proposed a routing mechanism that embodies expert knowledge and that reacts to resource failures by using fuzzy logic and possibility theory. Angsana and Passino(1994) proposed a new scheduling technique which was designed to emulate human scheduler. The implemented Fuzzy Conroller (FC). Sentieiro use fuzzy set theory in a non-classic approach called FLAS (fuzzy logic applied to scheduling) for short term planning and scheduling. Jones et. al (1993)and Nahavandi et. al (1995) also applied fuzzy environment in job shop scheduling as a part of FMS.

Custodio et al.(1994) use fuzzy set theory in a non-classic approach called FLAS (fuzzy logic applied to scheduling) for short term planning and scheduling. The proposed approach is hierarchical, with three decisional levels (high, medium, low) each one associated with production problems at different time horizons. Each level targets the short term planning and scheduling problem in a non-stationary fashion. Gohua and Yen (1999) designed an fuzzy logic system to dynamically guide the selection of dispatching rules for different problem instances at different stages by

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learning from fuzzy rules and previous solutions. In this research work, Fuzzy logic is applied to generate a fuzzy scheduling model in order to select the best job sequence and part routing for the jobs

II. Fuzzy logic in Job Sequencing and Routing

The present industrial trend of manufacturing low cost low-to-medium volumes of modular products with high variability demands manufacturing systems with flexibility and low delivery times. This led to manufacturing systems with small batch productions, low setup times and many decisional degrees of freedom. The scheduling problem consists of several decisional points. A first division into four parts can be made:

- Timing: that is, when to insert a part into the system;
- Sequencing: that is, defining the order with which different parts (batches, orders) are inserted into the system;
- Routing: that is, defining the route (machine, AGV, etc.) for a part in presence of alternatives;
- Priority setting: that is, defining a priority for parts, machine and resources in general so that a choice is directly implied.

The Fuzzy scheduler considers two particular rules in the scheduling problem: Sequencing of job and routing. The sequencing of jobs was approached using fuzzy controllers having rules with three antecedents (Processing time, Due date and Profit over Cost) and one consequent (Priority). The FLSs determine the priority of each job waiting for loading or in a machine buffer, so that whenever the load station or the machine are free the job with the highest priority among those waiting is chosen. The last decisional point that was considered is the routing problem, that is, the choice of one among many possible routes. In the problem considered this is equivalent to choosing the machine for next processing of a job, among the possible alternatives for that job.

The following assumptions on the FMS were made:

1. Tool management is not considered, i.e. it is supposed that all the tools are available where needed.
2. Failure of workstations and/or transport systems is not considered, i.e., the machines and/or transport subsystem are not subject to failure.
3. Orders arrive to the FMS as Poisson processes with a fixed inter-arrival time.
4. Production of orders occurs in batches, and the movement of the whole batch is considered, so that batch dimensions are not important.
5. Setup times are independent of the order in which operations are executed, i.e. they are constant and embodied in the operation times of each job (batch).
6. There are as many pallets and fixtures as are needed (this assumption is mitigated by the fact that the number of jobs in the system is constantly controlled).
7. The routing of every job is random and directly defined as a sequence of workstations the job has to go through. Thus, the route of a job is not defined in terms of the operations needed by the job. In other words, every operation corresponds directly to the workstation that will execute it, i.e., the routing is defined as a sequence of workstations (i.e., workstation 1, 5, 6, 2).
8. There can be multiple routing choices, i.e. at a certain point a job can be equivalently sent to different workstations (as specified in its routing plan) having different processing times.
9. Loading, unloading and processing times are random.
10. Due dates are assigned according to the total processing time of a job.
11. Each workstation can work only one job at a time.
12. The transport system is composed of automated guided vehicles (AGVs) and each AGV can transport only one job at a time.
13. Neither the weight of a piece nor the dimension of a batch affects the speed of AGVs, which is assumed to be constant.
14. Every workstation has one input buffer and no output buffer, therefore it will be free as soon as there is one free AGV that can transport the processed job to another workstation.
15. Delays in accessing the state information are neglected.
16. Among all the possible scheduling rules (Fanti contains a list of rules for a quite general FMS), the following are considered:
    - Sequencing for a job (selection of a piece among those waiting to receive service from a machine);
    - Routing decisions concerning the next required workstation.

