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Highlights

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By Khabibulla Turanov

Urals State University of Railway Transport (USURT), Russia

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ANALYTICALINVESTIGATIONOFWAGONSPEEDANDTRAVERSEDDISTANCEDURINGWAGONHUMPROLLINGUNDERTHEIMPACTOFGRAVITYFORCESANDHEADWIND

Strictly as per the compliance and regulations of:

Analytical Investigation of Wagon Speed and Traversed Distance during Wagon Hump Rolling under the Impact of Gravity Forces and Head Wind

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I. Formulation of a Problem

Analysis of the literature [1 – 5] shows that the dynamic model of the car from rolling down the hill with built correctly. The recommended formulas for determination of the distance traveled in скатывании car with slides [1] do not take into account the motion of the car on the profile of the hills in pure rolling wheels of wheel pairs of carriages and the rolling elements of bearing on the inner and outer rings, if not believe that such a movement indirectly taken into account the concept of the main specific resistance wₒ, which found empirically. Estimated rate of dissolution of the car with the roller coaster is found by the formula freely falling body, which does not comply with the physical sense of the problem being solved, as it should be defined as a result of solution of a differential equation of motion of the car, how this is done in [6 – 9]. The work is not yet covers the solution of a number of practical problems getting the car to the hill.

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Proceeding from this, in [10, 11] shows accounting moments of friction (net rolling wheel on the rail thread and in the bearings буксовых nodes front and rear bogies of a wagon with their subsequent replacement of contingent slip friction. It was noted that, if the active force in the form of the projection of the force of gravity and the forces of aerodynamic drag to the direction of rolling the car, acting on the car, the more marginal the friction force at the same time with rolling it is also possible movement of wheels on the rail lines.

Thus, up to the present time out of mind researchers were missed construction of the model of the car from rolling down the hill with in strict accordance with the provisions of the classical theoretical mechanics and, accordingly, the definition of speed and covered distance from rolling on the profile of the hills in the counter and/or wind.

II. Man-Made Assumption

Consider the General case, when the car with the sorting slides forward with a specified initial velocity v0 (usually 4÷5 km/h or 1.1 ÷ 1,38 m/s, and the maximum value of 9 km/h or 2.5 m/s). When wagon rolling down the hump with the roller coaster car will be face-the impacts are mostly external forces in the form of the force of gravity of the car with or without cargo $\overline{G}$ and the forces of aerodynamic drag (where $\overline{F}_{rw} \in \overline{F}'_{rwx}, \overline{F}'_{rwy}$). Distribution of the forces of gravity of the car body with a weight on the front and rear bogie depend on the technology of placing of cargo (symmetrically, or not symmetric about the axes of symmetry of the car) on the car.

Let the car roll off the sorting slides forward with portable speed $\overline{v}_e = \overline{v} = \overline{v}_w$ (unknown value) [12]. Wind speed in relation to the top of the hill (the earth) (i. e., the absolute velocity of the particles of air) $\overline{v}_{a.w}$ (the value specified by [13]) is directed along the horizontal axis *Oxyz*. Find the projection of the relative velocity of

the particle air (wind speed) $\overline{v}_{rw}$ (concerning the moving axes $O_1x_1y_1z_1$, connected with the wagon).

Show the dependence of the projection of the relative velocity of the particle air (wind speed) $\overline{V}_{rw}$ (the calculated value) of wind speed in relation to the top of the hill (the earth) (i. e., the absolute velocity of the particles of the air) $\overline{V}_{a.w}$ and the speed of the car $\overline{V} = \overline{V}_w$. Let us assume that the car rolls down from the top of the hill with a velocity $\overline{V}_e = \overline{V} = \overline{V}_w$ relative to the fixed coordinate system $Oxyz$, associated with the top of the hill. Take that with a wagon rigidly connected mobile coordinate system $O_1x_1y_1z_1$, and the particles of air, in turn, are moving at velocity $\overline{V}_{rw}$ relative to the moving system of coordinates $O_1x_1y_1z_1$ (i .e., cars) (Fig. 1) [12].
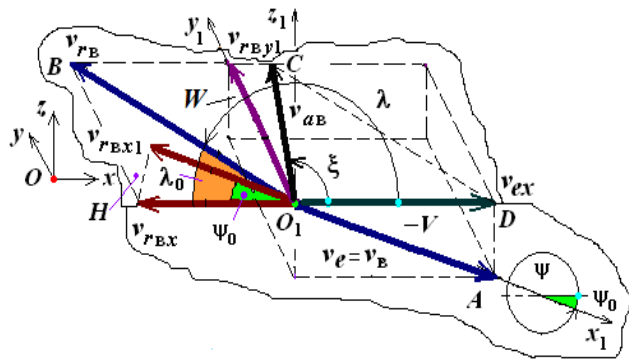
Figure 1 : Vector diagram of the speed of the car and the wind

In Fig. 1 indicated by: O the beginning of the motionless coordinate system $Oxyz$, rigidly connected with the top of the hill; O_1 the beginning of the moving coordinate system $O_1x_1y_1z_1$, rigidly connected to the wagon; (H, V and W horizontal, vertical and frontal plane; the angle of descent (in accordance with the profile of the hills value given); $\overline{V}_{rw}$ the relative velocity of the particles of air (wind speed) in relation to the moving reference system $O_1x_1y_1z_1$ (car) value (calculated); λ guide corner of the vector of relative velocity of the air particles along the axis Ox (calculated value); $\overline{V}_{a.w}$ the absolute velocity of the particles of the air against the earth (to the top of the hill) (value of the defined); ξ guide the angle of the vectors of absolute soon-of air particles along the axis Ox (the value given).

We believe that the relative velocity of the particles of air (wind speed) $\overline{V}_{r.w}$ is located on a horizontal plane H and is directed at an angle λ (or λ_0) to

the horizontal axis (axis Ox), and drive speed (the speed of the car) $\overline{V}_e = \overline{V} = \overline{V}_w$ in the vertical plane V and is directed at an angle of descent of rolling down ψ (or ψ_0) to the horizontal axis (axis Ox).

According to the theorem of addition of velocities at the complex motion [14, 15], we write

$$\overline{v}_{a.w} = \overline{v}_{ex} + \overline{v}_{r.w}, \qquad (1)$$

where $\overline{v}_{a.w}$ is the absolute velocity of a particle air (wind speed); $\overline{v}_{ex} = \overline{v}_x = \overline{v}_{wx}$ projection of portable speed (the speed of the car) $\overline{v}_e = \overline{v} = \overline{v}_w$ on the axis Ox:

$$v_{ex} = v_x = v_{wx} = v_e \cos(\psi_0), \qquad (2)$$

Taking into account the fact that ψ (or ψ_0) the tilt angle of the hill to the horizontal axis (axis Ox);

$\overline{v}_{r.w}$ the relative velocity of the particles of air (wind speed) in relation to the car.

