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Highlights

- Finite Element Method
- Laser Shock Peening Analysis
- Design of Metal Bellows
- Permanent Magnet Synchronous

Discovering Thoughts, Inventing Future

VOLUME 13 ISSUE 9 VERSION 1.0

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Effects of Simulation Parameters on Residual Stresses in 3D Finite Element Laser Shock Peening Analysis

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Abstract- Laser shock peening (LSP) is an innovative surface treatment technique, which is successfully applied to improve fatigue performance of metallic components. After the treatment, the fatigue strength and fatigue life of a metallic material can be increased remarkably owing to the presence of compressive residual stresses in the material. Recently, the incidences of cracking in Alloy 600 small-caliber penetration nozzles (CRDM (control rod drive mechanism) and BMI (bottom mounted instrument)) have increased significantly. The cracking mechanism has been attributed to primary water stress corrosion cracking (PWSCC) and has been shown to be driven by welding residual stresses and operational stresses in the weld region. For this reason, to mitigating weld residual stress, preventive maintenance of BMI nozzles was considered application of laser shock peening process. Effects of parameters related to finite element simulation of laser shock peening process to determine residual stresses are discussed, in particular parameters associated with the LSP process, such as the maximum pressure, pressure pulse duration, laser spot size and number of shots. It is found that certain ranges of the maximum pressure and pulse duration can produce maximum compressive residual stresses near the surface, and thus proper choices of these parameters are important. For the laser spot size, residual stresses are not affected, provided it is larger than a certain size. Magnitudes of compressive residual stresses are found to increase with increasing number of shots, but the effect is less pronounced for more shots.

Keywords: *FE analysis, LSP (laser shock peening), residual stress.*

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Ju Hee Kim [α] & Jong Woo Lee [σ]

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Keywords: FE analysis, LSP (laser shock peening), residual stress.

- Nomenclature

Le= element length

n= number of shots

Pmax= maximum peak pressure

td = pressure pulse duration

tp= solution time for dynamic analysis

ts= stability time limit

xp= laser spot size

σy^d = dynamic yield strength

HEL = Hugoniot elastic limit

LSP= laser shock peening

FE= finite element

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I. Introduction

Laser shock peening (LSP) is an innovative surface treatment technique, producing compressive residual stresses near the surface and thus improving fatigue performance of metallic components [1, 2]. Through the LSP processing, the surface of the metallic target is exposed to an intense laser beam with high density (in the GW/cm2 range) for short duration (tens of nanoseconds). The thermo-protective coating (black paint or taping) is vaporized because of the high-energy laser pulse, forming a plasma that reaches temperatures in excess of 10,000 °C. An extremely high pressure (the order of GPa) on the metal surface is generated bythe extremely rapid expansion of the heated plasma [1-3]. The high pressure then propagatesinto the material interior. As a result, plastic deformation occurs and a hardened layer is formed on the surface of the metallic target, enhancing mechanical properties such as hardness, fatigue strength, and stress corrosion cracking resistance.

In the present work, effects of parameters related to finite element (FE) simulation of LSP process to determine residual stresses is discussed. Simulations were performed using the general purpose FE program ABAQUS [4].

II. FE Analysis

a) Simulation Procedures

As the LSP process involves high speed impact and dynamic wave propagation, explicit time integration FE codes need to be employed, for instance, using the ABAQUS/Explicit code [4]. There can be two approaches to simulate the LSP process. The first approach is to use explicit time integration FE codes only(procedure 2). Although this approach is relatively easy to perform, it requires long computation times. This is because calculation times should be chosen to be sufficiently long, as full development of plastic deformation in the material during the LSP process takes much longer than the duration of the pulse pressure, due to reflection and interaction of shock waves propagating in the target.

The second, more efficient, approach is to combine ABAQUS/Explicit and ABAQUS/Implicit codes (procedure ①). In this approach, dynamic analysis is firstly performed using the ABAQUS/Explicit code. When the dynamic analysis is completed, the deformed element data with all transient stresses and strains information are then imported into the ABAQUS/Implicit code to calculate residual stress fields using static analysis. For cases considered in this paper, it is found that the above two approaches give the same results, and thus the latter (and more efficient) approach is used throughout the paper.

b) Modeling Pressure Loading

Assuming a constant absorbed laser power density I_o in the confined ablation mode, the maximum peak pressure induced by plasma, $P_{\max}$, is given by [1, 2, 5-7]

$$P_{\max}(\mathrm{GPa}) = 0.01\sqrt{\frac{\alpha}{2\alpha+3}}\sqrt{Z}\sqrt{I_o} \tag{1}$$

where α is the efficiency of the interaction; and Z is the reduced shock impedance between the material and the confining layer [1, 8].

$$\frac{2}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2} \tag{2}$$

Although the pressure–time history for simulating LSP is usually described using a Gaussian temporal profile, it is in fact very close to a triangular ramp because of very short pressure pulse duration (order of 100ns), as shown in Fig. 2. Thus, in this work, the pressure is assumed to increase linearly to the maximum pressure, P_{max}, and then decrease linearly for a total pulse duration, $2t_p$, as shown in Fig. 2.

c) Modeling Plastic Deformation Due to Shock Wave

As the shock wave propagates into the metal, plastic deformation occurs up to a depth at which the peak stress equals the Hugoniot elastic limit (HEL) of the material. The HEL is related to the dynamic yield strength at high strain rates, σ_y^d , according to [1, 2, 5-8]

$$HEL = \frac{(1-\nu)}{(1-2\nu)}\sigma_y^d \tag{3}$$

where ν is Poisson's ratio.

III. SENSITIVITY ANALYSIS FOR LSP SIMULATION

a) Geometry and FE mesh

As a generic problem, the present work considers one-sided laser peening on an infinite plate. The impact zone is assumed to be rectangular with a half-length x_p, as schematically shown in Fig. 3a. Corresponding three-dimensional (3D) FE quarter model is shown in Fig. 3b. The FE analysis domain has a half-length x_f (which is fixed to x_f =5 mm in this work). Outside the domain, infinite elements are used to simulate an infinite plate. For the element type, the first order elements (C3D8R for finite elements and CIN3D8 for infinite elements within ABAQUS) are used.

b) Material Properties

The material is assumed to be the 35CD4 50HRC steel alloy, of which physical and mechanical properties, taken from Ref. [1], are given in Table 1. Other parameters used in simulations are;

α=0.1, Z1=3.6 106(g/cm-2s-1) and Z2=0.165 106(g/cm-2s-1) [1, 8]

c) Parameters for Sensitivity Analysis

There are many parameters possibly affecting FE simulation results of the LSP process. They can be broadly categorized into two groups. The first group includes parameters associated with dynamic FE analysis, such as the mesh size L_e, solution time for dynamic analysis, t_s, time step, Δt_s and dynamic yield strength, σ_y^d. The other group includes parameters associated with the LSP process, such as the maximum pressure, P_{max}, pressure pulse duration, t_d, laser spot size, r_p and the number of shots, n. For sensitivity analysis, the reference values for these variables are chosen, as given in Table 2.1 Each variable is then systematically varied to see its effect on simulation results.

d) Validation

Before presenting results of sensitivity analysis, the present analysis is validated by comparing with existing experimental data [9]. The material was the 35CD4 50HRC steel alloy that is the same as the one considered in the present work. Laser peening parameters (P_{max}, t_d, x_p and n) were the same as the reference values given in Table 2. More detailed information on experiments can be found in Ref. [9].

Simulated residual stresses are compared with experimental results in Fig. 4. Figure 4a compares variations of σ_x and σ_y residual stresses in the surface (at y=z=0) with distance x. Variations of σ_x and σ_y residual stresses with depth z (at x=y=0) are compared in Fig. 4b. Experimental data show that both residual stresses, σ_x and σ_y, are similar. Despite differences between experimental and simulated residual stresses, overall trends in experimental data can be 1 Note that reference values for Pmax, td, xp and n were chosen to compare with existing experimental data, as will be described in the next subsection captured by simulation.

Considering uncertainties in experimental residual stress measurement, results in Fig. 4 suggest that FE simulation of the LSP process is reliable. Figure 5 shows a 3D profile of predicted residual stresses (von Mises stress) on the surface and in the depth directions, impacted at a spot size of x_p=2.5mm.

IV. Sensitivity Analysis Results

a) Effect of the Mesh Size

It is known that FE LSP simulation results are not affected by the element size, provided it is less than about 5% of the spot size, x_p [1, 5]. The critical element size is 125 μm for the present problem. To see the effect of the mesh size, three different FE models were prepared, having the element size ranging from L_e=100 μm to L_e=250 μm, and results are shown in Fig. 6. In Fig. 6 as well as in subsequent figures, two residual stress profiles are presented. The first one is variations of the σ_x residual stresses at the surface (y=z=0) with distance x, shown in Fig. 6a. The second result is variations of the σ_x residual stresses at the center of the laser spot (x=y=0) with depth z, shown in Fig. 6b. Results in Fig. 6 confirm the existing finding that simulated residual stresses are not affected when the element size is less than 5% of the spot size, x_p.

b) Time Step for Stability

In dynamic analysis, the time step, Δt_s, should be chosen to be smaller than the stability limit for numerical stability. The stability limit can be estimated from [1, 10, 11]

$$\Delta t_s = \frac{L_e}{C_d} = L_e\sqrt{\frac{\rho}{E}} \tag{4}$$

where L_e denotes the smallest element size; C_d is the wave speed of material; E is Young's modulus; and ρ is the mass density. For the present problem, C_d= $5.193\text{x}10^3$ m/s with L_e=125 μm gives $\Delta t_s \approx$5.78 ns. For the sake of space, results are not shown but simulated residual stress results are found not to be affected by the time step, provided that it is less than Δt_s, given by Eq.(4).

c) Solution time for dynamic analysis (t_s)

To obtain residual stress fields due to dynamic wave propagation by LSP, the solution time in dynamic analysis must be taken much longer than the laser duration time. Figure 7 shows dynamic stress profiles at four different times during dynamic analysis. Results show that simulated dynamic stress profiles are affected by t_s.

After t_s=2,000ns, the dynamic stress profile in the depth direction gradually becomes steady, but the dynamic stress profile at surface become steady only after t_s=5,000ns. Results suggest that the solution time for dynamic analysis should be chosen to be larger than 5,000ns, which is about hundred times larger than the pulse duration t_d=50ns.

d) Dynamic Yield Strength ($\sigma_Y{}^d$)

As the strain rate during the LSP process is faster than 10^{-6}s^{-1}, plastic deformation is determined by the dynamic yield strength, $\sigma_Y{}^d$. As information on $\sigma_Y{}^d$ may have uncertainty, the effect of $\sigma_Y{}^d$ is investigated by varying $\sigma_Y{}^d$ from 1.0GPa to 1.5GPa, and the results are shown in Fig. 8. Results show that magnitudes of compressive residual stresses decrease almost linearly with increasing $\sigma_Y{}^d$, due to the fact that increasing the material yield strength tends to increase material resistance against plastic deformation [11].

e) Maximum Pressure (Pmax,, see Fig. 2)

The plasma pressure pulse induced by LSP depends on the laser power density, as shown in Eq. (1). Increasing laser power density increases the magnitude of the pressure pulse on the material surface. The plastic deformation in the material depends mainly on the HEL. No plastic deformation occurs in the material for P_{max} <HEL. The plastic strain occurs with a purely elastic reverse strain for HEL< P_{max} <2×HEL, and the plastic strain fully occurs for P_{max} >2×HEL [1, 2, 6].

To see the effect of the laser power density on residual stresses, simulations are performed for P_{max}, ranging from 2.5GPa to 5GPa, and results are shown in Fig. 9. Note HEL=2.1GPa for the present problem. Results show that magnitudes of compressive residual stresses near the surface increase with increasing P_{max} up to P_{max} =4GPa. For P_{max} =5GPa, the magnitudes of compressive residual stresses in the surface are overall smaller than those for P_{max} =4GPa.

Along the depth direction, the plastically affected zone size increases with increasing P_{max}. For P_{max} =2.5GPa and 3GPa, magnitudes of compressive residual stresses decrease monotonically. However, for P_{max} =4GPa and 5GPa, they increase near the surface and then decrease. Results in Fig. 9 suggest that the case of P_{max} =4GPa can produce optimum laser peening treatment, which is fully consistent to the existing finding that materials can be optimally treated with P_{max} = (2–2.5)×HEL range [1, 6]. Results show that the choice of the laser power density is important in the LSP process to produce desired residual stress profiles.

f) Pressure Duration (td)

In addition to the laser power density, the pressure duration is another important parameter associated with the LSP process. Figure 10 shows the effect of the pressure duration of laser pulse on simulated residual stresses. In the surface, residual stress profiles for t_d =30ns and 50ns are similar. However, for t_d =100ns, residual stresses near the center become less compressive. For t_d =150ns, they can be even tensile. Along the depth direction, the plastically affected zone size increases with increasing t_d. For t_d =30ns and 50ns, magnitudes of compressive residual stresses decrease monotonically with the depth. For t_d =100ns, they increase near the surface and then decrease. For larger t_d, such trend is more pronounced. Results in Fig. 10 suggest that the pressure duration should be chosen properly to obtain desired residual stress profiles.

g) Laser Spot Size (x_p)

To see the effect of the laser spot size, simulations are performed for various laser spot sizes (r_p) ranging from 0.5mm to 2.5mm, with the fixed P_{max}=3GPa and pulse duration of t_d=50 ns, and results are shown in Fig. 11. The affected zone size of compressive residual stresses in the surface obviously increases with increasing laser spot size. However, residual stresses in the depth direction are not affected by the laser spot size, provided it is larger than 1.5mm.

h) Number of Shots (n)

In practice, the multiple LSP process can be performed to produce more compressive residual stresses. The effect of multiple LSP process (from single to four times) on simulated residual stresses is shown in Fig. 12. In simulation, the parameters associated with the LSP process are fixed; P_{max}=3GPa, x_p=2.5mm and t_d=50ns. Multiple LSP is applied to the same area. Results show that magnitudes of compressive residual stresses increase with increasing number of shots, but the effect on residual stresses is less pronounced for more shots.

i) FE results using LSP optimal process parameters

The surface and depth residual stress distributions resulting from the optimum parameters of LSP system are shown in Fig. 13. Then optimum LSP parameters such as peak pressure (2×HEL=4.2GPa), laser spot size (2.5mm), and laser pulse duration (100ns) are used in same conditions. As shown in Fig. 13a, after one impact using optimum LSP parameters on same area, the surface residual stresses have increased remarkably. It shows that the maximum compressive residual stresses increase to about 567MPa, which is 62% higher than that for P_{max}=3GPa, td=50ns. The distributions of the depth residual stresses plotted in Fig. 13b. Along the depth direction, the plastically affected zone size(L_p) decreases to about 1.42mm, which is 136% higher than that for P_{max}=3GPa, td=50ns. Therefore, residual stresses due to the LSP optimal process parameters result in a more effective residual stress.

V. Conclusions

In the present work, effects of parameters related to finite element (FE) simulation of LSP process to determine residual stresses are discussed. Two groups of parameters are considered: one those associated with dynamic FE analysis, such as the mesh size, solution time for dynamic analysis, time step and dynamic yield strength; and the other associated with the LSP process, such as the maximum pressure, pressure pulse duration, laser spot size and number of shots.

Conclusions can be summarized as follows.

- The mesh size should be chosen to be smaller than 5% of the spot size.
- The solution time for dynamic analysis should be chosen to be sufficiently long, about hundred times larger than the pulse duration.
- The effect of the dynamic yield strength on simulated residual stresses is almost linear.
- Certain ranges of the maximum pressure and pulse duration can produce maximum compressive residual stresses near the surface, and thus proper choices of these parameters are important.
- Residual stresses in the depth direction are not affected by the laser spot size, when it is larger than a certain size.
- Magnitudes of compressive residual stresses increase with increasing number of shots, but the effect is less pronounced for more shots.