III. Problem Definition

The FMS described in this paper consists of 4 different CNC machining centers with finite local buffer capacity, all capable of performing the required operations on each part type, a load/unload station and material handling system with an automated guided vehicle (AGV) which can carry one pallet at a time. The system produces three different part types, A, B and C, as shown in Table 1. It is assumed that it takes 3 minutes to load and unload a part on a pallet at load/unload station. The time to cross the distance between two consecutive MCs is assumed to be 0.5 minute. The arrangement of the FMC hardware is shown in Figure 2.

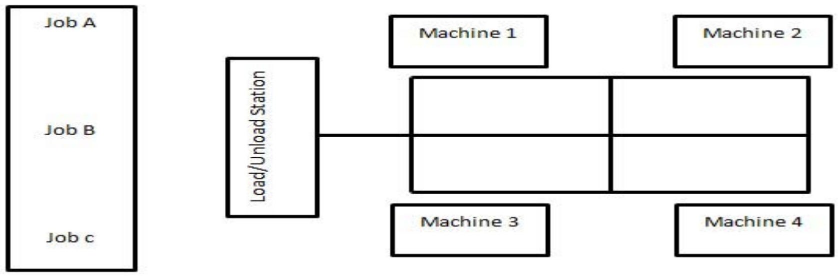

Fig. 2 : Diagram of the Case Study

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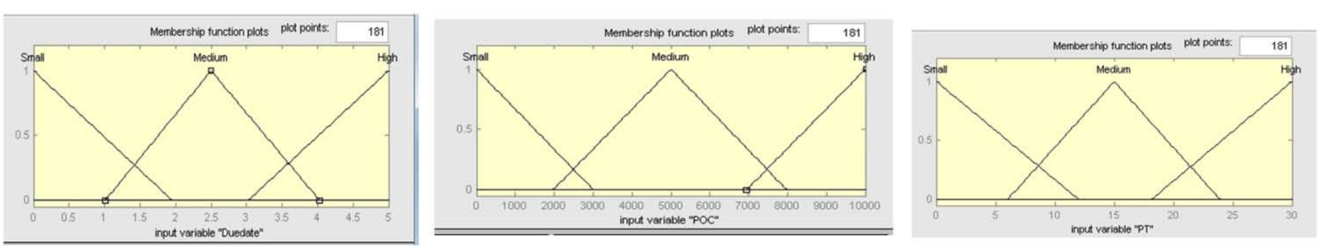
Each machine is capable of performing different operations, but no machine can process more than one part at a time. Each part type has several alternative routings. Operations are not divided or interrupted when started. Set up times are independent of the job sequence and can be included in processing times. The scheduling problem is to decide the sequence of the jobs and which alternative routes should be selected for each job.

IV. The Fuzzy Based Simulation Model

Proposed approach of this research is to identify different scheduling parameters such as, processing time, due date and profit over cost for Job sequencing and processing time, travel time, work in que for routing and construct their membership functions and fuzzy rules. Using these membership functions and fuzzy rules a fuzzy interference system (FIS) is developed to identify the priority of jobs and to identify the best route using MATLAB fuzzy logic toolbox.

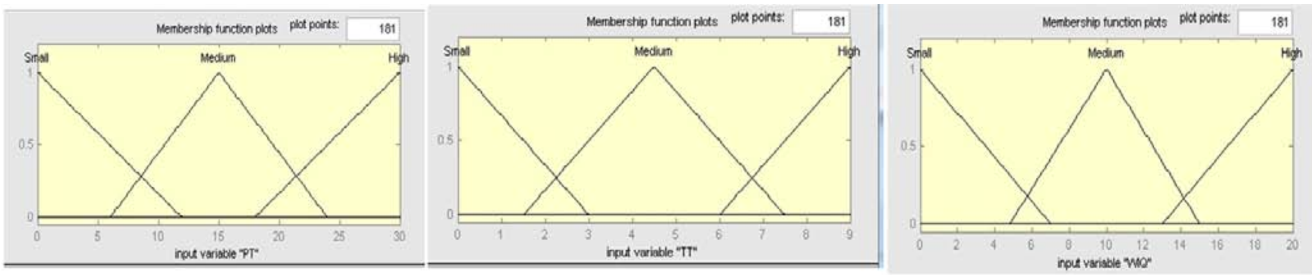
Three variables are selected to identify the job priority, named, processing Time (PT), De Date and Profit over Cost (POC). All the variables are assigned with triangular membership function and divided into three zones Small, Medium and High. The output of these variables is priority varying from 0 to 1. The priority variable is also assigned with triangular membership function and divided into 9 portions. Minimum (MN), Negative Low (NL), Low (LO), Negative Average (NA), Average (AV), Positive Average (PA), High (HI), Positive High (PH) and Maximum (MX). The membership functions for each fuzzy set are shown in figure .