Keep in mind that if the wind direction is opposite to the direction of movement of the car (i. e. wind, see Fig. 1), the vector equation (1), in accordance with rule subtract of vectors [12, 14], can be written as:

$$\overline{v}_{aw} = \overline{v}_{ex} + (-\overline{v}_{rw}),$$

where

$$\overline{v}_{rw} = \overline{v}_{ex} - \overline{v}_{aw}. \qquad (3)$$

Projection (3) on the axis Ox when the wind is of the form [12, 14]:

$$v_{rw.x} = v_e \cos(\psi_0) - v_{aw} \cos(\xi), \qquad (4)$$

where ξ the angle between the vector $\overline{v}_{aw}$ (the absolute velocity of a particle air (wind speed)and longitudinal axis Ox, rad.

In accordance with the expression (4) the force of aerodynamic drag $\overline{F}_{rw}$ for oncoming wind determined depending on the speed of the car from rolling on the profile of slides, N:

the axis Ox

$$F'_{rwx}(v_e) = 0{,}5c_w \rho_w A_t \left(v_e \cos(\psi_0) - v_{aw} \cos(\xi) \right)^2 ; \qquad (5)$$

the axis Oy

$$F'_{rw.y} = 0{,}5c_w \rho_w A_b \left(v_{rw} \sin(\lambda_0) \right)^2. \qquad (5, a)$$

In the last formulas [14]: c_w – dimensionless experimental coefficient resistor of air, depending on the shape of the body and how it is directed at the movement (usually take depending on the shape of the surface in the range from 0,55 up to 1.2, for example, the cylindrical body, having in the cross-section of a circle (trumpet) $c_w = 0{,}6$; for the flat surface of the $c_w = 1{,}1$); ρ_w – average air density (kg/m³) (usually take 1,26 of 1.29); A_t – area of the front surface of the car with a cargo of, m²: $A_t = 2B \times 2H$ (where $2B$ and $2H$ – the width and height of the windward surfaces of wagons loaded with, m); A_b – area the side of the wagon loaded with: $A_b = 2L \times 2H$ (where $2L$ – the length of the windward side surfaces of wagons with cargo, m), m².

In (5, a), and guide the corner λ the relative velocity of the particle air (wind speed) $\overline{v}_{r.w}$ are according to the theorem of sinus

$$\sin(\lambda) = \frac{v_{aw}}{v_{rw}} \sin(\xi). \qquad (6)$$

Note that according to (5) of the projection of the forces of aerodynamic drag $\overline{F}_{rw}$ in the direction of the sliding carriages for the wind is a function that depends on the projection of the load speed of the wagon $\overline{v}_{ex} = \overline{v}_x = \overline{v}_{wx}$ (see. (2)), i. e. $F'_{rwx}(v_e)$.

III. FORMATION OF A DESIGN MODEL OF THE CAR FROM ROLLING

A simplified model of the car from rolling down the hill with, taking into account the friction rolling wheels car with a slip, take the model shown in Fig. 2, and the calculation model - in Fig. 3 [3 – 5, 11].
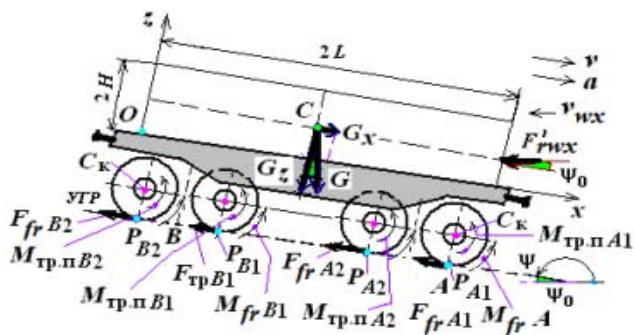
Figure 2 : A simplified model of the car from rolling down the hill with

In Fig. 2. marked: $M_{fr.bA}$ ($M_{fr.bA} \in \{M_{fr.bA1}, M_{fr.bA2}, M_{fr.bA'1}, M_{fr.bA'2}\}$) and $M_{fr.bB}$ ($M_{fr.bB} \in \{M_{fr.bB1}, M_{fr.bB2}, M_{fr.bB'1}, M_{fr.bB'2}\}$) internal forces in the form of points of friction in the bearings bucks nodes front and A rear B trolley car, and $M_{fr.b} = M_{fr.bA} + M_{fr.bB}$; P_{A1}, P_{A2}, P_{B1}, P_{B2} instant centers speeds [3 – 5].
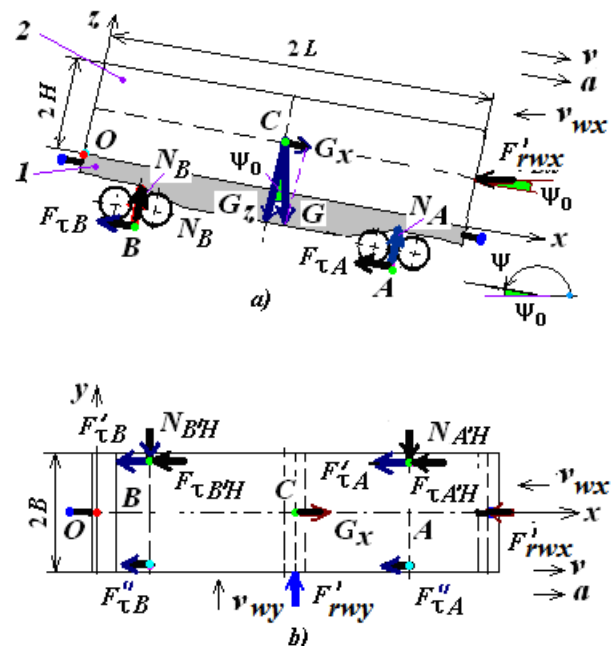
Figure 3 : Calculation model of the car from rolling down the hill with a) the view from the side; b) the view from the top

The force of friction of the rolling of a wheel with a slip $F_{\text{fric}}^{\text{sl}}(\overline{v}_e)$, as the force of the braking of a wagon $F_{\text{torm.}}(v_e)$, aimed in the direction opposite to the from rolling car with slides, can be represented in the form of [3, 4, 9, 11, 15]:

$$F_{\text{torm.}}(\overline{v}_e) = F_{\text{fric}}^{\text{r}}(v_e) + f_{\text{sl0}} F'_{\text{rwy}}, \qquad (7)$$

where $F_{\text{fric}}^{\text{r}}(\overline{v}_e)$ is a conventional sliding friction in pure rolling wheels and the rolling elements in the bearings bucks nodes [10]:

$$F_{\text{fric}}^{\text{r}}(v_e) = f_0 \big(G \cos(\psi_{0,50}) + F_{rw}'(v_e) \times \sin(\psi_{0,50}) \big).$$ (8)

where f_0 is a conditional (or) the coefficient of friction [11, 14, 15]:

$$f_0 = \frac{n_w f_r}{r_r} + \frac{n_b f_{r0}}{r_b} \frac{k}{n_{bn} n_{tq}};$$ (8, a)

f_{sl0} is the coefficient of sliding friction ridges of wheels on the rails (usually take $f_{sl0} = 0{,}25$);

F_{rwy}' projection of the forces of aerodynamic drag on the transverse axis of the car (according to (5) the value of the calculated) [15].