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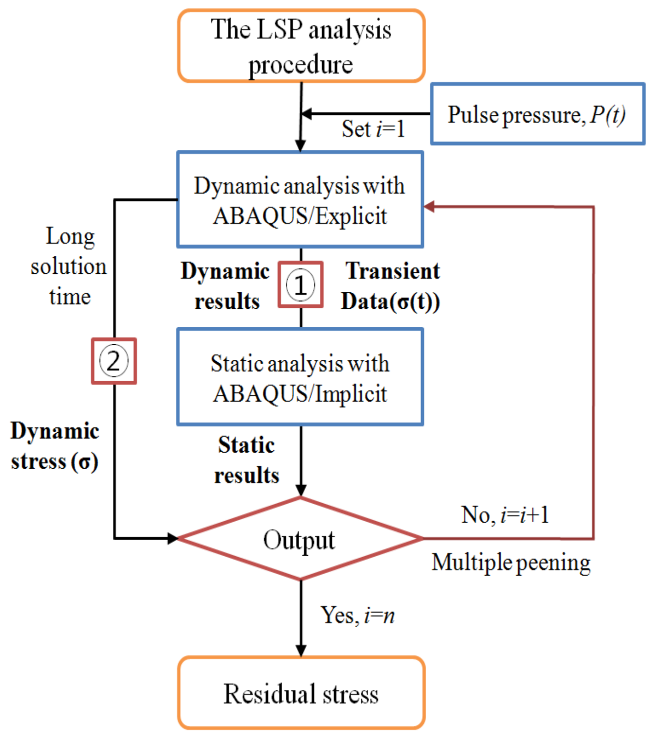


Figure 1 : Procedure of LSP simulation

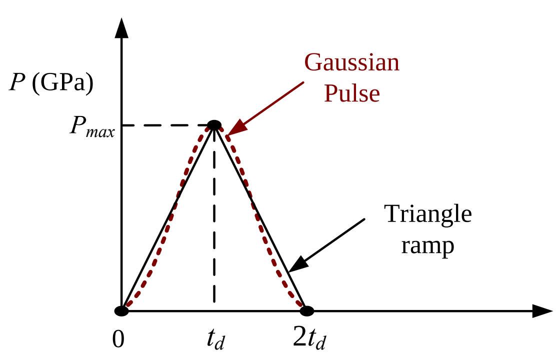


Figure 2 : Pressure-time history for LSP simulation

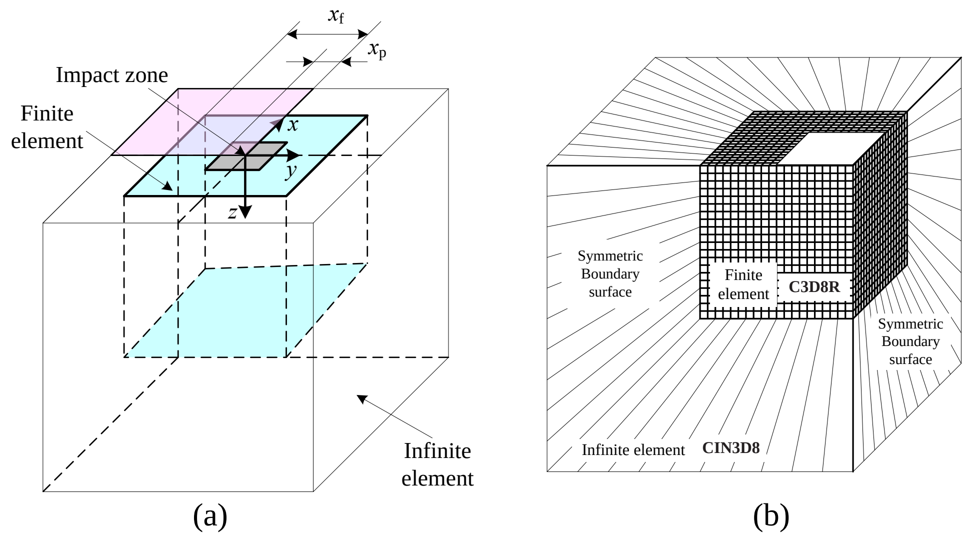


Figure 3 : (a) Geometry of LSP and (b) 3D FE mesh (quarter model)

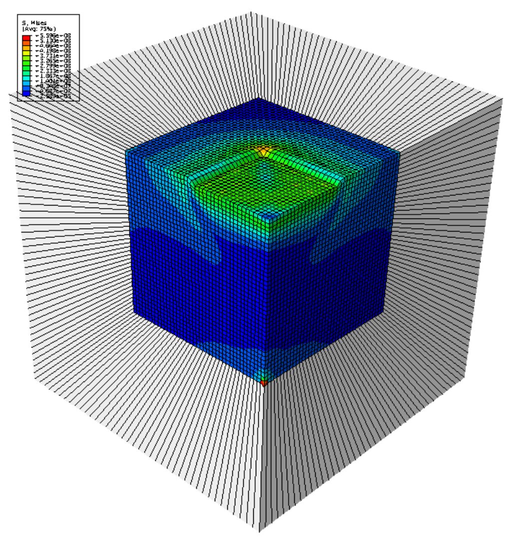


Figure 4 : Distribution of residual stresses along the surface and in depth for single LSP

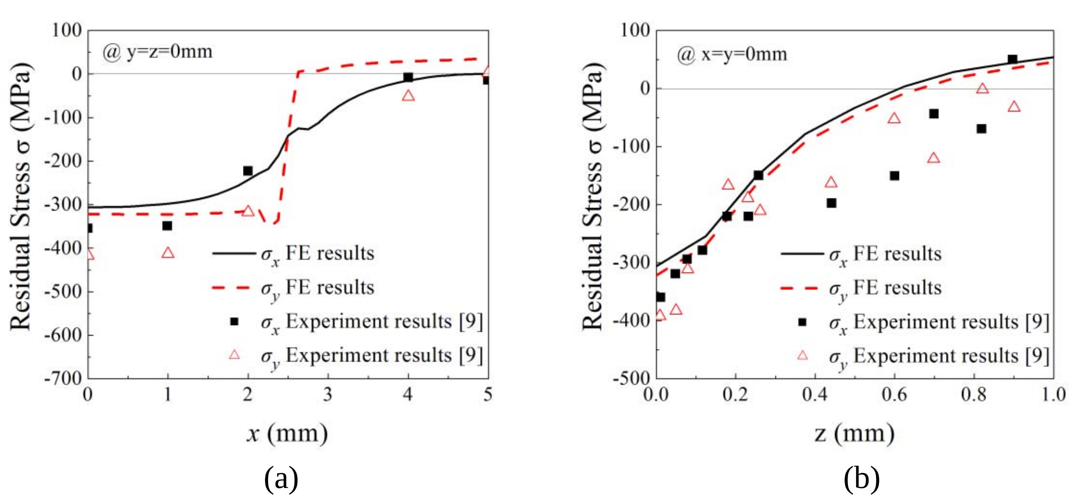
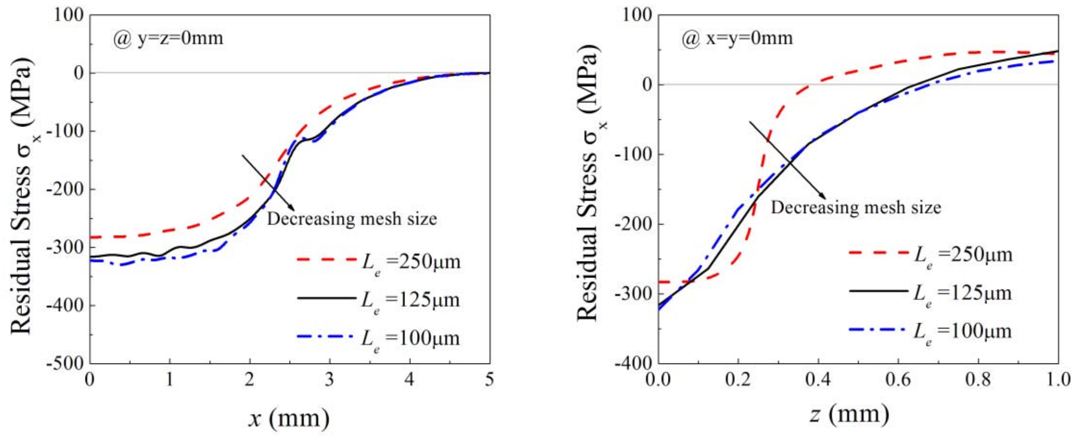
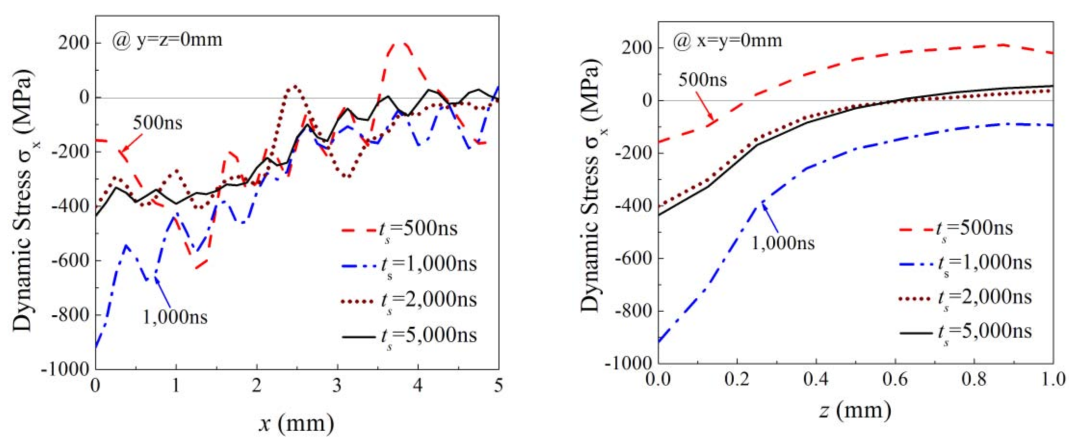


Figure 5 : Comparison of simulated FE residual stress results with experimental data [9]



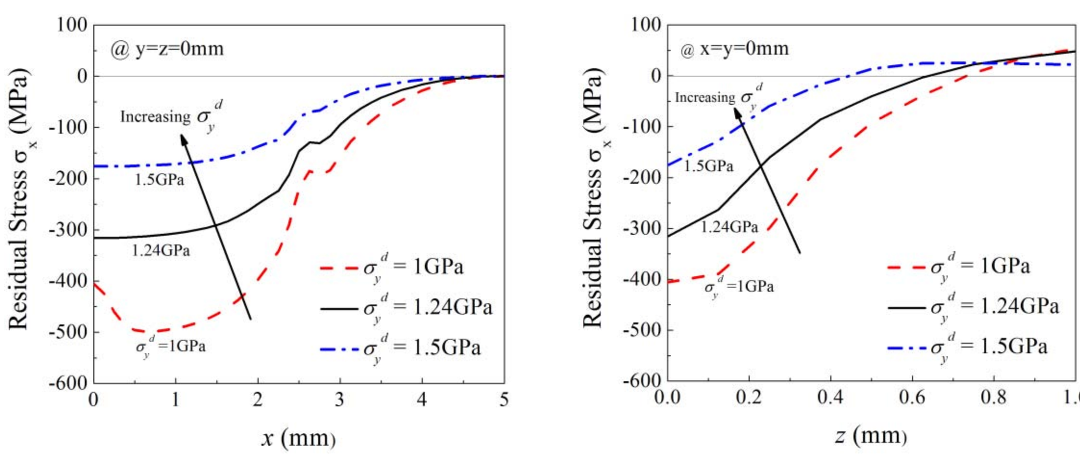
(a) (b)

Figure 6 : Effect of the mesh size on simulated residual stress profiles



(a) (b)

Figure 7 : Effect of the solution time for dynamic analysis on simulated dynamic stress profiles



(a) (b)

Figure 8 : Effect of the dynamic yield strength on simulated residual stress profiles

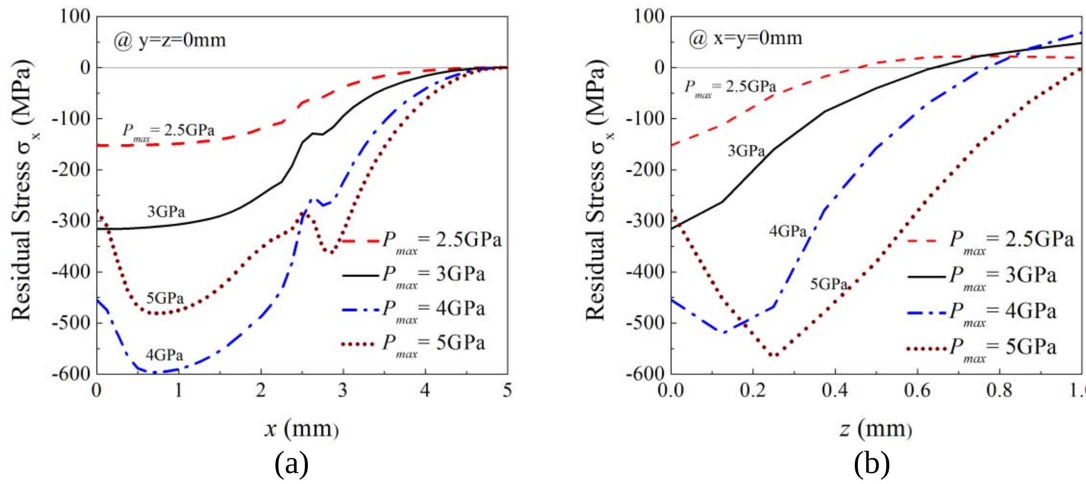


Figure 9 : Effect of the peak pressure on simulated residual stress profiles

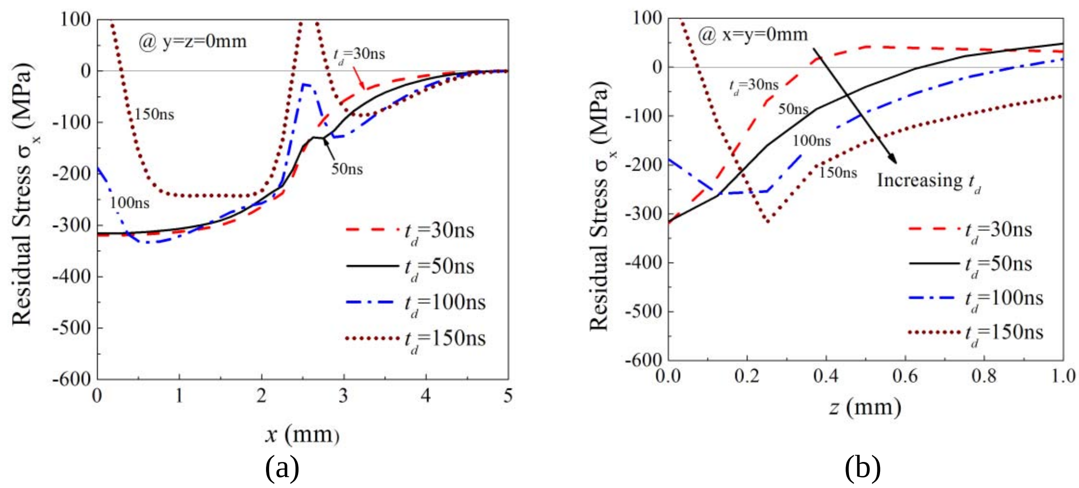


Figure 10 : Effect of the pressure durations on simulated residual stress profiles

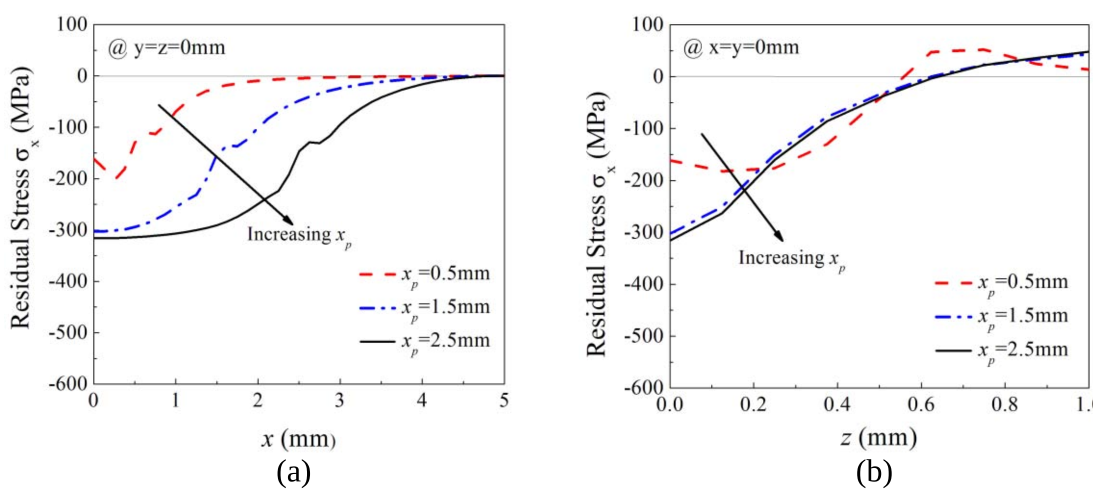


Figure 11 : Effect of the laser spot size on simulated residual stress profiles

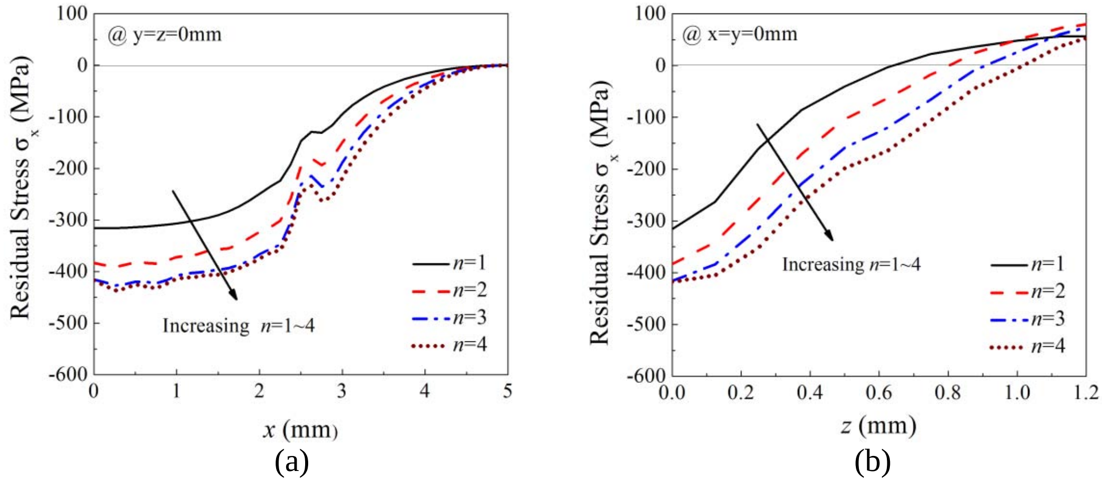


Figure 12 : Effect of the multiple laser impacts on simulated residual stress profiles