(a) (b) (c)

Fig. 3 : Membership functions of fuzzy input variables; (a) Due Date (b) Profit Over Cost (c) Processing Time

Three variables are selected to identify the best route, named, Work in Queue (WIQ), Tavel Time (TT) and Processing Time (PT). All the variables are assigned with triangular membership function and divided into three zones Small, Medium and High. The output of these variables is priority varying from 0 to 1. The priority variable is also assigned with triangular membership function and divided into 9 portions. Minimum (MN), Negative Low (NL), Low (LO), Negative Average (NA), Average (AV), Positive Average (PA), High (HI), Positive High (PH) and Maximum (MX).



(a) (b) (c)

Fig.4 : Membership functions of fuzzy input variables; (a) Processing Time (b) Travel Time (c) Work in Queue

In case of job sequencing, the variables of processing time, due date and profit over cost have three states each. The total number of possible ordered pairs of these states is 27. For each of these ordered pairs of states, we have to determine an appropriate state of variable job priority. A convenient way of defining all required rules is a decision table, which is given below.

Table 1 : Inference Rules for Job Sequencing using Three Inputs and One Output

Processing Time	Profit Over Cost			Due Date
	Small	Medium	High	
Small	HI	PH	MX	Small
Medium	PA	HI	PH	Medium
High	AV	PA	HI	High
Small	AV	HI	PH	Small
Medium	LO	NA	NA	Medium
High	NL	NA	PA	High
Small	NA	NA	NH	Small
Medium	NL	NA	AV	Medium
High	MN	NL	NA	High

The job priority criteria now used to derive fuzzy inference rules shown as an example :

1. If (Processing Time is Small) and (Profit over Cost is Small) and (Due date is Small) then (Priority is High)
2. If (Processing Time is Small) and (Profit over Cost is Medium) and (Due date is Small) then (Priority is Positive High)

....

......

27 If (Processing Time is High) and (Profit over Cost is High) and (Due date is High) then (Priority is Negative Negative Average)

In case of route selection, the variables of processing time, work in queue and travel time have three states each. Similar to job sequencing, the total number of possible ordered pairs of these states is 27 and or each of these ordered pairs of states, we have to determine an appropriate state of variable route priority. The decision table is given below,

Table 2 : Inference Rules for Route Selection using Three Inputs and One Output

Processing Time	Work in Queue			Travel Time
	Small	Medium	High	
Small	MX	PA	NA	Small
Medium	MX	PA	PL	Medium
High	PH	AV	PL	High
Small	PH	AV	LO	Small
Medium	PH	AV	NL	Medium
High	HI	AV	NL	High
Small	HI	AV	NL	Small
Medium	HI	NA	MN	Medium
High	PA	NA	MN	High

The route priority criteria now used to derive fuzzy inference rules shown as an example :

1. If (Processing Time is Small) and (Work in Queue is Small) and (Travel Time is Small) then (Route Priority is Maximum)
2. If (Processing Time is Small) and (Work in Queue is Medium) and (Travel Time is Small) then (Route Priority is Positive Average)

....

....

27. If (Processing Time is High) and (Work in Queue is High) and (Travel Time is High) then (Route Priority is Minimum)

V. The Experimental Result

Three jobs are considered here with three different processing times, due dates and profit over costs. They are determined based on customer requirements and the cost of the raw materials needed to finish the jobs. Processing time here is the ideal time, means time needed if it was machined in just one machine.

Table 3 : Priority of jobs are calculated using Fuzzy Interference System (FIS)

Job Name	Processing Time (Minute)	Profit over Cost (Tk)	Due Date (Day)
A	17	6500	4
B	19	6000	1
C	8	4000	2

Table 4 : Priority of Jobs

Job Name	Priority	Normalized Priority
A	0.375	0.223
B	0.708	0.422
C	0.593	0.355

The overall system comprises 4 different CNC machining centers (MCs), all capable of performing the required operations on each part type, a load/unload station and material handling system with one automated guided vehicle (AGV) which can carry one pallet at a time. The system produces three different part types, A, B and C. It is assumed that it takes 3 minutes to load and unload a part on a pallet at load/unload station.