In (8, a), and the following designations are accepted: n_w number of wheels of the cart, pieces. ($n_w = 8$); f_r the friction coefficient of friction, since this ratio is equivalent to the shoulder of a friction pair of ka-treatment (the wheel on a track $f_r = 5 \times 10^{-6}$, steel hardened steel $f_r = 1 \times 10^{-6}$), r_r wheel radius, equal to the freight car 0,475 m; $n_{bn} = 8$ number bucks nodes in the cart, pieces.; $f_{к0}$ the friction coefficient of the rolling elements in the rings of the bearing (usually take

0,001×10⁻³), m; n_{tq} the total quantity of the rolling elements, which include the load in each of the bearing, pieces.; k is a constant factor, taken depending on the location of the rolling elements and type of bearings quality of (for the calculation shall take $k = 4{,}6$) [16]; n_b number in the bearings bucks nodes in the cart, pieces. ($n_b = 16$); r_n outer radius of the inner ring of the bearing raceways, m (0,079 m).

Introducing the concept of "shift" $F_{\text{sh}.x}$ and "restraint" $F_{\text{res}.x}$ of forces, due to the active and all jet forces, we obtain [5 – 8]:

$$F_{\text{sh}.x} = G_x = G \sin(\psi_0);$$ (9)

$$F_{\text{res}.x}(v_e) = F_{rwx}'(v_e) \cos(\psi_0) + F_{\text{torm.}}(v_e).$$

Rewrite the last expression with the account of (7) and (8)

$$F_{\text{res}.x}(v_e) = F_{wx}'(v_e) \times \cos(\psi_0) + f_0 \begin{pmatrix} G \cos(\psi_0) + \\ F_{rwx}'(v_e) \sin(\psi_0) \end{pmatrix} + f_{sl0} F_{rwy}',$$

and after transformations

$$F_{\text{res}.x}(v_e) = F_{wx}'(v_e)\big(\cos(\psi_0) + f_0 \sin(\psi_0)\big) + f_0 G \cos(\psi_0) + f_{sl0} F_{rwy}'.$$ (10)

The condition of the car from rolling on the first main area of the slide with a slope of not steeper than 50 ‰ at the length of this section of up to 50 m is [10]

$$F_{\text{sh}.x} \gg F_{\text{res}.x}(v_e).$$ (11)

Hence, the excess forces $\Delta F_{к,50} = F_{\text{sh}.x} - F_{\text{res}.x}(v_e)$. This force arises in the first specialized site of the hill and is the driving force. It causes the slide car given the force of gravity G with a velocity $v_{e,50}(t)$ and the acceleration of the $a_{50}(t)$. The force depends on the foundations of the Mr. from the angle of rolling hills $\psi_{0,50}$ and, to some extent, from the coefficient of friction ridges of wheels on the rails, as well as the condition of rolling bearings in буксовых nodes carts. Therefore, in order to ensure the movement of the car at the end of the first specialized site slides with the velocity $v_{e,50}(t)$ less than the speed of input $v_{ewx}(t)$ at the first brake position (I BP), i. e. $v_e(t) < v_{ewx}(t)$, is sufficient selection of rational values $\psi_{0,50}$ as the basic geometric parameter slides.

IV. Methods of Solution

The formation of dynamic and constructing a mathematical model of the car from rolling down the hill with is based on classical concepts and provisions of theoretical and applied mechanics (for example, the theorem of addition of velocities under complex movement, roll, slip, slide with rolling, communications, the reaction of communication, the principle clear constraints, the basic law of the dynamics of the absolute motion (the principle of the D'Alembert); basic concepts of differential and integral calculus [12 – 14]).

V. Methods of Constructing the Mathematical Model of the Car from Rolling Down the Hill with

We shall take into account, that the car rolled down the hills steadily so a portable acceleration of the car $\overline{a}_e = \overline{a}$ is the absolute acceleration $\overline{a}_{\text{abs}} = d\overline{v}_{\text{abs}}/dt$ [14, 15].

Substituting (9) and (10) of the basic law of the dynamics for a portable car (or the principle of D'Alembert) in the coordinate form [12 – 15] we have:

$$M \frac{dv}{dt} = F_{sh.x} - F_{res.x}(v_e).$$

Imagine the last expression in the form of:

$$M \frac{dv}{dt} = F_0 - b_0 (v_e \cos(\psi_{0,50}) - c_0)^2 , \quad (12)$$

b_0 famous for the largest constant factor in (5) for the location of the forces of aerodynamic drag F'_{wx}, N/(m/s)²:

$$b_0 = 0{,}5 c_w \rho_w A_t \left(\cos(\psi_{0,50}) + f_0 \sin(\psi_{0,50})\right); \quad (14)$$

c_0 famous for the largest factor constant with the dimension of speed, m/s:

$$c_0 = v_{aw} \cos(\xi) \quad (15)$$

Marking for the convenience of recording $v_e \cos(\psi_{0,50})$ via the v and sharing both parts of (14) on the b_0, we will have

$$\frac{M}{b_0} \frac{dv}{dt} = a_0^2 - (v - c_0)^2 , \quad (16)$$

where a_0^2 known constant with the dimension of speed, (m/s)²:

$$a_0^2 = F_0 / b_0 . \quad (17)$$

VI. RESULTS OF SOLUTION

a) *Mathematical Modeling of The Speed of Sliding and Passed Way of the Car with the Roller Coaster*

Separating the variables in the equation (12), after transformation, we obtain [14, 15]:

$$\frac{b_0}{M} dt = \frac{dv}{a_0^2 - (v - c_0)^2} ,$$

where *M* is the mass of the car with the load, kg.