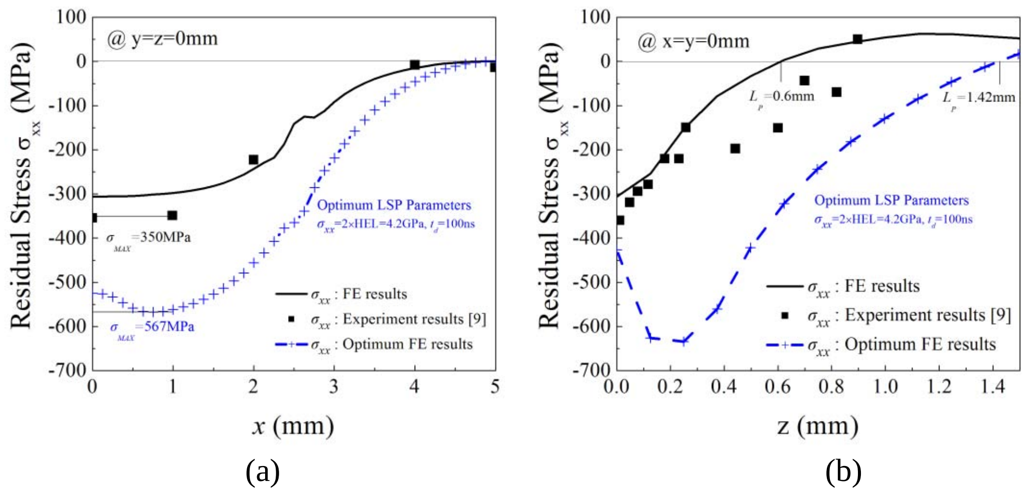


Figure 13 : Comparison of the Fe and experimental results with FE simulated results by optimum LSP parameters

Table 1 : Mechanical properties of the 35CD4 50HRC steel alloy [1]

ρ (kg/m^3)	ν	E (GPa)	σ_y^d (GPa)	HEL (GPa)
7800	0.29	210	1.24	2.1

Table 2 : Parameters and their ranges for sensitivity analysis

Parameter	Ref.	Ranges
Mesh size, L_e (mm)	**0.125**	0.25-0.1
Solution time for dynamic analysis, t_p (ns)	**5,000**	500-5,000
Dynamic yield strength, σ_y^d (GPa)	**1.24**	1-1.5
Maximum pressure, P_{max} (GPa)	**3**	2.5-5
Pressure pulse duration, t_d (ns)	**50**	30-150
Laser spot size, x_p (mm)	**2.5**	0.5-2.5
Number of shots, n (shot)	**1**	1-4

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Failure Analysis of a Universal Coupling using Finite Element Method

By Muhammad Ziaur Rahman, Debasish Adhikary & Tazmin Rashid Mumu
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Abstract- Generation of stress, displacement and strain in a universal coupling has been analyzed. Circumferential stress is applied at the yoke slot and also on the hub and simulated separately. The simulation is carried out with the help of SolidWorks 2010. To show the effect of temperature rise due to friction at the yoke slot, thermal load is gradually increased at the slot. The results are demonstrated both in the form of surface contour and graph. It has been showed that friction between yoke slot and hub can increase the temperature, which can eventually increase the thermal stress paving the way to failure of yoke or hub material. It is also found that the hub experiences a larger stress compared to the yoke when loaded under same pressure. Thus, the hub has the higher probability to fail than the yoke. At the end of the paper, some recommendations regarding universal coupling building material and reduction of friction have been made. Finally, the results obtained here are highly accurate and conform to the physical and loading conditions.

Keywords: universal coupling, finite element analysis, solidworks, stress, strain, displacement.

GJRE-A Classification : FOR Code: 091399p

FAILUREANALYSISOFAUNIVERSALCOUPLINGUSINGFINITEELEMENTMETHOD

Strictly as per the compliance and regulations of :

Failure Analysis of a Universal Coupling using Finite Element Method

Muhammad Ziaur Rahman [α], Debasish Adhikary [σ] & Tazmin Rashid Mumu [ρ]

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Keywords: universal coupling, finite element analysis, solidworks, stress, strain, displacement.

I. Introduction

Universal coupling is commonly used in rotating shaft that transmits rotary motion. It is a specialized rotary joint used to allow a rotating split shaft to deflect along its axis in any direction. This flexibility is achieved by constructing the joint with two U-shaped yokes (coupler) joined by a cross shaped hub (pin). One yoke is attached to the end of each portion of the split shaft and joined with the cross hub, with the U-sections oriented at 90°to each other. This arrangement allows the horizontal primary shaft to drive the inclined shaft with no undue friction or loss of speed or drive output potential. Typical applications of universal coupling include aircraft appliances, control mechanisms, electronics, instrumentation, medical and optical devices, ordnance, radio, sewing machines, textile machinery and tool drives. Fig. 1 shows a commercially available universal coupling and Fig. 2 shows CAD design of a coupling.

There are some available literature on universal coupling[3]. The novelty of the present literature is that it gives emphasis on yoke and hub separately. The main stress zone of a coupling is the yoke slot-hub interface and the hub corners. In the yoke slot-hub interface, the stress acts is circumferential. At the same time, friction at the interface generates heat. This heat generates thermal stress. So during the operation of a coupling, mainly two types of stresses works, namely circumferential stress and thermal stress. During our investigation, we applied circumferential stress at the yoke slot-hub interface to see how it affects the stress propagation in both the yoke and the hub. In addition, we applied thermal stress and increased it gradually to show how it influences generation of stresses. To show the strain rate and the displacement in the yoke, the strain contour and the displacement contour are also plotted. The simulation was carried out in SolidWorks 2010, the validity and acceptability of which is well established.

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Figure 1 : Commercially available universal coupling

Figure 2 : CAD design of a universal coupling

II. Solution Procedure

a) Formulation of the Problem

The equation of motion relating the two angular positions of the two yokes is given by,

$\tan \Upsilon_1 = \cos\beta \tan \Upsilon_2$

where, Υ_1 = angle of rotation of yoke 1

Υ_2 = angle of rotation of yoke 2

β = the angle of the yokes with respect to each other

The angles Υ_1 and Υ_2 in a rotating joint will be function of time. Differentiating the equation of motion with respect to time and using the equation of motion itself to eliminate a variable yields the relationship between the angular velocities $\omega_1 = d\Upsilon_1/dt$ and $\omega_2 = d\Upsilon_2/dt$

$$\omega_2 = \omega_1 \cos\beta/(1-\sin^2\beta\cos^2\Upsilon_1)$$

The angular velocities are not linearly related but rather are periodic with a period twice that of the rotating shafts. The angular velocity relation can again be differentiated to get the relation between the angular acceleration α_1 and α_2,

$$\alpha_2 = \alpha_1 \cos\beta/(1-\sin^2\beta\cos^2\Upsilon_1) - (\omega_1^2\cos\beta\sin^2\beta\sin 2\Upsilon_1)/(1-\sin^2\beta\cos^2\Upsilon_1)^2$$

b) *Solution Methodology*

The CAD drawing is carried out in SolidWorks 2010. At first yoke, hub and disc are drawn in part drawing option separately. Then these three things are assembled in assembly drawing option. The main parameters used during the drawing are given below.

Parameter	Dimension (mm)
Yoke base radius	100
Disc radius	100
Yoke base thickness	50
Yoke slot radius	25
Hub ends distance	200

The simulation too is carried out in SolidWorks 2010. The main parameters and variables used during simulation are given below.

Parameter	Type/Value
Simulation	Static
Fixture used	Fixed geometry
External load	Circumferential (1 MPa)
Mesh type	Solid mesh
No. of elements (hub)	7783
No. of elements (yoke)	7314
No. of nodes (hub)	12125
No. of nodes (yoke)	12059

Fig. 3 shows SolidWorks drawing of yoke, hub and disc before being assembled. Fig. 4 shows different parts of the yoke and the hub.

The main features used during drawing are extrude, extrude cut, mirror and mate. For simplicity, details description of the drawing has been avoided.

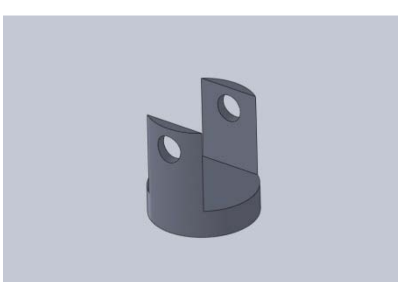

Figure 3(a) : Yoke of a universal coupling

III. Results and Discussion

In our specimen, the material considered is Al 1060 alloy. Modulus of elasticity of the material is E=69 GPa and Poisson's ratio is ν =0.33. The simulation has been carried out in room temperature, which is considered to be 25 °C. To find out the most critical condition in terms of stress and strain, the clearance between the hub and the slot of yoke is kept zero.

Fig. 5 shows the generation of strain across the yoke. It is found to be maximum along the edge of the yoke extension. Besides there is also an abrupt rise of strain at the extension-base intersection. The maximum value of strain is found to be 6.2×10^{-5} and the minimum value is found to be 1.93×10^{-8}. The value of strain around the slot is found to be almost 3×10^{-5}.

Fig. 6 is a demonstration of displacement, takes place during the operation of a universal coupling. The displacement is found to be maximum at the free end of the yoke extension. It is in conformity with the physical condition because the extension works as a cantilever and a cantilever with a load at the free end displays maximum displacement at that end. On the other hand the displacement is negligible at the base. It is also valid because the base is considered to be rigidly fixed. The maximum value of the displacement is found to be almost 0.02mm.

Fig. 7 shows the demonstration of von Mises stress generated in the yoke. Like the generation of strain, maximum stress is found along the edge and at the extension-base intersection of the yoke. The maximum value is found to be 6.03 MPa and the minimum value is found to be almost 0.00099 MPa. Stress around the slot is about 3 MPa, which is half of the maximum stress. So in terms of von Misesstress, the most critical zone of a yoke is the base-extension intersection and the edge of the yoke extension having the maximum probability to fail. But under the given load at room temperature, the yoke would not fail because the maximum stress is 6.03 MPa which is much smaller than the yield strength of Al 1060 alloy, which again is 27.57 MPa.

Fig. 8 shows relationship between temperature at the slot of the yoke and generation of maximum stress in the yoke. With increase of temperature in the slot surface, stress increases across the yoke. The relationship is linear in nature. That means the more friction between the hub and the slot of the yoke, the more temperature rise will be, hence the more stress generation will be. The friction can be reduced significantly using bearing and lubricant. From the figure it is evident that under given loading and restrained condition, the yoke material will fail if the operating as well as yoke temperature rises as much as 315K (42 ^{0}C).

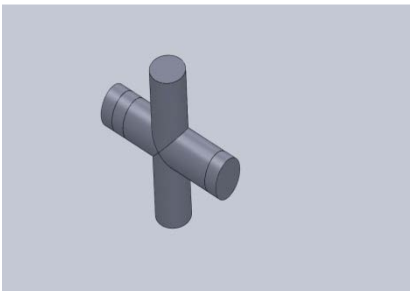

Figure 3(b): Hub of a universal coupling

Figure 3(c) : Disc of a universal coupling

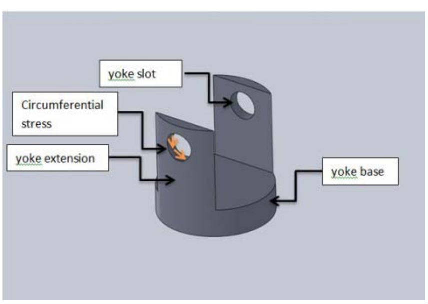

Figure 4(a) : Different parts of a yoke

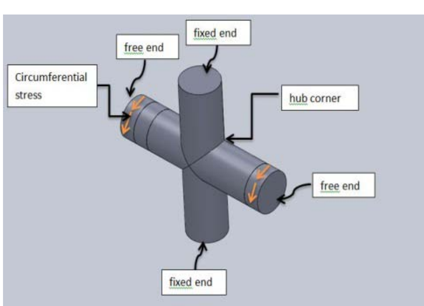

Figure 4(b) : Different parts of a hub

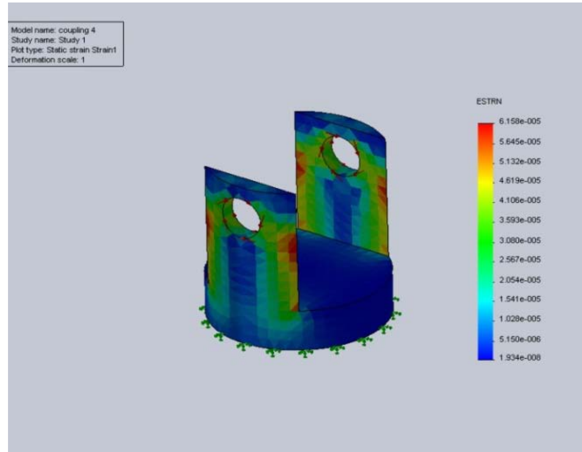

Figure 5 : Strain plot of yoke

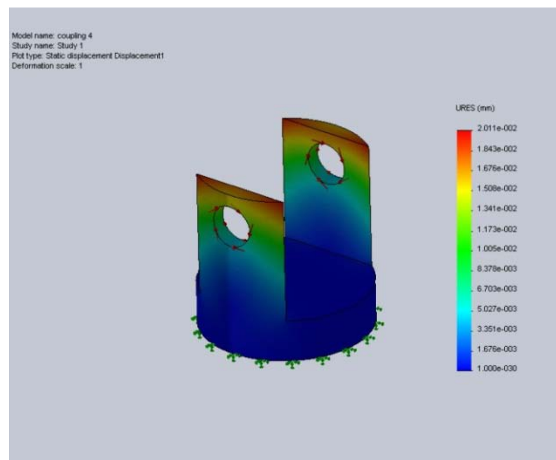

Figure 6 : Displacement plot of yoke

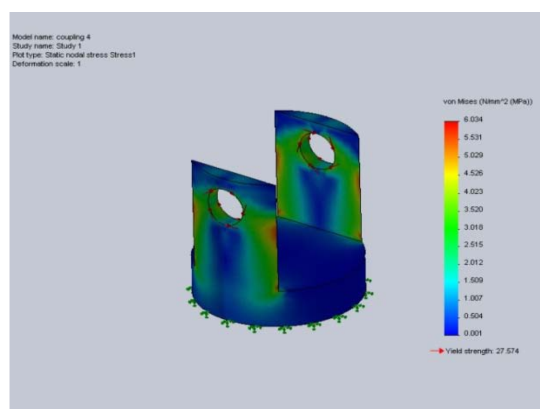

Figure 7 : Stress plot of yoke

Fig. 9 is a demonstration of relationship between strain rate and temperature. With the increase of temperature, as usual strain increases. The relationship is linear.

In Fig. 10, a relationship between temperature rise and displacement in the yoke has been showed. The relationship is not linear. The displacement at temperature 300K and 305K is almost the same, then there is an abrupt rise in displacement. The relationship is linear in the temperature range between 305K and 320K.