Table 5 : Processing Times in Different Machines

Machine	Job A	Job B	Job C
1	6	5	7
2	2	5	1
3	7	3	1
4	2	8	2

Table 6 : Route times for Job A

Route (Machine Sequence)	Work in Queue (In minutes)	Total Processing Time	Travel Time (Including Load/Unload time)
1-3-1-4	6	21	6.5
2-3-1-4	12	17	7
2-3-3-1	9	22	6

Table 6 : Route times for Job B

Route (Machine Sequence)	Total Processing Time	Travel Time (Including Load/Unload time)	Work in Queue (In minutes)
2-1-2-4	23	6	7
3-1-2-4	21	6	11
1-4-4-2	26	5.5	8

Table 7 : Route times for Job C

Route (Machine Sequence)	Total Processing Time	Travel Time (Including Load/Unload time)	Work in Queue (In minutes)
1-3-3-2	10	5.5	8
1-4-3-2	11	6.5	6
1-2-3-4	11	5	9

Table 8 : Route priority for Job A

Route	Priority	Normalized Priority
1-3-1-4	0.584	0.387
2-3-1-4	0.5	0.331
2-3-3-1	0.425	0.282

Table 9 : Route priority for Job B

Route	Priority	Normalized Priority
2-1-2-4	0.401	0.328
3-1-2-4	0.447	0.365
1-4-4-2	0.375	0.307

Table 10 : Route priority for Job C

Route	Priority	Normalized Priority
1-3-3-2	0.534	0.313
1-4-3-2	0.658	0.385
1-2-3-4	0.516	0.302

Table 11 : The final sequence

Job	Route
B	3-1-2-4
C	1-4-3-2
A	1-3-1-4

VI. Conclusion

The work presented in this paper was directed towards investigating the applicability of fuzzy techniques as a decision aid in the short-term control of flexible manufacturing systems. For this purpose a flexible manufacturing system for three jobs composed of four machines, one AGV, one load and one unload station and with routings and arrivals with fixed statistical characteristics was considered. A fuzzy scheduler for job sequencing and routing was developed. This scheduler uses fuzzy logic systems as well as fuzzy multiple attribute decision-making techniques. The thesis was done to increase performance by using fuzzy techniques and also in giving a systematic design procedure (lacking in the literature) that takes into account multiple objectives and needs no interface with linguistic directions from human experts (e.g., management).

In this research, hypothetical data are used to determine the job priority and routing. But, it would be more appropriate if actual data from a production system are used. Again, only job priority and routing are taken into account, some other criteria's can also be added. Several parameters are used to design the problem, but, yet there may be other parameters which can be added to make the model more accurate. Here, triangular membership functions were used. There are some other membership functions which could give different results. All possible rules are taken, but if more parameters were added, number of the rules would have been increased. All this changes may lead the model to better results.

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Metric SI units are supposed to generally be used excluding where they conflict with current practice or are confusing. For illustration, 1.4 l rather than 1.4 × 10-3 m3, or 4 mm somewhat than 4 × 10-3 m. Chemical formula and solutions must identify the form used, e.g. anhydrous or hydrated, and the concentration must be in clearly defined units. Common species names should be followed by underlines at the first mention. For following use the generic name should be constricted to a single letter, if it is clear.

Structure

All manuscripts submitted to Global Journals Inc. (US), ought to include:

Title: The title page must carry an instructive title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) wherever the work was carried out. The full postal address in addition with the e-mail address of related author must be given. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining and indexing.

Abstract, used in Original Papers and Reviews:

Optimizing Abstract for Search Engines

Many researchers searching for information online will use search engines such as Google, Yahoo or similar. By optimizing your paper for search engines, you will amplify the chance of someone finding it. This in turn will make it more likely to be viewed and/or cited in a further work. Global Journals Inc. (US) have compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Key Words

A major linchpin in research work for the writing research paper is the keyword search, which one will employ to find both library and Internet resources.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy and planning a list of possible keywords and phrases to try.

Search engines for most searches, use Boolean searching, which is somewhat different from Internet searches. The Boolean search uses "operators," words (and, or, not, and near) that enable you to expand or narrow your affords. Tips for research paper while preparing research paper are very helpful guideline of research paper.

Choice of key words is first tool of tips to write research paper. Research paper writing is an art.A few tips for deciding as strategically as possible about keyword search:

- One should start brainstorming lists of possible keywords before even begin searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in research paper?" Then consider synonyms for the important words.
- It may take the discovery of only one relevant paper to let steer in the right keyword direction because in most databases, the keywords under which a research paper is abstracted are listed with the paper.
- One should avoid outdated words.