Transforming the last equation with account of (9) and (10) and the fact that $G = Mg$, for the first specialized site slides with a slope of not steeper than 50 ‰ at the length of this section of up to 50 m we obtain:

$$M \frac{dv}{dt} = Mg\left(\sin(\psi_{0,50}) - f_0 \cos(\psi_{0,50})\right) - f_{sl0} F'_{rwy} - F'_{wx}(v_e)\left(\cos(\psi_{0,50}) + f_0 \sin(\psi_{0,50})\right).$$

where F_0 is the difference famous of the largest driving forces and the forces of resistance, the attached to the system "wagon - cargo", N:

$$F_0 = Mg\left(\sin(\psi_{0,50}) - f_0 \cos(\psi_{0,50})\right) - f_{sl0} F'_{rwy}, \quad (13)$$

or, having in mind that $d(v - c_0) = dv$,

$$\frac{b_0}{M} dt = \frac{d(v - c_0)}{a_0^2 - (v - c_0)^2} , \quad (18)$$

Taking the integrals of rational functions of both parts of the last equality, we have:

$$\frac{b_0}{M} t = \int_{v_0}^{v} \frac{d(v - c_0)}{a_0^2 - (v - c_0)^2} . \quad (19)$$

The right side of the last equality is a table integral of the rational of functions of the form [17]:

$$\int \frac{dx}{a^2 - x^2} = \frac{1}{2a} \ln \frac{a + x}{a - x} , \text{ when } |x| < a \neq 0 .$$

In accordance with this, the right-hand part of the expression (19) after the transformations are presented in the form of:

$$\frac{b_0}{M} t = \frac{1}{2a_0} \ln \left| \frac{a_0 - c_0 + v}{a_0 + c_0 - v} \right|_{v_0}^{v} . \quad (20)$$

Hence, substituting the limits of integration v and v_0 (initial speed of the car from rolling with slides), after transformations we obtain:

$$\frac{b_0}{M} t = \frac{1}{2a_0} \ln\left|\frac{a_0 - c_0 + v}{a_0 + c_0 - v} \frac{a_0 + c_0 - v_0}{a_0 - c_0 + v_0}\right|. \quad (21)$$

Denoting the second factor of expression under the sign of natural logarithm, as the attitude of well-known for the largest data,

$$d_0 = \frac{a_0 + c_0 - v_0}{a_0 - c_0 + v_0}, \quad (22)$$

rewrite (21) in the form of:

$$2a_0 \frac{b_0}{M} t = \ln\left|\frac{a_0 - c_0 + v}{a_0 + c_0 - v} d_0\right|.$$

Hence, the dependence of the time t on the speed of sliding carriage in portable moving $v(t) = v_e(t)$ has the form:

$$v = \frac{a_0(e^{\alpha t} - d_0) + c_0(e^{\alpha t} + d_0)}{e^{\alpha t} + d_0} = c_0 + \frac{a_0(e^{\alpha t} - d_0)}{e^{\alpha t} + d_0}.$$

Convert the last expression

$$v = c_0 + \frac{a_0 e^{\alpha t} - a_0 d_0 + a_0 d_0 - a_0 d_0}{e^{\alpha t} + d_0} = c_0 + \frac{a_0(e^{\alpha t} + d_0) - 2a_0 d_0}{e^{\alpha t} + d_0}.$$

Here we finally obtain the projection of the velocity of sliding the car to the axis Ox (see Fig. 1)

$$v(t) = c_0 + a_0 - \frac{2a_0 d_0}{d_0 + e^{\alpha t}}.$$

$$t = \frac{1}{\alpha} \ln\left|\frac{a_0 - c_0 + v}{a_0 + c_0 - v} d_0\right|. \quad (23)$$

where α – known in size constant, which the dimension of the 1/s:

$$\alpha = 2a_0 \frac{b_0}{M}. \quad (24)$$

Potentiating of the expression (23) and omitting intermediate mathematical calculations, we obtain:

$$v(e^{\alpha t} + d_0) = (a_0 + c_0)e^{\alpha t} - (a_0 - c_0)d_0$$

From here after a number of transformations find the projection of the velocity $v(t)$ for from rolling of a wagon according to the profile of slides from the impact of the projection of the force of gravity and the wind on the longitudinal axis of the

From the last formula, given that $v = v_e \cos(\psi_{0,50})$ (see equation (16)), find the speed of the car $v_e(t)$ in the direction of the slide of the hill on the axis $O_1 x_1$

$$v_e(t)_{50} = \frac{1}{\cos(\psi_{0,50})}\left(c_0 + a_0 - \frac{2a_0 d_0}{d_0 + e^{\alpha t}}\right). \quad (25)$$

Analyzing (25) note that the dependence of the speed of the car from rolling on the profile of the hills in time $v_e(t)$ exponential: the car can quickly get up to speed on the profile of the hill and continue almost uniformly, if you do not take any practical measures for its reduction, for example, do not use the brake devices. In addition, the speed of the car when rolling on the profile of the hills in the main depends on the angle of descent slides ψ_0 to the horizontal axis (Ox axis). The more the angle of descent $\psi0$, the less the denominator of (25) (i. e. $\cos(\psi_0)$), and the more the $v_e(t)$. From this it is clear that the required speed of the car to the drain of the roller coaster at constant external power factors should be found by modifying the profile of the roller coaster.

Again separating the variables (25) given that $v_e = \dfrac{dx_1}{dt}$, we will have

$$dx_1 = \frac{1}{\cos(\psi_{0,50})}\left((c_0 + a_0)dt - 2a_0 d_0 \frac{dt}{d_0 + e^{\alpha t}}\right).$$

Integrating the obtained expression in the range from 0 to t, we have:

$$x_1 = \frac{1}{\cos(\psi_{0,50})}\left((c_0 + a_0)t - 2a_0 d_0 \int_0^t \frac{dt}{d_0 + e^{\alpha t}}\right). \tag{26}$$

The second member of the right side of the last equality is a table integral containing the Exhibitor in the following form [17]:

$$\int \frac{dx}{a + be^{\alpha x}} = \frac{x}{a} - \frac{1}{\alpha a}\ln\left|a + be^{\alpha x}\right|,\ a \neq 0,\ \alpha \neq 0.$$

Introducing (26) in accordance with the last integral and substituting the limits of integration $(0, t)$ of this ratio, we finally obtain the:

$$x(t)_{50} = \frac{1}{\cos(\psi_{0,50})}\left((c_0 + a_0)t - 2a_0\left(\frac{1}{\alpha}\ln\left|\frac{d_0 + e^{\alpha t}}{d_0 + 1}\right| - t\right)\right). \tag{27}$$

From this it is clear that the distance traveled (path) of the car depending on the time describes the dependence of (27): with the increase of the time of sliding t car distance $x(t)$ is almost increases linearly.

In the particular case, from the expression (27) at $t = 0$, we have $v = 0$, $x = 0$.

Passing to the limit as $t \to \infty$, you can get the maximum speed of the car

$$v_{max} = \frac{1}{\cos(\psi_{0,50})}(c_0 + a_0). \tag{28}$$

If the first specialized site slides with a slope of not steeper than 50 ‰ has a length of more than 50 m, this area may consist of two core elements, and the second element can be made with a slope of 30 ÷ 35 ‰. In this case the speed of the roll of the car and the path to find (25) and (27) in the form of:

$$v_{e,30} = \frac{1}{\cos(\psi_{0,30})}\left(c_0 + a_{0,30} - \frac{2a_{0,30}d_{0,30}}{d_{0,30} + e^{\alpha_{30}t}}\right); \tag{25, a}$$

$$x(t)_{30} = \frac{1}{\cos(\psi_{0,30})}\left((c_0 + a_{0,30})t - 2a_{0,30}\left(\frac{1}{\alpha_{30}}\ln\left|\frac{d_{0,30} + e^{\alpha_{30}t}}{d_{0,30} + 1}\right| - t\right)\right), \tag{27, a}$$