Fig. 11 shows the distribution of von Mises stress in the hub. At the two free ends of the hub, circumferential pressure is applied at the slot-hub interface. The other two ends are assumed to be fixed. From the figure it is evident that, for the same loading condition as like in the yoke, generation of

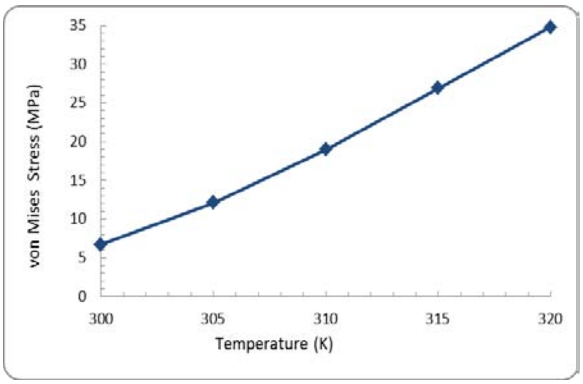

Figure 8 : Stress- Temperature relation(load constant)

stress in the hub is larger. In case of yoke, the maximum stress generation is 6.03 MPa, where as in case of hub it is 7.577 MPa, which is about 20.4% larger than the previous one. That means between the yoke and the hub, the hub will fail first, provided that both of them are facing same loading conditions. The extreme failure regions are found at the corners of the hub.

IV. Conclusions

Stress and strain generated in a universal coupling is discussed elaborately. Attention is mainly given to the yoke slot and the hub because they are the main frictional zones. Effect of thermal stress has also been demonstrated in case of the yoke. It is showed that friction can cause significant thermal effect which eventually can increase the stress intensity of the yoke. For example, if the temperature at the slot of the yoke increases up to 315K (42°C), the material may yield, because the generated stress will cross the yield strength of Al 1060 alloy.

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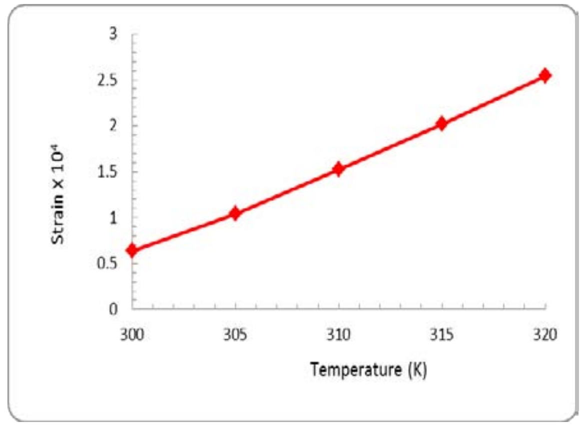

Figure 9 : Strain-Temperature relation (load constant)

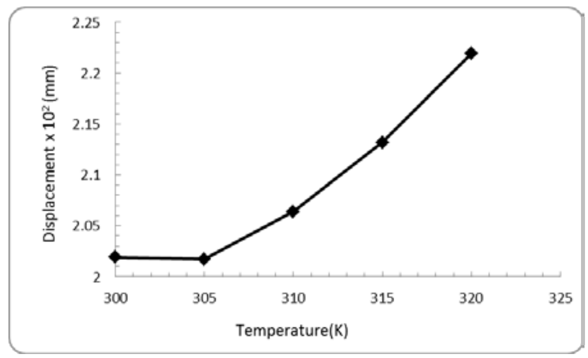

Figure 10 : Displacement-Temperature relation (load constant)

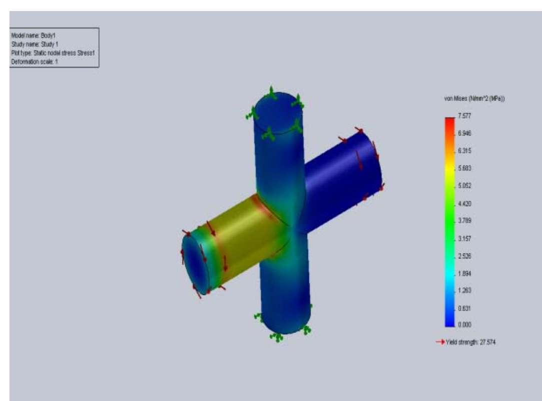

Figure 11 : Stress plot in the hub

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Experimental Investigation & Analysis of Wear Parameters on Al/Sic/Gr - Metal Matrix Hybrid Composite by Taguchi Method

By Rachit Marwaha, Mr. Rahul Dev Gupta, Dr. Vivek Jain & Er. Krishan Kant Sharma
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Abstract- Metal matrix hybrid composites (MMHCs) are now gaining their usage in aerospace, automotive and other industries because of their inherent properties like high strength to weight ratio, hardness and wear resistance, good creep behaviour, light weight, design flexibility and low wear rate etc. Al alloy base matrix reinforced with silicon carbide (10%) and graphite (5%) particles was fabricated by stir casting process. The wear and frictional properties of metal matrix hybrid composites were studied by performing dry sliding wear test using pin on disc wear test apparatus. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. A L9 Orthogonal array was selected for analysis of data. Investigation to find the influence of applied load, sliding speed and track diameter on wear rate as well as coefficient of friction during wearing process was carried out using ANOVA. Objective of the model was chosen as smaller the better characteristics to analyse the dry sliding wear resistance. Results show that track diameter has highest influence followed by load and sliding speed.

Keywords: taguchi method, orthogonal array, ANOVA, metal matrix hybrid composites.

GJRE-A Classification : FOR Code: 091399

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Rachit Marwaha [α], Mr. Rahul Dev Gupta [σ], Dr. Vivek Jain [ρ] & Er. Krishan Kant Sharma [ω]

Abstract- Metal matrix hybrid composites (MMHCs) are now gaining their usage in aerospace, automotive and other industries because of their inherent properties like high strength to weight ratio, hardness and wear resistance, good creep behaviour, light weight, design flexibility and low wear rate etc. Al alloy base matrix reinforced with silicon carbide (10%) and graphite (5%) particles was fabricated by stir casting process. The wear and frictional properties of metal matrix hybrid composites were studied by performing dry sliding wear test using pin on disc wear test apparatus. Experiments were conducted based on the plan of experiments generated through Taguchi's technique. A L9 Orthogonal array was selected for analysis of data. Investigation to find the influence of applied load, sliding speed and track diameter on wear rate as well as coefficient of friction during wearing process was carried out using ANOVA. Objective of the model was chosen as smaller the better characteristics to analyse the dry sliding wear resistance. Results show that track diameter has highest influence followed by load and sliding speed.

Keywords: taguchi method, orthogonal array, ANOVA, metal matrix hybrid composites.

I. Introduction

Composite materials to meet the global demand for light weight, high performance, environmental friendly, wear and corrosion resistant materials. Metallurgists from aerospace, defence and nuclear industries have developed a large range of super alloys and heat resistant materials like ceramics and composite materials. Metal matrix composites (MMC) are suitable for applications requiring combined strength, thermal conductivity, damping properties. These properties of MMC enhance their usage in automotive and tribological applications. MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. The matrix is the monolithic material into which the reinforcement is embedded and is completely continuous e.g. metallic, ceramic and polymer. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications the matrix is usually a lighter metal such as aluminium, magnesium or titanium and provides a compliant support for the reinforcement example of metallic matrix. Aluminium alloys are widely used in the automotive industry because of their high strength to weight ratio as well as high thermal conductivity. It is used particularly in automobile engines as cylinder liners as well as other rotating and reciprocating parts such as the piston, drive shafts and brake rotors and in other applications in automotive and aerospace industries.

Aluminium matrix composites (AMCs) refer to the class of light weight high performance aluminium centric material systems. The reinforcement in AMCs could be in the form of continuous/discontinuous fibres, whisker or particulates, in volume fractions ranging from a few percent to 70%. Properties of AMCs can be tailored to the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing route.

When at least three materials are present, it is called a hybrid composite. Al/SiC/Gr-MMHC is one of the important hybrids composite among MMC, which have SiC & Gr particles with Aluminum matrix. The SiC is harder than Tungsten carbide (WC) and Graphite particles provide high resistance to wear in the hybrid composite.

Ceramic particles such as SiC are commonly added as a second reinforcement material in MMC hybrid composite to an increase in wear resistance, elastic modulus; and decrease in the thermal expansion coefficient for contact sliding application, i.e. brake disk rotors.

The hybrid metal matrix composite like Al/SiC/Gr MMC is one of the composites which have many unique properties over Al/SiC-MMC or Al/Gr-MMC. The wear resistance of Al/SiC/Gr composites increases with the increase of the graphite particle size. The improvement of wear resistance id due to the enhancement of lubrication tribo-layer composed of a chemical mixture of graphite as well as SiC particles and some fine particles containing aluminium.

A pin on disc wear test apparatus consists of a stationary pin under an applied load in contact with a

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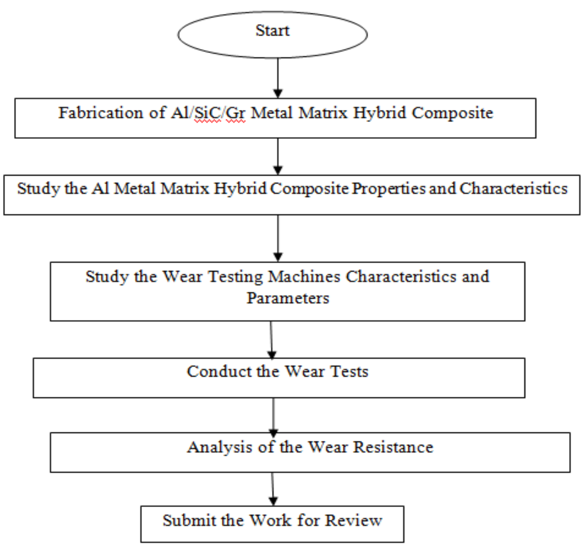
rotating disc. The pin can have any shape to simulate a specific contact, but in this set up square pins are used for experimentation. The pin on disc measures the friction and sliding wear properties of dry surfaces of a variety of bulk materials and coatings. The pin on disc tester consists of a rotating disc of the material to be tested against a stationary pin, usually made of the specimen to be tested, referred to as the pin. The rotational speed, normal load and the duration of time interval are the parameters set for test.

II. Experimental Procedure

Stir casting technique has been used to prepare the work-piece samples. These work-piece samples Al/SiC/Gr- Metal Matrix Hybrid Composite have been utilized for testing on wear and corrosion testing machine.

The two muffle furnaces were used for preparing Al/SiC/Gr Hybrid MMC for experimentations by stir casting.

Experiments conducted on the basis of the initial chosen parameters and at random parameters setting for both the tests. The phasing of research work is represented by following flow chart:-



The melting of matrix material aluminium was carried in a muffle furnace in a range of 760 ± 100C. The crucible material was graphite. A view of the furnaces has been shown in Figure 2.1 below:

Figure 2.1 : Muffle Furnace used for Fabrication of Hybrid Composite

Scraps of aluminium were preheated up to a temperature of 4500C in muffle furnace before melting and mixing Silicon Carbide (SiC) and Graphite (Gr). Particles of Silicon Carbide (SiC) and Graphite (Gr) were also preheated up to a temperature of 11000C in second muffle furnace for 2-3 hours. Crucible used for pouring of composite slurry in the mould was also heated up to 760 0C to make their surfaces oxidized.

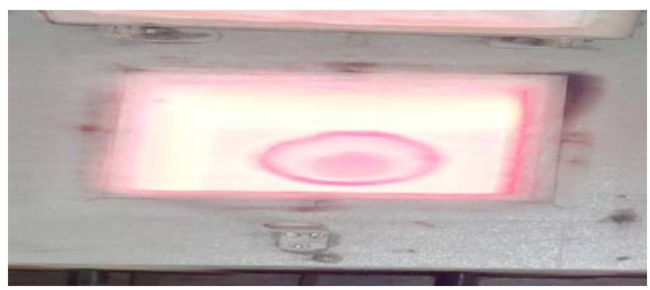


Figure 2.2 : Preheating of Aluminium Scrap

Figure 2.3 : Preheted Mixer of SiC and Graphite Powder

The furnace temperature was first raised above the liquidus to melt the alloy scraps completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated Silicon Carbide (SiC) and Graphite (Gr) particles were added and mixed manually.

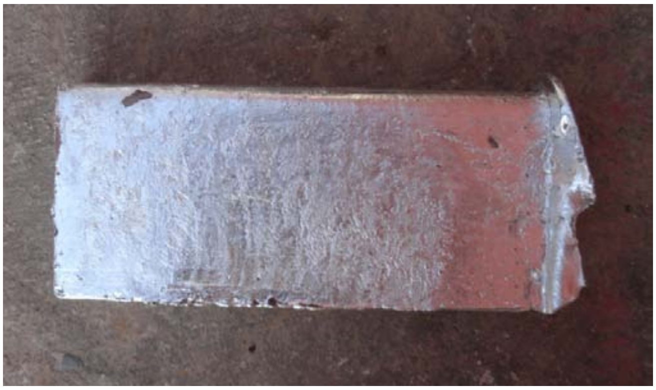


Figure 2.4 : Prepared Al/SiC/Gr MMHC

III. Wear Test

A pin on disc wear test apparatus consists of a stationary "pin" under an applied load in contact with a rotating disc. The pin can have any shape to simulate a specific contact, but spherical tips are often used to simplify the contact geometry. The pin on disc tester measures the friction and sliding wear properties of dry or lubricated surfaces of a variety of bulk materials and coatings. The pin on disc tester consists of a rotating disc of the material to be tested against a stationary sphere, usually made of cemented carbide, referred to as the pin. Although the pin surface can also be wear and friction tested. The normal load, rotational speed, and the wear track diameter are all to be set by the user prior to the pin on disc test.

Figure 3.1 : Pin on Disc Machine for Wear Test Al/SiC/Gr MMHC

In the experimentation, the specimens to be tested are taken in the form of a pin and are allowed to slide against a heat treated steel disc. For dry sliding wear test the disc is rotated in varying speed and applied the different load on pin based, and varying sliding distance on Taguchi design of experiments showing in Table 3.1 below. The wear rate is calculated from weight loss measurements taken by weight balance machine (with accuracy 0.01mg) after sliding. Specimens are cleaned by acetone.

Table 3.1 : Parameters and Their Levels for Wear Test of Al/SiC/Gr MMHC

Sr. No	Input Parameters	Levels		
1	Load	50	100	150
2	Sliding Speed (rpm)	500	1000	1500
3	Track Diameter (mm)	50	75	100

The analysis was done on the basis of L^9 (3^3) orthogonal array for wear rate which is shown in Table 3.2. Here, different parameters of load, sliding speed and track diameter are taken into consideration.

Finally, the weight loss due to wearing of the pin i.e. the difference between the final and the initial weight was measured on the Digital Analytical Weight measuring machine.

Table 3.2 : L^9 (3^3) Orthogonal Array for Wear Test

Experiment No.	Parameters and their Levels		
	Load (N)	Speed (rpm)	Track diameter (mm)
1	50	500	50
2	50	1000	75
3	50	1500	100
4	100	500	75
5	100	1000	100
6	100	1500	50
7	150	500	100
8	150	1000	50
9	150	1500	75

And wear rate was calculated and analysis was done with the help of Taguchi method.

IV. Results and Discussions

The aim of the experimental plan is to find the important factors and combination of factors influencing the wear process to achieve the minimum wear rate. The experiments were developed based on an orthogonal array, with the aim of relating the influence sliding speed (rpm), load (N) and track diameter (mm) for the wear test. Taguchi recommends analyzing the S/N ratio using conceptual approach that involves graphing the effects and visually identifying the significant factors.

Table 4.1 : Weight loss observation during Wear Test

Sr. No.	Weight of the material before testing (gms)	Weight of the material after testing (gms)	Weight loss(gms)
1.	17.05	16.86	0.19
2.	17.93	17.70	0.23

3.	17.68	17.45	0.23
4.	17.65	17.43	0.22
5.	17.98	17.74	0.24
6.	17.36	17.09	0.27
7.	17.82	17.51	0.31
8.	17.87	17.62	0.25
9.	17.98	17.71	0.27
10.	17.10	16.92	0.18
11.	18.02	17.76	0.26
12.	17.92	17.63	0.29
13.	17.85	17.54	0.31
14.	17.74	17.39	0.35
15.	17.56	19.38	0.18
16.	18.12	17.66	0.46
17.	17.72	17.45	0.27
18.	17.58	17.24	0.34
19.	17.25	17.06	0.19
20.	18.33	18.05	0.28
21.	17.78	17.45	0.33
22.	17.55	17.20	0.35
23.	18.18	17.79	0.39
24.	17.66	17.43	0.23
25.	17.52	17.03	0.49
26.	18.07	17.79	0.28
27.	17.80	17.39	0.41

The Table 4.1 shows the Experimental results for coefficient of friction. In this table the μ_1, μ_2, μ_3 shows the value of coefficient of friction. These values of coefficient of friction come from pin on disc apparatus.