Keywords are the key that opens a door to research work sources. Keyword searching is an art in which researcher's skills are bound to improve with experience and time.

Numerical Methods: Numerical methods used should be clear and, where appropriate, supported by references.

Acknowledgements: Please make these as concise as possible.

References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

References to information on the World Wide Web can be given, but only if the information is available without charge to readers on an official site. Wikipedia and Similar websites are not allowed where anyone can change the information. Authors will be asked to make available electronic copies of the cited information for inclusion on the Global Journals Inc. (US) homepage at the judgment of the Editorial Board.

The Editorial Board and Global Journals Inc. (US) recommend that, citation of online-published papers and other material should be done via a DOI (digital object identifier). If an author cites anything, which does not have a DOI, they run the risk of the cited material not being noticeable.

The Editorial Board and Global Journals Inc. (US) recommend the use of a tool such as Reference Manager for reference management and formatting.

Tables, Figures and Figure Legends

Tables: Tables should be few in number, cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g. Table 4, a self-explanatory caption and be on a separate sheet. Vertical lines should not be used.

Figures: Figures are supposed to be submitted as separate files. Always take in a citation in the text for each figure using Arabic numbers, e.g. Fig. 4. Artwork must be submitted online in electronic form by e-mailing them.

Preparation of Electronic Figures for Publication

Even though low quality images are sufficient for review purposes, print publication requires high quality images to prevent the final product being blurred or fuzzy. Submit (or e-mail) EPS (line art) or TIFF (halftone/photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Do not use pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings) in relation to the imitation size. Please give the data for figures in black and white or submit a Color Work Agreement Form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution (at final image size) ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs) : >350 dpi; figures containing both halftone and line images: >650 dpi.

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Figure Legends: Self-explanatory legends of all figures should be incorporated separately under the heading 'Legends to Figures'. In the full-text online edition of the journal, figure legends may possibly be truncated in abbreviated links to the full screen version. Therefore, the first 100 characters of any legend should notify the reader, about the key aspects of the figure.

6. AFTER ACCEPTANCE

Upon approval of a paper for publication, the manuscript will be forwarded to the dean, who is responsible for the publication of the Global Journals Inc. (US).

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(Free of charge) from the following website:

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the search? Will I be able to find all information in this field area? If the answer of these types of questions will be "Yes" then you can choose that topic. In most of the cases, you may have to conduct the surveys and have to visit several places because this field is related to Computer Science and Information Technology. Also, you may have to do a lot of work to find all rise and falls regarding the various data of that subject. Sometimes, detailed information plays a vital role, instead of short information.

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11. Revise what you wrote: When you write anything, always read it, summarize it and then finalize it.

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21. Arrangement of information: Each section of the main body should start with an opening sentence and there should be a changeover at the end of the section. Give only valid and powerful arguments to your topic. You may also maintain your arguments with records.

22. Never start in last minute: Always start at right time and give enough time to research work. Leaving everything to the last minute will degrade your paper and spoil your work.

23. Multitasking in research is not good: Doing several things at the same time proves bad habit in case of research activity. Research is an area, where everything has a particular time slot. Divide your research work in parts and do particular part in particular time slot.

24. Never copy others' work: Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

25. Take proper rest and food: No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

26. Go for seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

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.

28. Make colleagues: Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

29. **Think technically:** Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

31. Adding unnecessary information: Do not add unnecessary information, like, I have used MS Excel to draw graph. Do not add irrelevant and inappropriate material. These all will create superfluous. Foreign terminology and phrases are not apropos. One should NEVER take a broad view. Analogy in script is like feathers on a snake. Not at all use a large word when a very small one would be sufficient. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Amplification is a billion times of inferior quality than sarcasm.

32. Never oversimplify everything: To add material in your research paper, never go for oversimplification. This will definitely irritate the evaluator. Be more or less specific. Also too, by no means, ever use rhythmic redundancies. Contractions aren't essential and shouldn't be there used. Comparisons are as terrible as clichés. Give up ampersands and abbreviations, and so on. Remove commas, that are, not necessary. Parenthetical words however should be together with this in commas. Understatement is all the time the complete best way to put onward earth-shaking thoughts. Give a detailed literary review.

33. Report concluded results: Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

34. After conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print to the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects in your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- 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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