where $b_{0,30}$, $a_{0,30}$, $d_{0,30}$ and $\alpha_{0,30}$ according to (14), (17) (22) and (24) are constant, determined from the following relationships

$$b_{0,30} = 0{,}5c_w\rho_w A_t\left(\cos(\psi_{0,30}) + f_0\sin(\psi_{0,30})\right); \tag{14, a}$$

$$a_{0,30}^2 = F_{0,30}/b_{0,30} \tag{17, a}$$

taking into account the fact that, according to the (13),

$$F_{0,30} = Mg\left(\sin(\psi_{0,30}) - f_0 \cos(\psi_{0,30})\right) - f_{\text{ск0}} F'_{rwy} ; \qquad (13, a)$$

$$d_{0,30} = \frac{a_{0,30} + c_0 - v_{0,30}}{a_{0,30} - c_0 + v_{0,30}}, \qquad (22, a)$$

taking into account the fact that $v_{0,30}$ the initial velocity of the car from rolling on the second core element of the roller coaster at $t = t_1$, which is equal to the finite speed of the first core element $v_{0,50}$ for $t = t_1$, $v_{0,30} = v_{0,50}$.

$$\alpha_{30} = 2a_{0,30} \frac{b_{0,30}}{M} . \qquad (24, a)$$

Analyzing the obtained results of the research, we note that the speed of sliding cars $v_{e,30}(t)$ at $t = t_2$ (see. (25, a)), as the speed of the input $v_{ewx}(t)$ at the first brake position (I BP), obtained with the method of

selection of rational values of the gradient of slides $\psi_{0,50}$ and $\psi_{0,30}$ should be less than the maximum speed input on I BP, i. e. $v_{e,30}(t) = v_{ewx}(t) < [v_l] = 8,5$ m/s [11, 18]. This must be a condition to the speed of sliding the car at the end of the second section of the $v_{e,30}(t)$ at $t = t_2$ would be less than the speed at the end of the first section of the $v_{e,50}(t)$ for $t = t_1$, i. e. $v_{e,30}(t) = v_{e,50}(t)$.

Using the method of binding decisions of the piecewise-linear equations on the basis of the dimensionless delayed a single function Heaviside [19], the speed of movement of the subway car and the path traversed by any stretch of the slides within a profile up to the moment of braking, s:

$$v_e(t) = \frac{1}{\cos(\psi_0)} \left(c_0 + a_0 - \frac{2a_0 d_0}{d_0 + e^{\alpha t}} \right) \sigma_0(t - t_i); \qquad (29)$$

$$x(t) = \frac{1}{\cos(\psi_0)} \left((c_0 + a_0)t - 2a_0 \left(\frac{1}{\alpha} \ln\left| \frac{d_0 + e^{\alpha t}}{d_0 + 1} \right| - t \right) \right) \sigma_0(t - t_i), \qquad (30)$$

where $\sigma_0(t - t_i)$ (where $t_i \in (t_1, t_2)$) dimensionless delayed single Heaviside function, allowing you to imagine the time t one analytical expression, fit for any value of the coordinates of the t_i in the interval of $0 \le t \le t_i$, and $\sigma_0(t - t_i) = 0$ for $t_i < t$.

Thus, using the principle of the D'Alembert mechanics, method of separation of re-variables, the table integrals of rational functions and integral containing the Exhibitor, as well as linking method of solutions of piecewise-linear functions are deduced analytical formulas for determining the speed of the car from rolling on the profile of slides $v_e(t)$ and the distance $x(t)$ with the passage of time.

VII. Conclusions

a) Obtained on the basis of classical provisions of theoretical mechanics, computational and mathematical models rolling off the wagon with the sorting slides under the influence of the projection of the forces of gravity and the force of resistance to the wind on the longitudinal axis of the allowed us to determine the speed of the car from rolling $v_e(t)$ and the distance $x(t)$ on the first main area of the slide with the passage of time. In the particular case, the

obtained analytical expressions of the dynamics of rolling the car will find the ultimate formula to determine the speed and distance covered, or only from the impact of the projection of the force of gravity on longitudinal axis, or from the effects of only the wind.

b) Analysis of the results of analytical researches allowed to establish, that the speed of the car when скатывании on the profile of the hills in the main depends on the angle of descent slides ψ_0 to the horizon. The more the angle of descent ψ_0, the less cos (ψ_0) and the more than $v_e(t)$. From this it is clear that the required speed of the car to the drain of the roller coaster at constant external power factors should be found by modifying the profile of the roller coaster.

c) The results of analytical studies of the dynamics of rolling of a wagon according to the first high-speed site slides can be used for all other parts of the slide with account of peculiarities of deceleration forces on these sites.

The distinctive feature of (novelty) derived analytical formulas for the speed of the car from rolling on the high-speed road rolling down the hump is in the representation of the forces of aerodynamic resistance

of the wind depending on the speed of the car from rolling ve(t) on the profile of slides and correct accounting of the forces of resistance, resulting in the movement of the car. The obtained results of the research, are available for designers sorting slides, are a step forward in solving this problem.

The advantage of (importance) of this methodology is the possibility to construct a mathematical model of the car from rolling with sorting slides taking into account the dependence of the force of aerodynamic resistance of the wind to the speed of the car from rolling ve(t) , speed   and direction of air flow (ξ).

In the perspective of the received results of researches can be used in solving the technical problem of definition of rational geometric parameters (profile ψ0) slides and kinematics characteristics of the car (v(t), x(t)) at its from rolling with sorting the roller coaster.

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Investigation of Fatigue Crack Growth Rate in Fuselage of Large Transport Aircraft using FEA Approach

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Abstract- Transport aircraft is a highly complex airframe structure. The aircraft fuselage shell is composed of stressed skin, circumferential frames and longitudinal stringers. The skin is connected to frames and stringers mostly by rivets. Fuselage has a number of riveted joints and is subjected to a major loading of differential internal pressurization. When the fuselage is pressurized and depressurized during each takeoff and landing cycle of aircraft, the metal skin of fuselage expands and contracts resulting in metal fatigue. Fatigue damage accumulates during every cycle of loading in the airframe structure during its operation. The accumulated damage reaches a critical value, a fatigue cracks initiate from riveted holes and propagate to critical sizes leading to catastrophic failure of the structure. The large transport aircraft are designed to tolerate large fatigue cracks. This paper focuses its attention on damage tolerance design of a fuselage structure of transport aircraft. The objective of this paper is to investigate crack initiation, and crack growth rate in the flat stiffened panel of fuselage structure. The longitudinal crack is initiated from the rivet hole location and stress intensity factor is calculated using modified virtual crack closure integral (MVCCI) method during each stage of crack propagation.

Keywords: differential internal pressurization, fatigue crack growth rate, longitudinal crack, metal fatigue, MVCCI method, stiffened panel, stress intensity factor.