Table 4.2 : Mean value and S/N Ratio for Coefficient of Friction

Exp. No.	Load (N)	Speed (rpm)	Track diameter (mm)	Coefficient of friction μ_1	Coefficient of friction μ_2	Coefficient of friction μ_3	S/N ratio	MEAN
1.	50	500	50	0.52	0.65	0.88	3.106023	0.683333
2.	50	1000	75	0.37	0.6	0.51	5.980254	0.493333
3.	50	1500	100	0.81	0.31	0.46	4.931343	0.526667
4.	100	500	75	0.71	0.31	0.24	6.590274	0.42
5.	100	1000	100	0.71	0.4	0.24	6.187645	0.45
6.	100	1500	50	0.76	0.76	0.64	2.826624	0.72
7.	150	500	100	0.65	0.19	0.21	7.758124	0.35
8.	150	1000	50	0.74	0.56	0.48	4.390577	0.593333
9.	150	1500	75	0.75	0.27	0.22	6.421922	0.413333

The Table 4.2 shows the analysis of variance (ANOVA) results for the coefficient of friction for three factors varied at three levels.This analysis is carried out for a confidence level of 95%.Sources with a P-value less than 0.05 were condsidered to have a statitstically significant contribution to the performance measures.In table 4.3 and 4.4 the last column shows the percentage contribution (Pr) of each parameter.

It can be observed from the Table 4.3, that the track diameter has the highest influence (74.62%) on coefficient of friction. Hence track diameter is an important factor to be taken into consideration

Table 4.3 : Analysis of variance for S/N Ratio

Source	DF	Seq SS	Adj SS	Adj MS	F ratio	P	Pr (%) Contribution
Load	2	3.5606	3.5606	1.78032	27.01	0.036	16.12
Speed	2	1.9092	1.9092	0.95461	14.48	0.065	8.64
Track Diameter	2	16.4820	16.4820	8.24099	125.04	0.008	74.62
Error	2	0.1318	0.1318	0.06591			0.62
Total	8	22.0836					100

during wear process followed by applied load(16.12%) and sliding speed (8.64%).

The Table 4.4 shows the analysis of variance (ANOVA) results for the coefficient of friction for three factors varied at three levels. This analysis is carried out for a confidence level of 95%.Sources with a P-value less than 0.05 were condsidered to have a statitstically significant contribution to the performance measures. In table 4.4 the last column shows the percentage contribution (Pr) of each parameter.

It can be observed from the table 4.4, that the track diameter has the highest influence (78.00%) on coefficient of friction.

Table 4.4 : Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F ratio	P	Pr (%) Contribution
Load	2	0.020830	0.020830	0.010415	216.31	0.005	16.28
Speed	2	0.007207	0.007207	0.003604	74.85	0.013	5.63
Track Diameter	2	0.099756	0.099756	0.049878	1035.92	0.001	78.00
Error	2	0.000096	0.000096	0.000048			0.090

Hence track diameter is an important factor to be taken into consideration during wear process followed by applied load (16.28%) and sliding speed (5.63%).From the analysis of variance and S/N ratio, it is inferred that the track diameter has highest contribution on cofficient of friction followed by load and sliding speed.

The coefficient of friction is decreases with increase in load & the coefficient of friction is increases with increase in sliding speed & for track diameter first the coefficient of friction is decreases by increasing the track diameter from 50 to 75 mm and after that when the track diameter further increases from 75 to 100 mm the coefficient of friction remains constant.

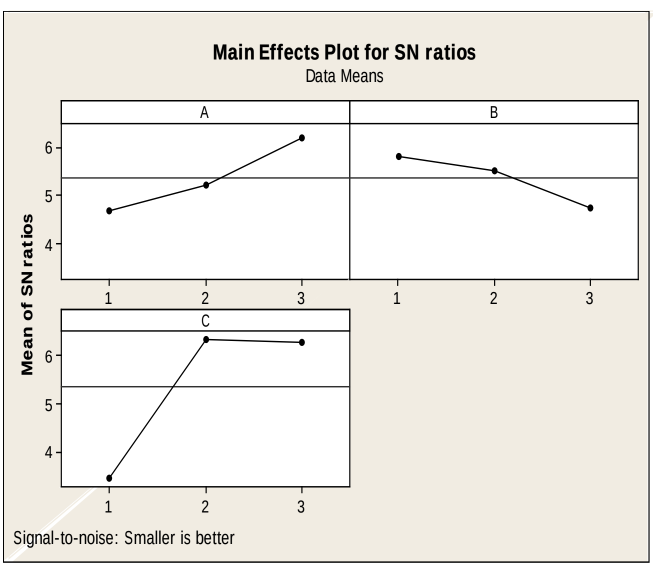


Figure 4.1 : Main Effects Plot for S/N ratios – Coefficient of friction

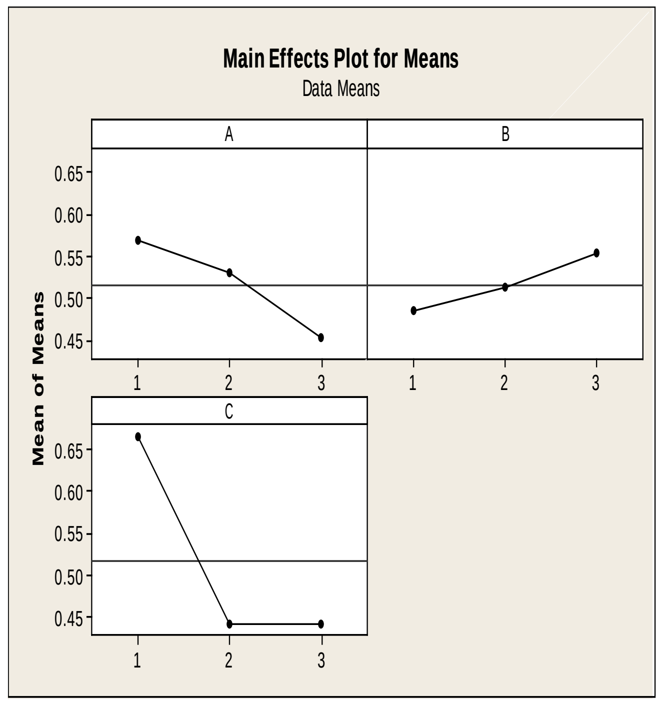


Figure 4.2 : Main Effects Plot for Means– Coefficient of friction

Table 4.5 shows the ranking of wear parameters for optimizing the coefficient of friction. It can be observed that track diameter has the largest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC.

Table 4.5 : Response Table for Signal to Noise Ratios-Smaller is better (coefficient of friction)

Level	Load	Speed	Track Diameter
1	4.673	5.818	3.441
2	5.202	5.519	6.331
3	6.190	4.727	6.292
Delta	1.518	1.092	2.890
Rank	2	3	1

The speed has the smallest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC.

Table 4.6 : Response Table for Means- Smaller is better (Coefficient of friction)

Level	Load	Speed	Track Diameter
1	0.5678	0.4844	0.6656
2	0.5300	0.5122	0.4422
3	0.4522	0.5533	0.4422
Delta	0.1156	0.0689	0.2233
Rank	2	3	1

Table 4.6 shows the ranking of wear parameters for optimizing the coefficient of friction. It can be observed that track diameter has the largest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC. The speed has the smallest effect on the coefficient of friction of Al/SiC/Gr Hybrid MMC.

V. CONFIRMATION EXPERIMENT

The optimal values of the response characteristics (coefficient of friction & weight loss) along with their respective confidence intervals have been predicted. The results of confirmation experiments are also presented to validate the optimal results. The optimal levels of the process parameters for the selected response characteristics have already been identified. The optimal value of each response characteristic is predicted considering the effect of the significant parameters only. The average values of the response characteristics obtained through the confirmation experiments must lie within the 95% confidence interval.

a) Coefficient of Friction

The optimum value of CF is predicted at the optimal levels of significant variables which have already been selected as load (A3), speed (B1) and track diameter (C2)

The estimated mean of the response characteristic (CF) can be determined as

$$\mu_{CF} = A_3 + B_1 + C_2 - 2T$$

T = overall mean of coefficient of friction= $(\mu_1+\mu_2+\mu_3)/27$ = 0.516

Where μ_1, μ_2 and μ_3 values of A_3, B_1 and C_2 are taken from Table 4.1 & 4.2:

A_3 = average value of surface roughness at the third level = 0.4522

B_1= average value of surface roughness at the first level = 0.4844

C_2= average value of surface roughness at the second level = 0.4422

Substituting the values of various terms in the above equation,

μ_{CF} = 0.4522 + 0.4844 + 0.4422 -2 (0.516) = 0.3468

The 95 % confidence intervals of confirmation experiments (CICF) are calculated by using the Equations:

$$CI_{CE} = \sqrt{F_\alpha(1, f_e)V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

Where, Fa (1, fe) = The F ratio at the confidence level of (1-a) against DOF 1 and error degree of freedom

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean response}]} = 27 / (1+6) = 3.857$$

N = Total number of results = 9 x 3 = 27
R = Sample size for confirmation experiments = 3
V_e = Error variance = 0.000048 (Table 4.4)
fe = error DOF = 2 (Table 4.4)

$F_{0.05}$ (1,2) = 18.5 (Tabulated F value;)
So, CI_{CF} = ± 0.0229, and

Therefore, the predicted 95 % confidence interval for confirmation experiments is:

Mean μ_{CF} - CICF < μ CF< Mean μ CF + CICF 0.3239 < μ CF < 0.3697

The optimal values of process variables at their So, CI_{CF} = ± 0.0613, and selected levels are as follows:

Third level of load (A_3): 150 N
First level of Speed (B_1): 500 r.p.m
Second level of track diameter (C_2): 75 mm

Therefore, the predicted 95 % confidence interval for confirmation experiments is:

$$\text{Mean } \mu_{WL} - \text{CIWL} < \mu \text{ WL} < \text{Mean } \mu \text{ WL} + \text{CIWL } 0.1132 < \mu \text{ WL} < 0.2358$$

The optimal values of process variables at their selected levels are as follows:

Third level of load (A_1): 50 N

First level of Speed (B_2): 1000 r.p.m

Second level of track diameter (C_1): 50 mm

Table 5.1 : Predicted and Confirmation Experiments Results of Single Response Optimization at Optimal Setting

Performance Measures/ Responses	Optimal Set of Parameters	Predicted Optimal Value	Predicted Confidence Interval at 95% Confidence Level	Experimental Value	Percentage (%) Error
Coefficient of friction	A3 , B_1 and C_2	0.3468	$0.3239 < \mu$ CF < 0.3697	0.3386	2.36

Table 5.1 shows the Predicted and Confirmation Experiments Results of Single Response Optimization at Optimal Setting. The table shows the predicted optimal value, experimental value.

The experimental value shows that the value lies within the range of predicted confidence interval at 95% confidence level. The table also shows the percentage (%) error. The percentage (%) error should be less than 10%. The result shows that the (%) error is less than 10%.

VI. Conclusions and Future Scope

In present work, experimental investigation of Wear Rate of Al/SiC/Gr Hybrid MMC components was carried out. A total of twenty seven (27) experiments were carried out to identify the Wear Rate and to suggest optimized parametric value for minimize Wear Rate. Following are the conclusions drawn from the study on wear test using Taguchi's technique.

a) Conclusions of Wear Test

The lowest coefficient of friction observed at applied load 150N, 500 rpm sliding speed and 75 mm track diameter. The highest wear rate is observed at applied load 50 N, 1500 rpm sliding speed and 50 mm track diameter.

It can be observed that track diameter (78%) has highest influence on coefficient of friction followed by sliding speed (5.63%) & applied load (16.28%) and for weight loss also the contribution of track diameter is (59.50%) and applied load is (38.55%) for Al/Sic/Gr MMHC.

It is concluded that combinations for minimum coefficient of friction is $L_3S_1TD_2$ i.e. 150N load, 500 rpm sliding speed, and 75 mm track diameters.

b) Future Scope

The present investigation was done on Al/SiC/Gr hybrid MMC with 10% SiC and 5% Gr, for further investigations, variation in the percentage of SiC and Gr can be used for experimentation.

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CAD Program for Design of Metal Bellows

By Do-Hoon Kim, Jin-Gun Park, Dong-Bum Kim, Jeong - O Kim, In-Hwan Lee & Hae-Yong Cho

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Abstract- Metal bellows is a precision component that is welded along the peripheries of both inside and outside diameters. A development of computer aided design program for the three kinds of welded metal bellows has been studied by Auto LISP language of AutoCAD in this thesis. In this study, this program is sequentially constructed dialog boxes, with which the expected shape of the metal bellows would be obtained quickly and exactly by input of the basic data that the initial radius, inner and outer diameters, pitch, thickness of plate and land length is given. The effects on stress distribution of the bellows can be estimated using a commercial FEM code of ANSYS Workbench when altering some design variables. As a result, this program studied in this paper revealed the advantages as follows, users can obtain the shape of the bellows more easily by input the variables or adding more information, moreover, this program can be revised simply by changing the variables according to the demands in industry and the drawing of metal bellows can be connected to other CAD programs for modeling and FEM analysis.

Keywords: metal bellows, autocad, autolisp, diaphrgm, ansys workbench, pro/engineer.

GJRE-A Classification : FOR Code: 091499

CADPROGRAMFORDESIGNOFMETALBELLOWS

Strictly as per the compliance and regulations of :

CAD Program for Design of Metal Bellows

Do-Hoon Kim [α], Jin-Gun Park [σ], Dong-Bum Kim [ρ], Jeong - O Kim [ω], In-Hwan Lee [¥] & Hae-Yong Cho [§]

Abstract- Metal bellows is a precision component that is welded along the peripheries of both inside and outside diameters. A development of computer aided design program for the three kinds of welded metal bellows has been studied by Auto LISP language of AutoCAD in this thesis. In this study, this program is sequentially constructed dialog boxes, with which the expected shape of the metal bellows would be obtained quickly and exactly by input of the basic data that the initial radius, inner and outer diameters, pitch, thickness of plate and land length is given. The effects on stress distribution of the bellows can be estimated using a commercial FEM code of ANSYS Workbench when altering some design variables. As a result, this program studied in this paper revealed the advantages as follows, users can obtain the shape of the bellows more easily by input the variables or adding more information, moreover, this program can be revised simply by changing the variables according to the demands in industry and the drawing of metal bellows can be connected to other CAD programs for modeling and FEM analysis

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- NOMENCLATURE

R_0 = external radius

L = the end length of upper plate

A = the end area of up total bellows

K = spring constant

δ = the maximum deformation

F_r = reflect of stress

N = the number of convolution

I. Introduction

Metal bellows is an elastic element that consists of very thin metal plate with ring ripple, it can absorb vibration in direction of axis and radius to avoid damaging system.[1,2] Welded metal bellows is a precision component welded along the peripheries of inside and outside diameters, therefore, it is more flexible and compressive than other bellows and widely used for connection pipes, protection device and heat abstractor for protecting system through itself deformed and absorbing vibration.[3]

Recently, the demands for the metal bellows are rapidly increasing. Welded metal bellows is not only used in general industry, such as automobile, Ships and pump, but also used in aircraft and other space field, in addition, the study of bellows is active in biological, such as artificial heart.[4,5] The need of domestic metal bellows is gradually increasing in production, but the design principle has not been established and it would waste of time to design different dimensions of metal bellows by using AutoCAD. So the auto program is needed by just entering some main data of the bellows by using the program of AutoLISP.

In this paper, in order to meet the demand for the automatic design, three kinds of welded metal bellows would be designed and the diaphragm of bellows would be developed by using AutoLISP in AutoCAD, finally, the designed bellows would be examined by using ANSYS Workbench program.

II. Background Theory

Metal bellows is consisted of many convolutions, one of which is very important because it determines the whole design of diaphragm and it is a precision component which is welded along the edge of peripheries both inside and outside diameters as shown in Fig. 1. Therefore, elastic[6,7] and plastic[8] theory is used as a foundation for the design of the bellows.

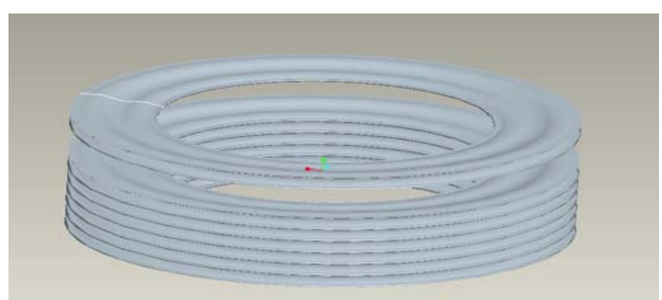

Figure 1 : The shape of bellows

a) The Basic Design Principle

The shape of bellows in this paper is more flexible than others because it consists of up and low thin plate. Although the principle of three waves of bellows has been confirmed, the inter side of bellows bears too large stress. In this paper, not only three waves bellows has been optimized, but also the shape of four and five waves bellows has also been developed.

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The design principle is based on workshop[9] and reference. The name of symbols is shown in Fig. 2(a), (b) and (c).

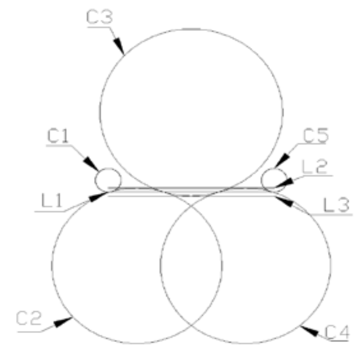

Figure 2(a) : Design principle of three waves bellows

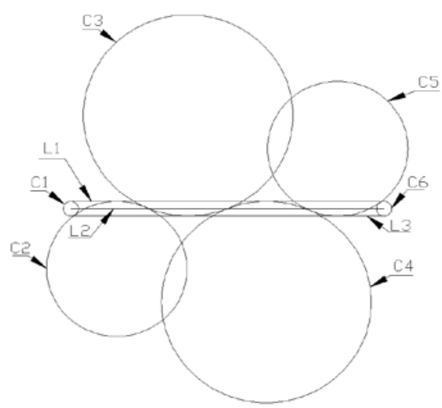

Figure 2(b) : Design principle of four waves bellows

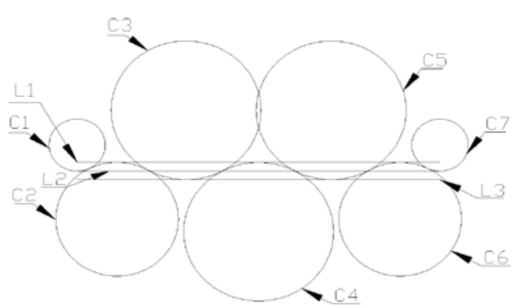

Figure 2(c) : Design principle of five waves bellows

b) *Constitution of CAD program*

The system is much effective and simple as shown in Fig. 3.

Loading the main program which is made up of three kinds of bellows that are three, four and five waves shapes. The main program was loaded in AutoCAD. There are three kinds of bellows which users can choose. Every window is a subroutine program. Users

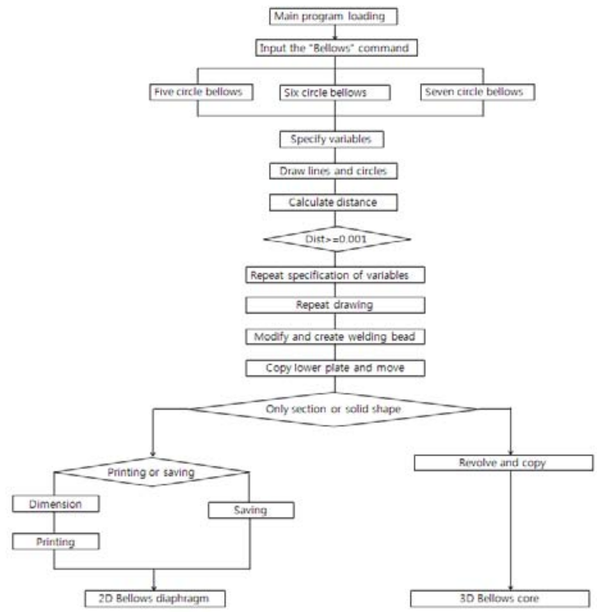

Figure 3 : The composition of program

can choose the 2D or 3D diaphragm to process. A dialog box will appear after choosing the type of bellows. Users can input initial radius, inside and outside diameter, thickness and straight distance to design program. Last, input data of the bellows, the program would automatically compute after inputting data of bellows. Users could choose saving or output after creating 2D drawing and click window to output drawings for other program to use or print it. The 3D shape of bellows would directly output without appearance using dialog box.

III. Design and Analysis Program

In this paper, the AutoCAD and Pro/ENGINEER program were needed to verify the bellows diaphragm. Finally, FEM program of ANSYS Workbench will be used to analyze it.

After running program, the shape of 2D bellows is shown in Fig. 2 and save it as the format of Dxf file in AutoCAD. Then insert 2D CAD file to 3D design program of Pro/ENGINEER. Create Modeling in Pro/ENGINEER and save it as Parasolid file which would be used in ANSYS Workbench. AutoLISP has a lot of functions with great computing ability. It loads from the file that was saved before, and then computing the data, and all of the commands are able to AutoCAD. Moreover, all institutions modeling can be achieved by using commands of AutoLISP language in AutoCAD and the auto program is developed by using AutoLISP language. The 3D shape of bellows also can be used for other programs or outputs. In this way it will help users more effectively.

IV. Design and Analysis Program

In this study, three kinds of welded metal bellows diaphragm were designed by using AutoLISP language in AutoCAD. The expected shape of bellows would be automatically obtained by just inputting the basic data of bellows. The analysis of deformation and stress is very difficult because the shape of bellows is complex. Therefore the deformation and stress is analyzed by using FEM program ANSYS Workbench.

In order to know how the various of initial radius, the diameters of both inside and outside, the pitch and thickness affect to the shape of bellows, many types of bellows were simulated according to different dimensions of bellows.

a) CAD Program

After running program the right shape of bellows would be automatically created according to the design principle.

In order to get welded metal bellows, the plasma laser is needed, so the design program includes welded bead. The input data includes the bead of the line. The shape of bead of inner bellows is fully created, and the outer one is half created and the size of the bead is three times of the bellows's thickness. Finally, the analysis of the bead is carried out by using FEM tool.

Diaphragm would not be generated if the value of initial radius is too small or too large, when inputting data of the bellows in AutoCAD. Errors would appear when using the program as follows. For the initial radius, such as shown in Fig. 2, if radius of C1 and C5 is six times longer than L1, C2 and C4 would not be created, for the length of line, it should be longer than bead and for the pitch, it should be longer than three times of thickness.

From above we can see that if the input data is too large or small the shape of bellows would not be created, users should input the proper data because the diaphragm is based on the design principle.

The dimensions of three, four and five waves bellows are shown in Fig. 4(a), (b) and (c). The AutoCAD program developed in this paper can generate the appropriate value, it is possible to create drawings output as well as to the file to the finite element analysis.

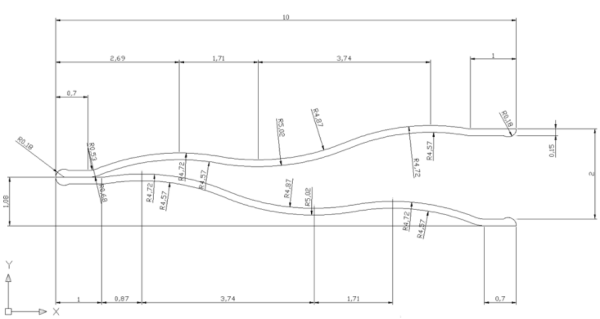

Figure 4(a) : The dimension of three waves bellows

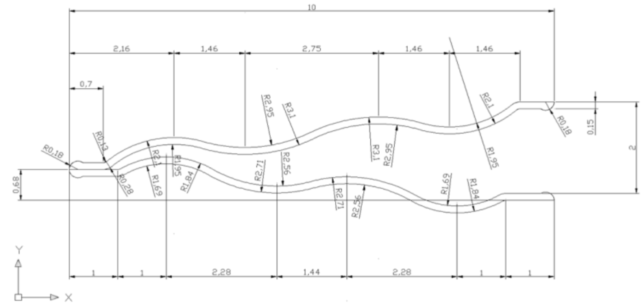

Figure 4(b) : Design principle of four waves bellows

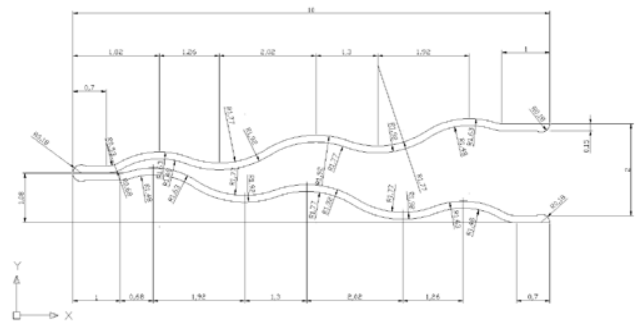

Figure 4(c) : Design principle of five waves bellows

- Finite Element Analysis
- Analysis boundary condition

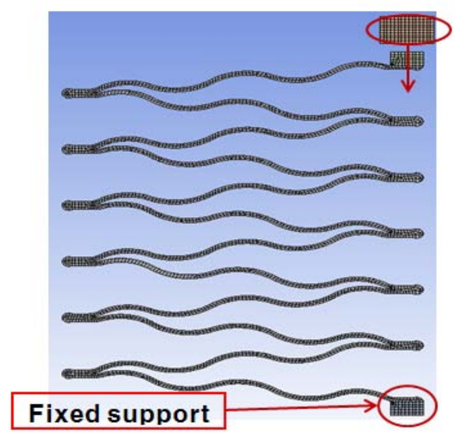

Figure 5 : Shape and boundary conditions of the bellows analysis

Welded metal bellows was simulated by using ANSYS Workbench a finite element analysis program, and modeled Y-axis symmetry, with 1/360° a shape in order to shorten the time of the analysis. The fixed lower and gave the axisymmetric conditions, and was compressed bellows by lowering the plate above. Designed according to the displacement of the bellows, the stress and strain were calculated. Bellows designed to investigate interference during compression the bellows through modification of the shape and designed.

The property of welded metal bellows is SUS304, poisson's ratio is 0.3 and young's module is 2.1E+05 MPa.

Both the axis and welded end of bellows bears pressure and tension. In order to analyze the shape of bellows, the part of bellows was modeled form one convolution to four convolutions. The stress of pressure and tension was given to the face of end of up. The mass of face value is 10 kg and the pressure is as follows:

$$p = \frac{F}{A}, A = \pi \times \left\{ R_0{}^2 - (R_0 - L)^2 \right\} \qquad (1)$$

Where, R_0 is external radius and L is the end length of upper plate. A is the end area of up total bellows. According to the end of bellows the area is different. The reflect stress is the same as the stress of pressure.

Boundary condition based on the condition of pressure. The below of bellows is fixed and the upper portion of bellows was pressed make it just could move up and down.

The condition of tension is same with the pressure. However, both inner and outer lines are not contacted with each other. So the face contact is not used.

In order to consider the design parameters of the bellows, the value of different bellows of initial radius, external diameter, inner diameter, pitch, thickness and length of line are shown in Table 1.

Table 1 : Model specifications FEA

Model	Initial Radius (mm)	Diameter (mm)		Pitch (mm)	Thickness (mm)	Short length (mm)	Long length (mm)
		Inner	Outer				
M01	0.2	39	59	2	0.15	0.7	1
M02	0.2	39	59	2	0.15	0.7	1
M03	0.2	39	59	2	0.15	0.7	1
M04	0.6	39	59	2	0.15	0.7	1
M05	0.6	39	59	2	0.15	0.7	1
M06	0.6	39	59	2	0.2	0.7	1.1
M07	0.6	39	59	2	0.2	0.7	1.1
M08	0.6	39	59	2	0.2	0.7	1.1

There are three models and the basic dimensions of model are as follows M01. The dimensions of the M02 and M03 are the same as the dimensions of four and five waves bellows. The dimensions of model have been confirmed but convolution has been not yet. The convolution determines deformation and stress, so the result is different with other convolutions. In order to get correct result, the effect on the number of convolution to model was examined.

Fig. 6 shows the spring constant and stress graph according to different convolution from 1 to 7. Tension is 115 MPa and pressure is 107 MPa when the convolution is four. According to the above, the convolution of model is confirmed over four.

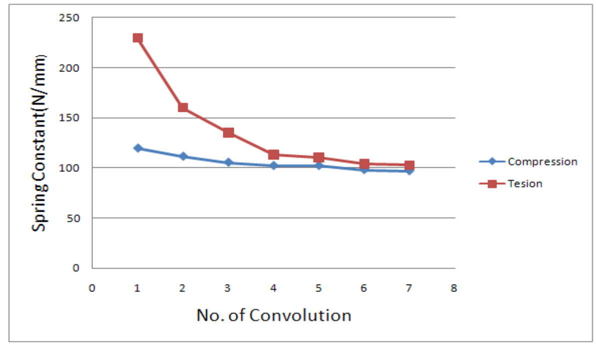

Figure 6 : Number of convolution and spring constant

b) Spring Constant

The bellows constant is obatined as based on the pressure and tension 10 kg.

$$K = \frac{F_r}{\delta} \times N \qquad (2)$$

Where, K is spring constant and δ is the maximum deformation. F_r is reflect of stress and N is the number of convolution.

The tension and pressure of spring constant of basic model are 113.56 N/mm and 102.08 N/mm. The pressure of deformation is bigger than the tension of deformation.

The spring constant would be small when the initial radius is big, and the pitch, thickness and strength of line would be big when the spring constant is small and especially the thickness is significant to the spring constant.

c) Deformation and Stress Analysis

The design parameters of all models are listed in Table 1. M01 is three waves bellows and the long length of line is two times longer than the short length of line. M02 is four waves bellows and M03 is five waves bellows. The von Misses stress is as shown Fig. 7(a), (b) and (c), when these three models are given by the maximum compression. The stress of M01 is 636.05 MPa and the stress of M02 is 696.86.18 MPa and the stress of M03 is 663.43 MPa.

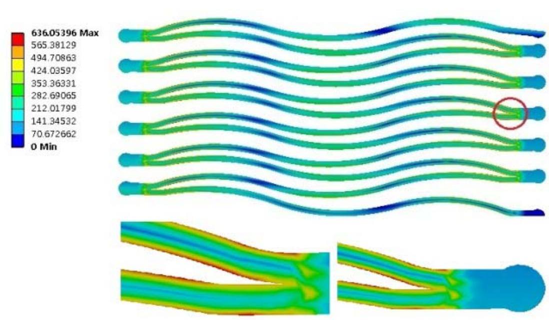

Figure 7(a) : The stress of three waves bellows

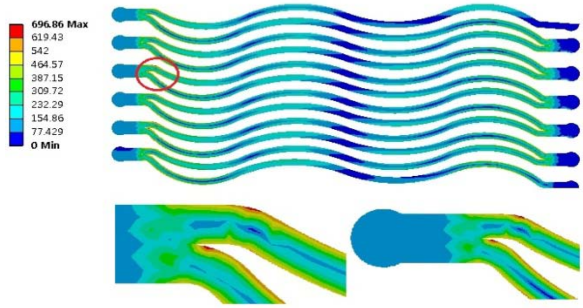

Figure 7(b) : The stress of four waves bellows

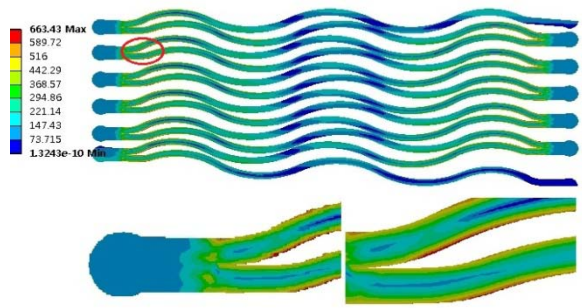

Figure 7(c) : The stress of five waves bellows

And the von Misses stress is shown in Table 2, when these three models are given the same pressure of 10 kg. The stress of M01 is 682.78 MPa and the stress of M02 is 582.94 MPa and the stress of M03 is 640.92 MPa. All the maximum stresses appear in inside part of welded.

The design principle of four waves bellows is asymmetry and the initial radius are the same before.

Table 2 : Deformation and stress

Model	Load		Time (s)	Displacement (mm)	Maximum (MPa)
M01	Compression	10Kg (98.06N)	1	1.0091	682.78
	Tension	10Kg (98.06N)	2	0.65369	489.75
M02	Compression	10Kg (98.06N)	1	0.90249	582.94
	Tension	10Kg (98.06N)	2	0.9117	582.83
M03	Compression	10Kg (98.06N)	1	0.95309	640.92
	Tension	10Kg (98.06N)	2	0.98523	485.94

M04 and M05 are the design optimization models of three and five waves bellows. All dimensions are the same but initial radius is three times larger than before.

Table 3 shows that the value of pressure stress of M04 and M05 are 72.22 MPa and 42.59 MPa that are smaller than M01 and M03. The value of tension stress of M04 and M05 are 32.14 MPa and 57.42 MPa that are smaller than M01 and M03. The design principle of four waves bellows is asymmetry and the initial radius are the same before.

Table 3 : Deformation and stress

Model	Load		Time(s)	Displacement (mm)	Maximum (MPa)
M04	Compression	10Kg (98.06N)	1	0.95531	610.56
	Tension	10Kg (98.06N)	2	0.86303	457.61
M05	Compression	10Kg (98.06N)	1	1.0894	598.33
	Tension	10Kg (98.06N)	2	0.95626	428.52

The stress of bellows M06, M07 and M08 are examined when the thickness is changed from 0.15 mm to 0.2 mm. Table 4 shows the value of pressure stresses are 437.54 MPa, 476.78 MPa and 368.38 MPa. All of the values are smaller 100 MPa than before. The values of tension stress are 350.19 MPa, 391 MPa and 343.98 MPa and reduced approximately to 150 MPa.