GJRE-A Classification : FOR Code: 290204

INVESTIGATIONOFFATIGUECRACKGROWTHRATEINFUSELAGEOFLARGETRANSPORTAIRCRAFTUSINGFEAAPPROACH

Strictly as per the compliance and regulations of:

Investigation of Fatigue Crack Growth Rate in Fuselage of Large Transport Aircraft using FEA Approach

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Abstract- Transport aircraft is a highly complex airframe structure. The aircraft fuselage shell is composed of stressed skin, circumferential frames and longitudinal stringers. The skin is connected to frames and stringers mostly by rivets. Fuselage has a number of riveted joints and is subjected to a major loading of differential internal pressurization. When the fuselage is pressurized and depressurized during each takeoff and landing cycle of aircraft, the metal skin of fuselage expands and contracts resulting in metal fatigue. Fatigue damage accumulates during every cycle of loading in the airframe structure during its operation. The accumulated damage reaches a critical value, a fatigue cracks initiate from riveted holes and propagate to critical sizes leading to catastrophic failure of the structure. The large transport aircraft are designed to tolerate large fatigue cracks. This paper focuses its attention on damage tolerance design of a fuselage structure of transport aircraft. The objective of this paper is to investigate crack initiation, and crack growth rate in the flat stiffened panel of fuselage structure. The longitudinal crack is initiated from the rivet hole location and stress intensity factor is calculated using modified virtual crack closure integral (MVCCI) method during each stage of crack propagation. Fatigue crack growth rate can be estimated by using Paris law under spectrum loading analysis in the structure. In this paper for modeling CATIA V5 software is used and MSC PATRAN is used for meshing the stiffened panel and static linear stress analysis is carried out using MSCNASTRAN.

Keywords: differential internal pressurization, fatigue crack growth rate, longitudinal crack, metal fatigue, MVCCI method, stiffened panel, stress intensity factor.

I. Introduction

Aircraft structure is example where structural efficiency results in light weight and high operating stresses. The major part of the aircraft structure consists of built-up panels of sheets and stringers, such as wing and fuselage skin panels, spar webs and stiffeners. Despite all precautions, cracks have arisen in many of these structural elements. These cracks reduce the stiffness and the total load carrying capacity of the structure. Thus, they reduce the performance of the aircraft and limit the availability of the aircraft at the time of aircraft maximum performance. The fuselage is the main structure in the aircraft that holds crew, passengers and cargo. An aircraft fuselage structure must be capable of withstanding many types of loads and stresses. The principal source of the stresses in this structure is the internal pressure in high altitude caused by difference of cabin pressurization and reduction of the outside pressure with increase in altitude, but the structure is also subjected to other loads, such as bending, torsion, thermal loads, etc. The aircraft fuselage is composed of the skin consisting of a cylindrical shell typically 2 mm thick, circular frames and axial stringers, and normally these components are manufactured with an aluminium alloy and are connected by rivets. The skin of fuselage is to carry cabin pressure and shear loads, longitudinal to carry the longitudinal tension and compression loads due to bending, circumferential frames to maintain the fuselage shape and redistribute loads into the skin, and bulkheads to carry concentrated loads including those associated with pressurization of the fuselage.

II. Literature Review

Fatigue loads in a pressurised fuselage are mostly due to pressure cycles that occur with each takeoff or landing cycle during flight. The most common fatigue crack orientation in a pressurised fuselage is a longitudinal crack along the direction of maximum hoop stress. Damage tolerant designs use fracture mechanics data and analysis to predict crack growth rates and critical crack lengths [1]. Cabin pressure results in radial growth of the skin and this radial growth is resisted by frames and stringers giving local bending along the fastener lines. Fuselage skin panels are curved and these panels are under biaxial tension loading due to cabin pressure. Cabin pressurization is the main source of loading causing longitudinal skin cracks. Two types of damage most frequently associated with the structural integrity of the fuselage are longitudinal cracks under high hoop stresses induced by cabin pressurization and circumferential cracks under stresses from vertical bending of the fuselage. The prime objective was to present a systematic investigation of the damage

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tolerance design capability of typical aircraft fuselage structure for longitudinal cracks using linear elastic fracture mechanics [2]. Damage tolerant fuselage is supposed to sustain cracks safely until it is repaired or its economic service life has expired. Strength assessment of the structures is necessary for their in service inspection and repair. Damage tolerance analysis should provide information about the effect of cracks on the strength of the structure. Damage tolerance evaluation must include a determination of the probable locations and modes of the damage due to fatigue, corrosion, or accidental damage. The aircraft must be capable of successfully completing a flight during which likely structural damage occur as a result of bird impact. The crack propagation stage is studied by using stress intensity factor approach [3].

There are different methods used in the numerical fracture mechanics to calculate stress intensity factors (SIF). The crack opening displacement (COD) method and the force method were popular in early applications of FE to fracture analysis. The virtual crack extension (VCE) methods proposed by Parks [5] and Hellen [4] lead to increased accuracy of stress intensity factor results. The virtual crack extension method requires only one complete analysis of a given structure to calculate SIF. Both the COD and VCE methods can be used to calculate SIF for all three fracture modes. The equivalent domain integral method which can be applied to both linear and nonlinear problems renders mode separation possible [6]. The VCCT, originally proposed in 1977 by Rybicki and Kanninen [7], is a very attractive SIF extraction technique because of its good accuracy, a relatively easy algorithm of application capability to calculate SIF for all three fracture modes. Andrzej Leski [8], the implementation of the Virtual Crack Closure Technique in engineering FE calculations. SIF was fundamental quantity that governs the stress field near the crack tip. It depends on the geometrical configuration, crack size and the loading conditions of the body. The stresses are higher in the vicinity of the crack tip, which are characterized by the parameter stress intensity factor. Sethuraman.R and S.K. Maiti [9] have given the mathematical formulae for calculating the stress intensity factor using finite element software tool called as modified virtual crack closure integral technique for mode I. Shamsuzuha Habeeb and K.S. Raju [10] worked on Crack Arrest Capabilities in Adhesively Bonded Skin and Stiffener. The crack arrest capabilities and the load bearing characteristic of a stiffened panel subjected to uniform remote displacement field. Stringers were usually joined to the skin using rivets. Fracture analyses were conducted on stiffened panels with crack tip opening displacement fracture criteria. A linear elastic static stress analysis was performed and the stress intensity factor was calculated for both the stiffened panel for various crack lengths keeping the

same loading condition. Fracture occurs when the stress intensity factor reaches a critical value.