Table 4 : Deformation and stress

Model	Load		Time (s)	Displacement (mm)	Maximum (MPa)
M06	Compression	10Kg (98.06N)	1	0.5283	437.54
	Tension	10Kg (98.06N)	2	0.46354	350.19
M07	Compression	10Kg (98.06N)	1	1.1175	476.78
	Tension	10Kg (98.06N)	2	0.4078	391
M08	Compression	10Kg (98.06N)	1	0.64379	368.38
	Tension	10Kg (98.06N)	2	0.6054	343.98

V. Conclusion

In this paper, metal bellows is developed by using AutoLISP in AutoCAD and the deformation, stress of bellows has been analyzed through ANSYS Workbench, the results were as follows

- Three kinds of welded metal bellows has been developed automatically in CAD program. Inputting the basic design of 2D and 3D bellows is easy using the basic data in dialog box.
- Unskilled person can be accessed easily in the design. The 3D or 2D shape bellows design can easily draw in the printer or plotter form AutoCAD drawing.

- The dimensions of three, four and five waves bellows have the each characteristic. It must be suitably selected in consideration of the sizes and the process of machining the actual field.
- The spring constant of five waves bellows is bigger than three waves of bellows when the same parameter of bellows was defined.
- When applied to the field bellows designed, it is possible to reduce time and cost during production of the product.

VI. Acknowledgement

This work (A Development of Automatic Design Program for Metal Bellows Diaphragm of Small and Medium Business Administration, NO. 2011070601) was supported by Business for Cooperative R&D between Industry, Academy, and Research Institute funded Korea Small and Medium Business Administration in 2011.

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Modelling, Simulation of Permanent Magnet Synchronous Machine Drive using FOC Technique

By Rajendra Aparnathi & Ved Vyas Dwivedi
CU Shah University, India

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Keywords: permanent magnet synchronous machine (PMSM), field oriented control (FOC), voltage source inverter (VSI).

GJRE-A Classification : 040401

MODELLINGSIMULATIONOFPERMANENTMAGNETSYNCHRONOUSMACHINEDRIVEUSINGFOCTECHNIQUE

Strictly as per the compliance and regulations of :

Modelling, Simulation of Permanent Magnet Synchronous Machine Drive using FOC Technique

Rajendra Aparnathi [α] & Ved Vyas Dwivedi [σ]

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I. Introduction

An electrical drive, as shown in Fig. 1.1 can be defined in terms of its ability to efficiently convert energy from an electrical power source to a mechanical load. The main purpose of the drive is to control a mechanical load or process. The direction of energy flow is generally from electrical to mechanical i.e. motoring mode with power flow from the power source to the mechanical load via the converter and machine as shown in Fig. 1.1. However the energy flow can be reversed in some cases, in that case the drive often is configured bi-directional to allow energy flow from the mechanical load to the power source. Modern electrical drives as considered utilize power electronic devices to (digitally) control this power conversion process. A feature which is highlighted in Fig. 1.1 by the presence of the modulator and control unit The controller module shown in Fig. 1.1 must be able to communicate with higher level computer systems because drives are progressively networked. Communication links to high level computer networks are required to support a range of functions, such as commissioning, initialization, diagnostics and higher level process control.

The embedded digital controller shown in Fig. 1.1 houses the high-speed logic devices, processors and electronic circuitry needed to accommodate the sensor signals derived from mechanical and electrical sensors. Further the most suitable control algorithms must be developed to facilitate the power conversion processes within the drive. With the advent of new materials and new design tools, novel machine concepts such as linear machines, PM magnet, switched reluctance and transversal flux machines etc. have been developed over the past twenty years. Power electronic devices have on the other hand been around for about forty five years, while high-speed digital devices have only been available over the past twenty five years.

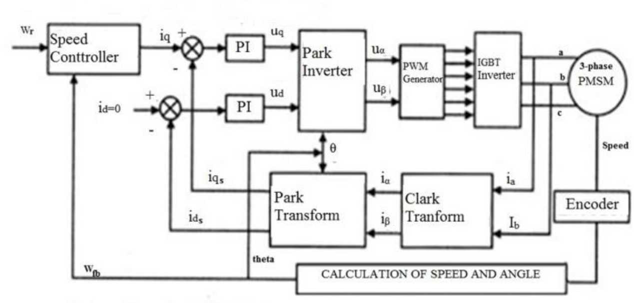

Figure 1 : Basic block diagram of drive system

The Suitable control algorithm named field-oriented control has been developed. Ongoing drive development is fuelled by the continuous emergence of new drive related drive product such as new processors, sensors and most importantly new control algorithms. Such developments enhance drive robustness, improve reliability, and expand the use of electrical drives to other industrial applications, hitherto considered to be unfeasible. The power range associated with these industrial applications is impressive and typically ranges from a few miliwatts to hundreds of megawatt, which underlines the flexibility and broad application base of modern drive technology. One of the recently used electrical machines is the Permanent Magnet Synchronous Machine (PMSM), because of its resemblance with the Direct Current machine in terms of controls.

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II. PMSM Drive Scheme

Permanent Magnet Synchronous Machines are being increasingly used in industrial applications because of the many advantages they present over the other types of machines. These machines are compact and have very high efficiency, and the drives associated are well developed and reliable. However, the main drawback for these drives is the need for an accurate knowledge of the rotor position to achieve the most efficient drive.

An optical encoder usually ensures this accurate knowledge of the shaft position. This encoder introduces extra cost, extra wiring leading to a decrease in the overall reliability of the drive. One particular type of PMSM known as Brushless Direct Current (BLDC) machine uses three or fewer low-resolution sensors to operate, and has trapezoidal waveforms. Nevertheless these machines have a non-negligible torque ripple. In applications where a smooth torque profile is required or where vibrations have to be low these machines cannot replace the sinusoidal PMSM.

Numerous researches have been conducted to eliminate the encoder in PMSM drives and it is necessary to find among them a realistic sensorless method whose implementation is feasible for a defined set of industrial applications, taking into account its complexity and reliability.

One can find various names for the same motor based on different approaches or points of view. Brushless synchronous AC motors are one type of synchronous motor. Synchronous AC motors are sinusoidal current-driven machines that use a quasi-sinusoidal distributed AC stator winding and inverter. The three main types are shown in Figure 2. Figure 2. (a) Shows the cross-section of a surface-mounted PM-motor (SMPM). Radial or straight-through magnetized permanent magnets are fixed to an iron rotor core. The magnets are normally glued to the rotor surface. Due to its isotropic rotor, the d- and q-axis inductances are identical.

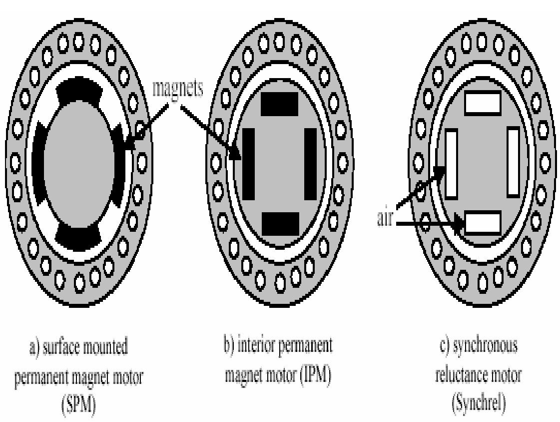

Figure 2 : Cross section of the three main types of PMSM

Therefore no reluctance torque occurs. In Figure 2.2b, a possible design of an interior permanent magnet motor (IPM) is presented in which the magnets are buried in the rotor core. Setting the magnets inside the rotor improves the mechanical strength and magnetic protection. An IPM motor exhibits both magnetic and reluctance torque. These features allow the PMSM drive to be operated in high-speed mode by incorporating the field –weakening technique. Figure 2.2c shows the cross-section of a synchronous reluctance motor. Without permanent magnets, the reluctance motor produces only reluctance torque.

III. Detailed Modelling of PMSM

Detailed modeling of PM motor drive system is required for proper simulation of the system. The d-q model has been developed on rotor reference frame as shown in Fig. 3. At any time t, the rotating rotor d-axis makes and angle θr with the fixed stator phase axis and rotating stator mmf makes an angle α with the rotor d-axis. Stator mmf rotates at the same speed as that of the rotor.

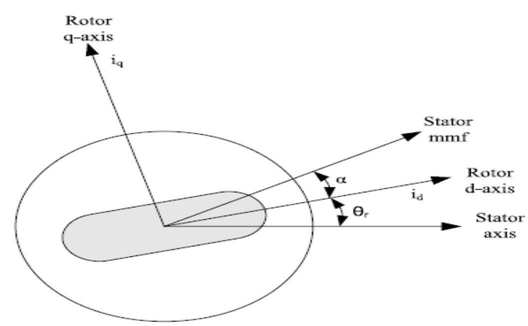

Figure 3 : Motor axes

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

- ✓ Saturation is neglected.
- ✓ The induced EMF is sinusoidal.
- ✓ Eddy currents and hysteresis losses are negligible.
- ✓ There are no field current dynamics.

Voltage equations with respect to rotor axis are given by:

$$v_q = R_s i_q + w_r \lambda_d + \rho \lambda_q \qquad (1)$$

$$v_d = R_s i_d - w_r \lambda_q + \rho \lambda_d \qquad (2)$$

Flux Linkages are given by

$$\lambda_q = L_q i_q \quad (3) \qquad \lambda_d = L_d i_d + \lambda_f \quad (4)$$

Substituting equations (3) and (4) into (1) and (2)

$$v_q = R_s i_q + w_r (L_d i_d + \lambda_f) + \rho \lambda_q \qquad (5)$$

$$v_d = R_s i_d - w_r L_q i_q + \rho (L_d i_d + \lambda_f) \qquad (6)$$

Arranging equations (5) and (6) in matrix form

$$\begin{pmatrix} v_q \\ v_d \end{pmatrix} = \begin{pmatrix} R_s + \rho L_d & w_r L_d \\ -w_r L_q & R_s + \rho L_d \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} w_r \lambda_r \\ \rho \lambda_f \end{pmatrix} \quad (7)$$

The developed motor torque is being given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_d i_q - \lambda_q i_d\right) \quad (8)$$

IV. Equivalent Circuit of Permanent Magnet Synchronous Motor

Equivalent circuit of the motor is used for study and simulation of motor. From the d-q modelling of the motor using the stator voltage equations the equivalent circuit of the motor can be derived. Assuming rotor d axis flux from the permanent magnets is represented by a constant current source.

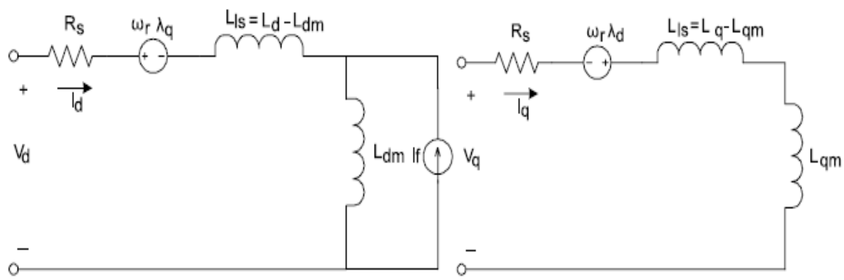

Figure 5 : Equivalent circuit of Permanent Magnet Synchronous Motor

V. Current Controlled Voltage Source Inverter

The motor is fed form a voltage source inverter with current control. The control is performed by regulating the flow of current through the stator of the motor. Current controllers are used to generate gate signals for the inverter. Proper selection of the inverter devices and selection of the control technique will guarantee the efficacy of the drive. Voltage Source Inverters are devices that convert a DC voltage to AC voltage of variable frequency and magnitude. They are very commonly used in adjustable speed drives and are characterized by a well defined switched voltage wave form in the terminals. Fig. 6 shows a voltage source inverter. The AC voltage frequency can be variable or constant depending on the application.

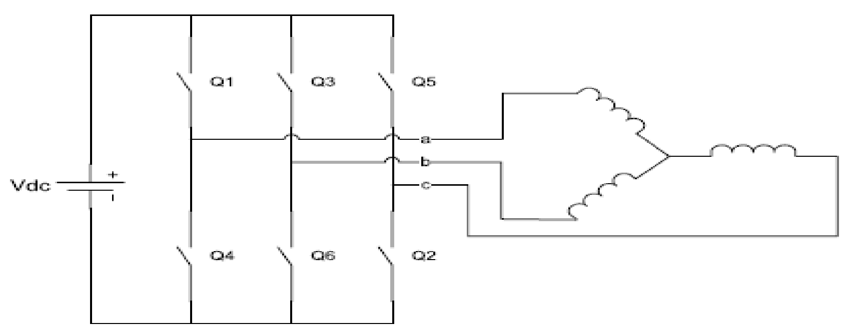

Figure 6 : Voltage Source Inverter Connected to a Motor

Three phase inverters consist of six power switches connected as shown in Fig. 6 to a DC voltage source. The inverter switches must be carefully selected based on the requirements of operation, ratings and the application. There are several devices available today and these are thyristors, bipolar junction transistors, MOS field effect transistors, insulated gate bipolar transistors and gate turn off thyristors.

VI. Coordinate Transforms

Through a series of coordinate transforms determine and control the time invariant values of torque and flux with classic PI control loops. The process begins by measuring the 3-phase motor currents. The instantaneous sum of the three current values is zero. Therefore by measuring only two of the three currents we can determine the third. Because of this fact hardware cost can be reduced by the expense of the third current sensor.

a) Clarke Transform

The first coordinate transform, called the Clarke Transform, moves a three-axis, two-dimensional coordinate system, referenced to the stator, onto a two-axis system, keeping the same reference.

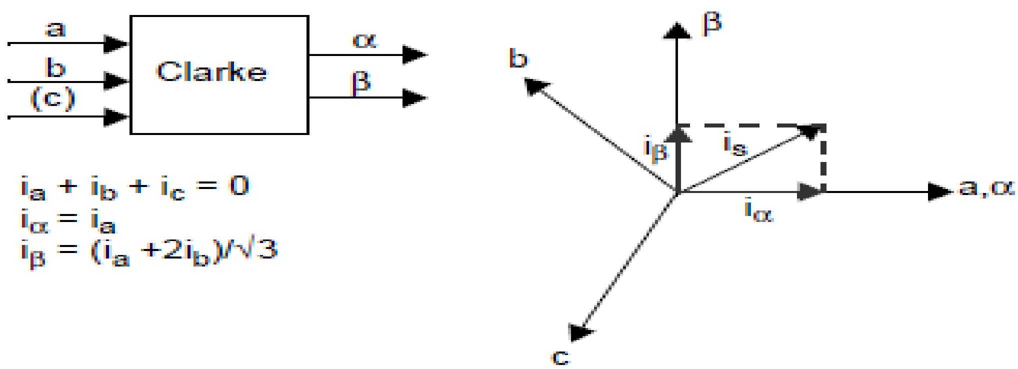

Figure 7 : Clarke Transform

b) *Park Transform*

At this point, you have the stator current represented on a two-axis orthogonal system with the axis called **α-β**. The next step is to transform into another two-axis system that is rotating with the rotor flux. This transformation uses the Park Transform. This two-axis rotating coordinate system is called the d-q axis. **θ** represents the rotor angle.

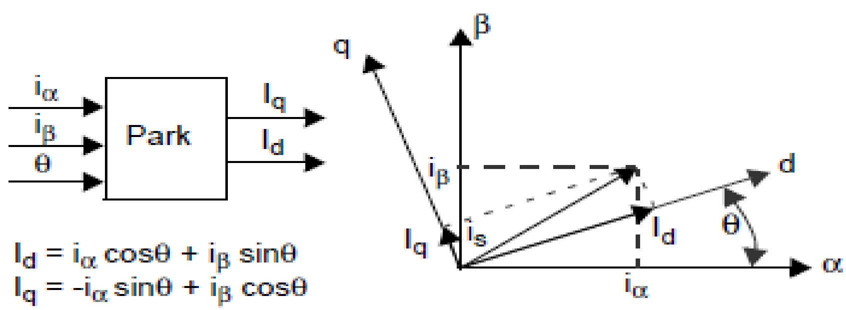

Figure 3.3 : Park Transform

c) *PI Control*

Three PI loops are used to control three interactive variables independently. The rotor speed, rotor flux and rotor torque are controlled by a separate PI module. There are three interdependent PI control loops in this application. The outer loop controls the motor speed. The two inner loops control the transformed motor currents, id and iq. As mentioned previously, the id loop is responsible for controlling flux, and the iq value is responsible for controlling the motor torque.

d) *Inverse Park Transform*

After the PI iteration, you have two voltage component vectors in the rotating d-q axis. You will need to go through complementary inverse transforms to get back the 3-phase motor voltage. First, you transform from the two-axis rotating d-q frame to the two-axis stationary frame **α-β**. This transformation uses the Inverse Park Transform.

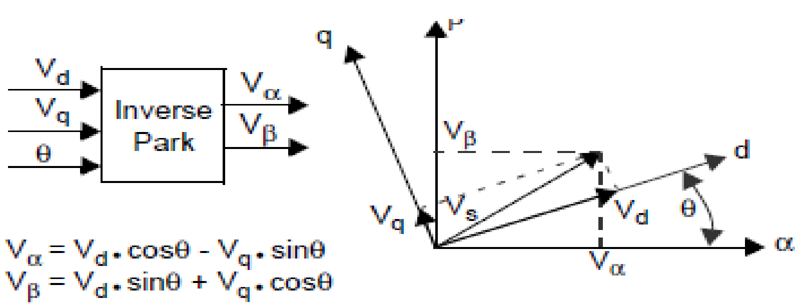

Figure 8 : Inverse Park transform

e) Inverse Clarke Transform

The next step is to transform from the stationary two-axis **α-β** frame to the stationary three-axis, 3-phase reference frame of the stator. Mathematically, this transformation is accomplished with the Inverse Clark Transform.

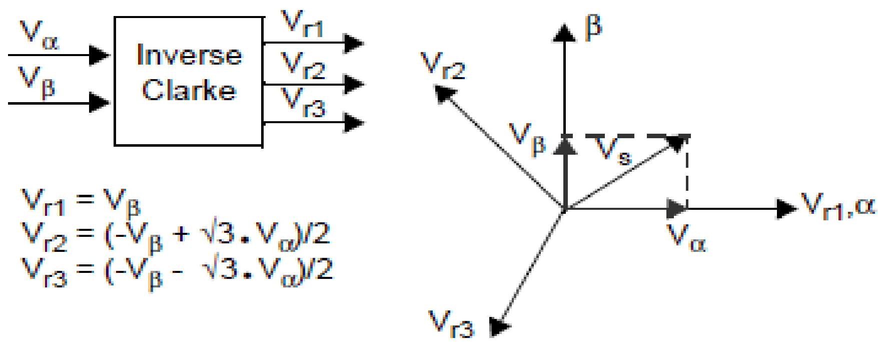

Figure 9 : Inverse Clarke Transform

VII. Current Control Technique

The power converter in a high-performance motor drive used in motion control essentially functions as a power amplifier, reproducing the low power level control signals generated in the field orientation controller at power levels appropriate for driving the machine. High-performance drives utilize control strategies which develop command signals for the AC machine currents. The basic reason for the selection of current as the controlled variable is the same as for the DC machine; the stator dynamics (effects of stator resistance, stator inductance, and induced EMF) are eliminated. Thus, to the extent current regulatory functions as an ideal current supply, the order of the system under control is reduced and the complexity of the controller can be significantly simplified.

Current regulators for AC drives are complex because an AC current regulator must control both the amplitude and phase of the stator current. The AC drive current regulator forms the inner loop of the overall motion controller. As such it must have the widest bandwidth in the system and must by necessity have zero or nearly zero steady-state error.

Both current source inverters (CSI) and voltage source inverters (VSI) can be operated in controlled current modes. The current source inverter is a "natural" current supply and can readily be adapted to controlled current operation. The voltage source inverter requires more complexity in the current regulator but offers much higher bandwidth and elimination of current harmonics as compared to the CSI and is almost exclusively used for motion control applications.

VIII. Hysteresis Current Controller

Hysteresis current controller can also be implemented to control the inverter currents. The controller will generate the reference currents with the inverter within a range which is fixed by the width of the band gap. In this controller the desired current of a given phase is summed with the negative of the measured current. The error is fed to a comparator having a hysteresis band. When the error crosses the lower limit of the hysteresis band, the upper switch of the inverter leg is turned on. But when the current attempts to become less than the upper reference band, the bottom switch is turned on. Fig. 10 shows the hysteresis band with the actual current and the resulting gate signals. This controller does not have a specific switching frequency and changes continuously but it is related with the band width.

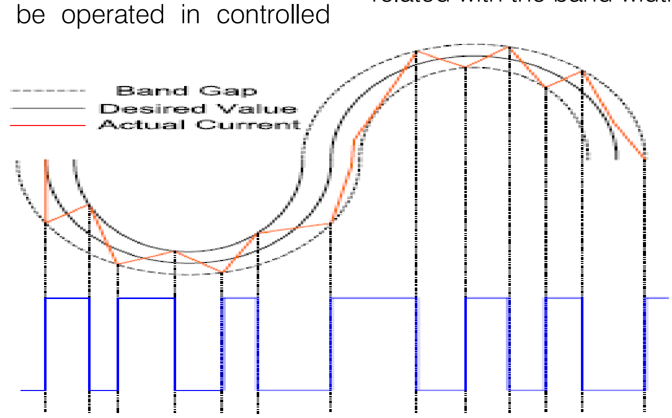

Figure 10 : PWM signal from Hysteresis controller

a) Modeling, Simulation

Study of electric motor drive needs the proper selection of a simulation tool. Their complex model needs computing tools capable of performing dynamic simulation. SIMULINK is a toolbox extension of the MATLAB program. It is a program for simulating dynamic systems.

Simulink has the advantages of being capable of complex dynamic system simulations, graphical environment with real time programming and broad selection of tool boxes. The simulation environment of Simulink has a high flexibility and expandability which allow the possibility of development of a set of functions for a detailed analysis of the electrical drive. Its graphical interface allows selection of functional blocks, their placement on a worksheet and description of signal flow by connecting their data lines using a mouse device. System blocks are constructed of lower level blocks grouped into a single makeable block. Simulink simulates analogue systems and discrete digital systems. Fig.-11 shows complete simulation diagram of PMSM drive using FOC technique. Here first take speed feedback, rotor angle position and three phase current for different calculation. Three phase current are first converted into two phase component using Clarke transformation and that component are again converted in to d-q component using Park transformation which is compared with the reference d-q component generated by comparing two speeds i.e. reference speed and feedback speed using PI speed controller. After comparison of two current we can get three reference phase current using inverse Clarke and Park transformation and using Hysteresis current controller compare the actual current MATLAB modeling results.

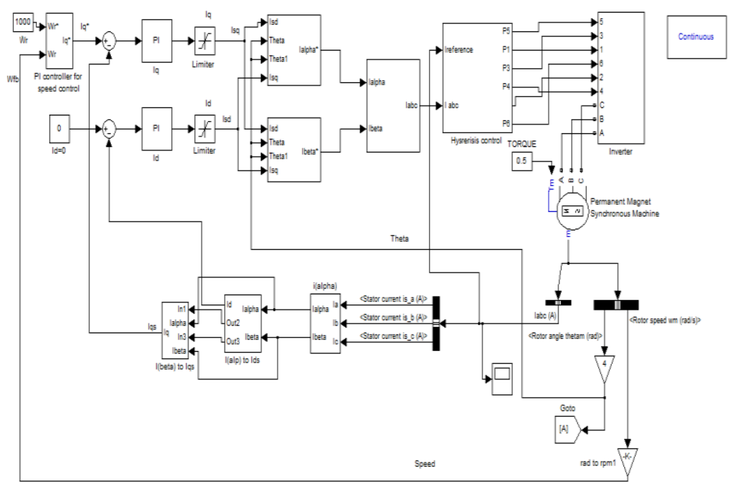

Figure 11 : Simulation circuit of PMSM Drive circuit

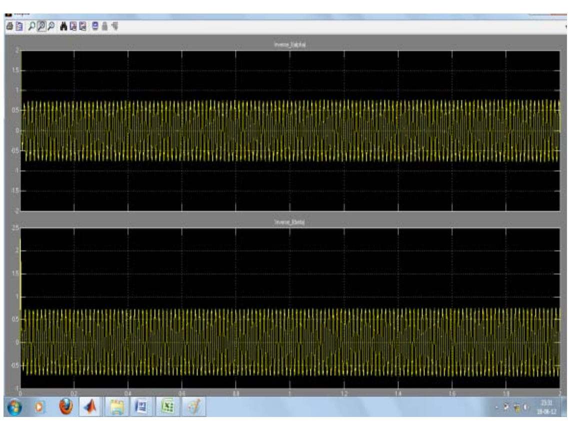

Figure 12 : Inverse Transformed current i_α and i_β

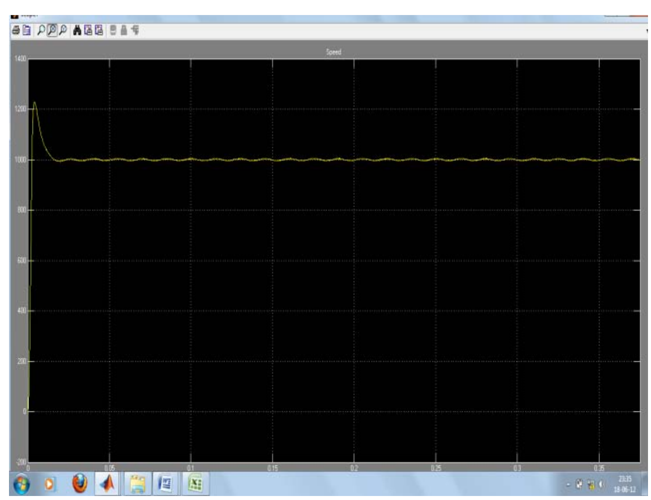

Figure 13 : Gating signal for upper switches of VSI

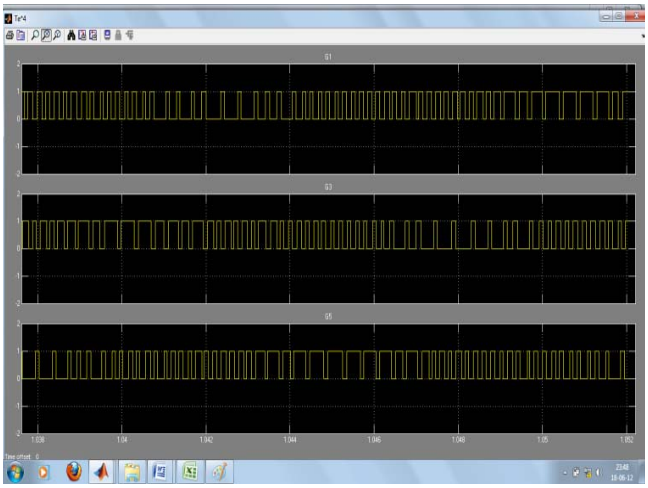

Figure 13 : Rotor speed

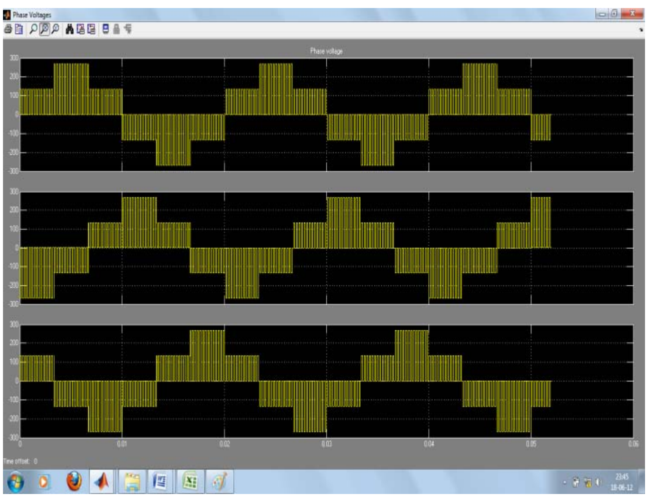

Figure 14 : Phase voltage

IX. Testing and Experimental Result

In college laboratory set up, we are using different controller and STM32F103 Processor is used for the control signal generation and these control signals are given to the 3-Phase IPM module. This chapter illustrates different experimental results Experimental Results:

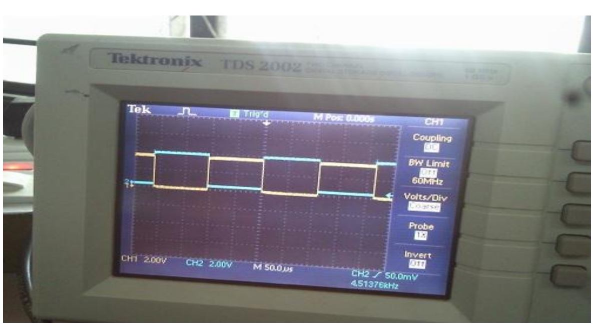

Figure 16 : gating signal showing delay

Table 1 : Speed v/s Voltage at constant torque

Speed (rpm)	Torque(N-m)	Voltage(Volt)
1700	1.6	244.2
1600	1.6	230.4
1600	1.6	210.2
1400	1.6	194.1
1300	1.6	180
1200	1.6	169.3
1100	1.6	166.4
1000	1.6	144.3
900	1.6	130
800	1.6	111.2
700	1.6	100.2
600	1.6	90.26

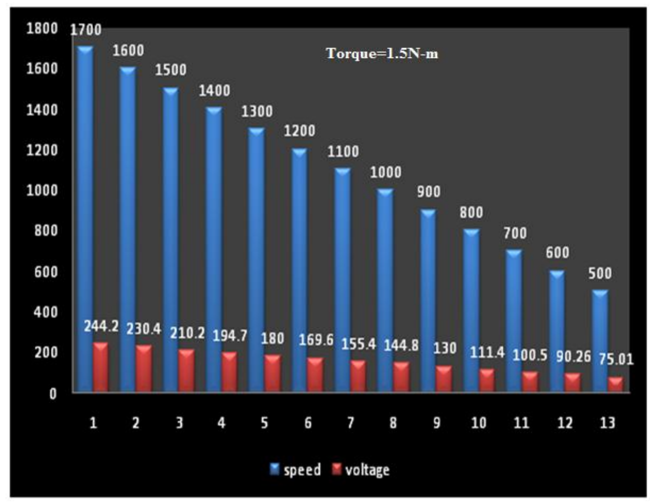

Figure 17 : Graph between speed and voltage

X. Conclusion

This paper covers major issues and solutions dealing with sensorless Field Orientation control of permanent magnet synchronous motor (PMSM) over wide speed range in constant torque region. A constant torque control technique has been implemented and the following conclusions can be drawn.

Moreover no saturation of current controller occurs under load conditions, resulting in control robustness in the constant torque region. A single shunt current sensing measurement has been developed for the estimation of rotor position angle in the sensorless Field Orientation Control of PMSM without saliency. Compared to conventional sliding mode observers, the proposed scheme has the feature which gives the flexibility to design parameters of single shunt current measurement with wide operating speed range.

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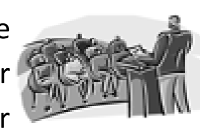

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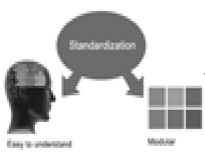

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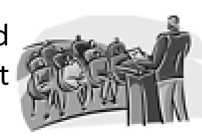

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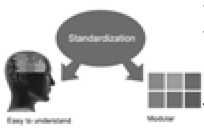

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TECHNIQUES FOR WRITING A GOOD QUALITY RESEARCH PAPER:

1. Choosing the topic: In most cases, the topic is searched by the interest of author but it can be also suggested by the guides. You can have several topics and then you can judge that in which topic or subject you are finding yourself most comfortable. This can be done by asking several questions to yourself, like Will I be able to carry our search in this area? Will I find all necessary recourses to accomplish 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.

2. Evaluators are human: First thing to remember that evaluators are also human being. They are not only meant for rejecting a paper. They are here to evaluate your paper. So, present your Best.

3. Think Like Evaluators: If you are in a confusion or getting demotivated that your paper will be accepted by evaluators or not, then think and try to evaluate your paper like an Evaluator. Try to understand that what an evaluator wants in your research paper and automatically you will have your answer.

4. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

5. Ask your Guides: If you are having any difficulty in your research, then do not hesitate to share your difficulty to your guide (if you have any). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work then ask the supervisor to help you with the alternative. He might also provide you the list of essential readings.

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7. Use right software: Always use good quality software packages. If you are not capable to judge good software then you can lose quality of your paper unknowingly. There are various software programs available to help you, which you can get through Internet.

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9. Use and get big pictures: Always use encyclopedias, Wikipedia to get pictures so that you can go into the depth.

10. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right! It is a good habit, which helps to not to lose your continuity. You should always use bookmarks while searching on Internet also, which will make your search easier.

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

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15. Use of direct quotes: When you do research relevant to literature, history or current affairs then use of quotes become essential but if study is relevant to science then use of quotes is not preferable.

16. Use proper verb tense: Use proper verb tenses in your paper. Use past tense, to present those events that happened. Use present tense to indicate events that are going on. Use future tense to indicate future happening events. Use of improper and wrong tenses will confuse the evaluator. Avoid the sentences that are incomplete.

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18. Pick a good study spot: To do your research studies always try to pick a spot, which is quiet. Every spot is not for studies. Spot that suits you choose it and proceed further.

19. Know what you know: Always try to know, what you know by making objectives. Else, you will be confused and cannot achieve your target.

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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

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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.

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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.
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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

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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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