The fatigue tests on cracked structures for a range of aircraft aluminium alloys and spectra to reveal a generalized relationship between crack growth and crack size that is consistent with the Frost–Dugdale hypothesis [11], predicted linear relationship between the log of the crack length. The problems that arose when attempting to predict crack growth led to the statement by Newman et al. [12] that, the threshold regime, there is something missing either in the model or the test data is being affected by the load reduction test procedure. Further study is needed to improve the determination of the threshold and near threshold behaviour for metallic materials. The ability of the Frost–Dugdale law to partially overcome these deficiencies is shown in [13] where the law is used to predict crack growth on a cycle by cycle basis in full-scale aircraft fatigue tests. As a structure ages, we frequently encounter the phenomenon of crack/damage growth. Elber and Wolf [14], worked on fatigue crack closure under cyclic tensile loading. The results showed that a fatigue crack can be closed at the crack tip for up to half of the loading amplitude, leaving this portion of the cycle ineffective in propagating the crack. An expression for the crack propagation rate in terms of effective stress amplitude was proposed. This expression was fitted to existing constant amplitude crack data for 2024-T3 aluminum alloy.

III.   Finite Element Analysis

The finite element method is a numerical technique for solving engineering problems. It is most powerful analysis tool used to solve simple to complicated problems. The pre-processing stage involves the preparation of nodal co-ordinates & its connectivity, meshing the model, load & boundary conditions and material information for finite element models carried in MSC PATRAN described in Fig. 1. The processing stage involves stiffness generation, modification and solution of equations resulting in the evaluation of nodal variables, run in MSC NASTRAN. The post-processing stage deals with the presentation of results, typically the deformed configurations, elemental stresses and forces etc.
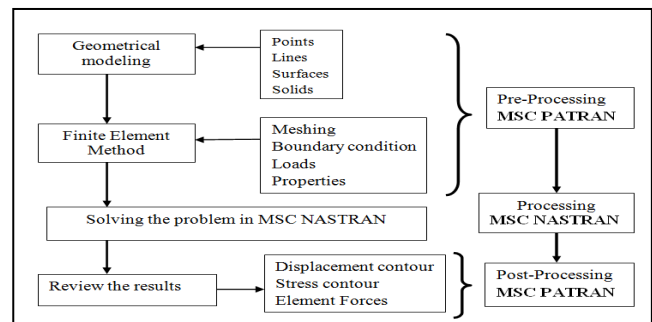
Figure 1 : Steps involved in Finite Element Analysis

a) Geometrical Configuration

Fuselage has cylindrical panel of radius 2000 mm, length 2500 mm and thickness of skin is 2 mm. It is the sectional cut out of the fuselage to do global stress analysis. The stiffened panel represents a most generic in fuselage structure. The stiffened panel dimensions are 2500 mm in the longitudinal direction and 1750 mm in transverse direction. The thickness of the stiffened panel skin is 2 mm. The stiffened panel has five frames (four bays) with 500 mm spacing and seven stringers (six bays) with 250 mm spacing. The frame has Z & L cross section with 753 mm^2 of cross sectional area and stringer has Z cross section with 177 mm^2 of cross sectional area. The thicknesses of all flanges of the stiffened panel are 3 mm. The frames and stringers are attached to the skin by row of rivet, 5 mm diameter placed at a pitch of 25 mm shown in Fig. 2 and corresponding cross sections shown in Fig. 3 and geometric modeling is carried out using CATIA V5 software as shown in Fig. 4.

Figure 4 : CAD model of the stiffened panel

b) Material Used for Analysis

Selection of aircraft materials depends on any considerations, which can in general be categorized as cost and structural performance. The key material properties that are pertinent to maintenance cost and structural performance are

- Density
- Young's modulus
- Fatigue strength
- Ultimate and Yield strengths
- Damage tolerance (fracture toughness and crack growth)
- Corrosion, etc.

Mechanical properties of the skin, stiffening members and rivets are required for finite element models. There is little information on the material properties of skin, stiffening members, and rivet material in the literature. Aluminium 2024-T3 and 2117-T4 is used for components fuselage and rivet respectively. Table 1 describes few material properties used for analysis.

Table 1 : Material properties used for the analysis [18-20]

Property	Aluminium 2024-T3	Aluminium 2117-T4
Density	2.77 g/cm^3	2.77 g/cm^3
Ultimate Tensile Strength	483 MPa	490 MPa
Tensile Yield Strength	362 MPa	350 MPa
Young's Modulus	72 GPa	71.7 GPa
Poisson's Ratio	0.33	0.33
Fracture Toughness	72.37 MPa√m	76.54 MPa√m
Material Constant, C	5 x 10^{-11}	4x 10^{-11}
Material Constant, n	3	3.2

IV. STRESS ANALYSIS OF THE STIFFENED PANEL

It involves in pre-processing stage, processing stage and post processing stage. Pre-processing stage involves details of mesh, load & boundary conditions. Pre-processing and post-processing stage is carried in MSC PATRAN.

Figure 2 : Detailed drafting view of the stiffened panel
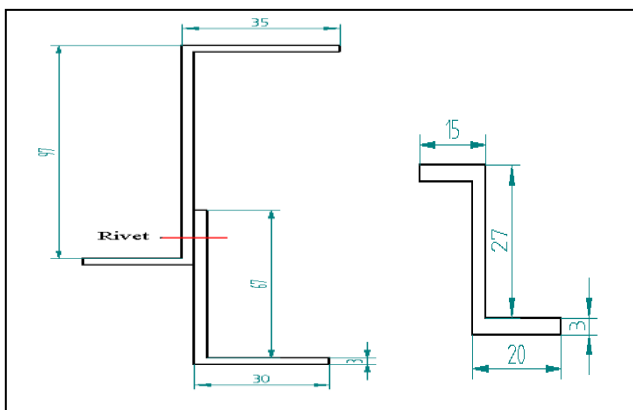
Figure 3 : Cross sections of frame and stringer

Table 2 : FE model summaries of the stiffened panel

Product description	Type of elements	No. of elements	Aspect ratio < 5
Skin	QUAD4	66820	1.00
Frame	QUAD4,TRIA3	38428	2.12
Stringer	QUAD4	42180	1.01
Rivet	BEAM	1340	--

a) Discretization of Geometrical Model

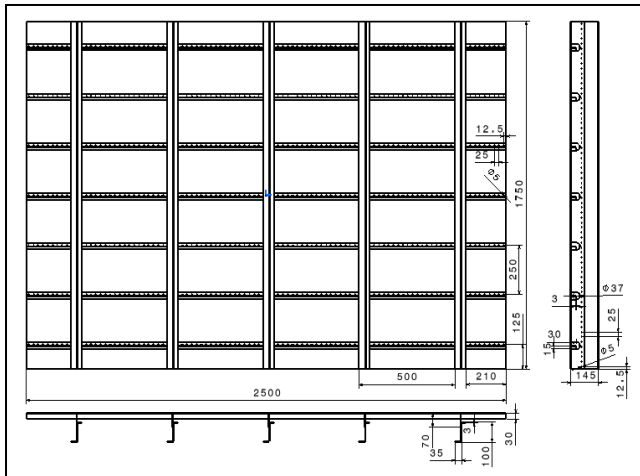The components of the stiffened panel are meshed by four noded shell elements. Skin of the stiffened panel is meshed by shell elements. Frame of the stiffened panel is meshed by 4 noded and 3 noded shell elements. Fine mesh is carried at mouse hole of frame to get accurate results. Three noded shell elements are used for the sake of continuity from fine mesh region to the coarse mesh region. The rivets are placed on the skin to hold the frames and stringers. Riveting is carried out by selecting the node on the skin and the corresponding node on the other component. Rivets are stimulated by using beam elements indicated in yellow color shown in Fig. 5 & Fig. 6. Aspect ratio should be less than 5 in all components of the stiffened panel. Meshing is checked for any duplicate nodes and elements. Table 2 gives number of elements and element type in the stiffened panel.
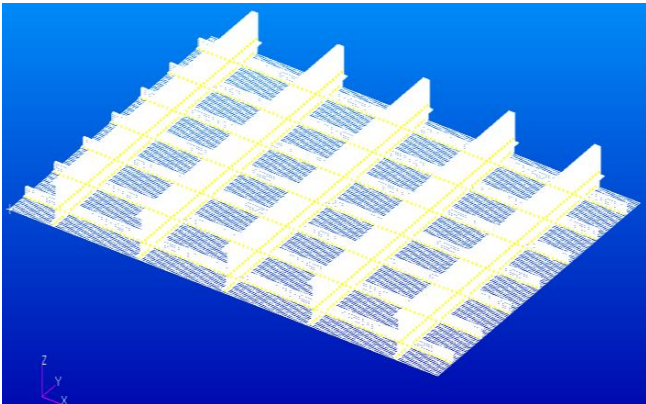
Figure 5 : FE Model of the stiffened panel
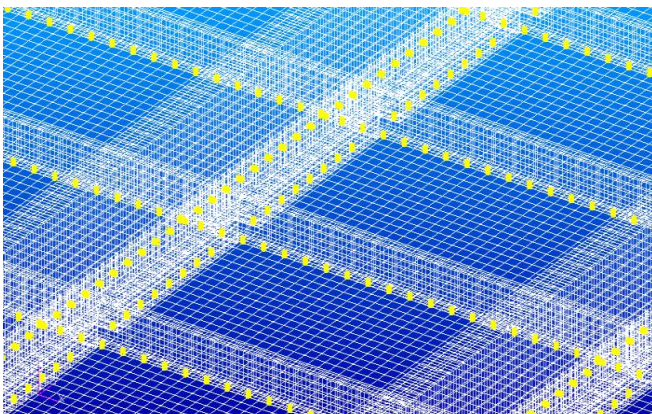
Figure 6 : Close up view of the stiffened panel with rivets

b) Load and Boundary Conditions

A differential internal pressure of 6 psi is considered for the current case. The hoop stresses are developed in the fuselage structure by application of internal pressurization. The hoop stress can be related with internal pressure in a thin walled pressure vessel:

$$\text{The hoop stress,} \quad \sigma_h = \frac{p \times r}{t} \tag{1}$$

Where r is the radius of fuselage shell (2000 mm) and t is the thickness of skin (2 mm). After applying these values, we get, the hoop stress 4.2 kg/mm². The radial hoop stresses developed in the fuselage cylindrical shell are equals to tensile stresses of the stiffened panel. The hoop stress developed in the model and corresponding cross sectional area gives the tensile load. This tensile stress is uniformly distributed over the cross section. Uniformly distributed tensile load is applied on the stiffened panel in transverse axial direction. Uniformly distributed load is applied on edges of skin and frame in the transverse direction. But, the stringers are not subjected to any loading, because stringers are passing in longitudinal direction in the stiffened panel. At other end, all the edge nodes of stiffened panel are constrained in all six degree of freedom.

c) Stress Contour for skin and frame

The maximum stress on skin is found at the rivet location where the rivets are used to fasten the frames and stringer on the skin. The tensile stress is uniformly varying from fixed end to loading end. The magnitude of maximum tensile stress is 8.19 kg/mm² shown in Fig. 7 at rivet location. The maximum stress locations are the probable locations for crack initiation. Skin is the most critical stress locations for the crack initiation. Generally longitudinal crack is initiated from rivet hole.

The maximum stresses are induces at mouse hole cut outs and found magnitude of maximum tensile stress is 13.4 kg/mm² shown in Fig. 8. This stresses are uniform in all the stringer cut outs. The maximum tensile stress locations are the probable locations for crack initiation.
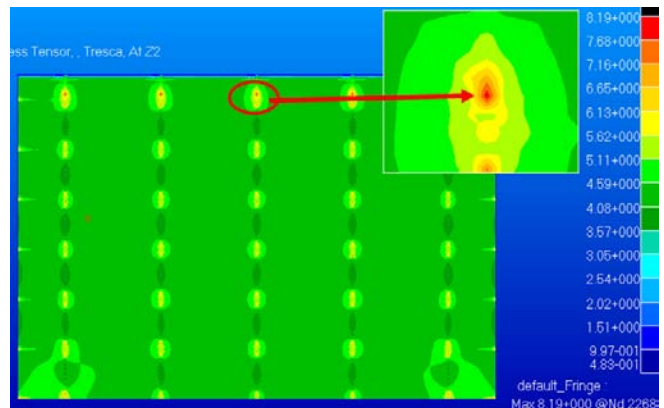
Figure 7 : Stress contour for skin
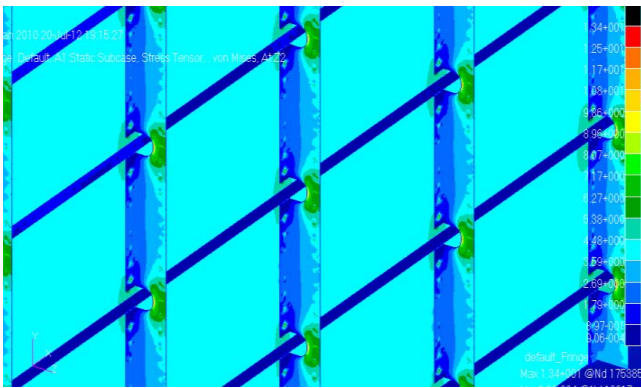
Figure 8 : Stress contour for frame

d) Crack Intiation in the Stiffened Panel

From the stress analysis of the stiffened panel, cracks are initiated from the maximum tensile stress location. There are two structural elements at the rivet location near the high stress location. Even though maximum stresses are found on mouse hole cut outs, cracks are initiated in perpendicular to the loading direction. Skin is the most critical stress locations for crack initiation. So, the maximum tensile stress location on stiffened panel is at skin near the rivet hole. Crack iniation period is studied by using stress concentration factor. Once crack is initiating from rivet location and it linkup with next rivet location, then it become lead crack and finally it leading to catarostrophic failure. Longitudinal crack is initiating from rivet location, which is perpendicular to loading direction. The crack is propagating as a function of number of fatigue cycles due internal pressurization.

The first approximation of the stiffened panel with a centre longitudinal crack is considered for varying crack length in the skin shown in Fig. 9. Crack iniation period is studied by using stress concentration factor, which does not play much important role.
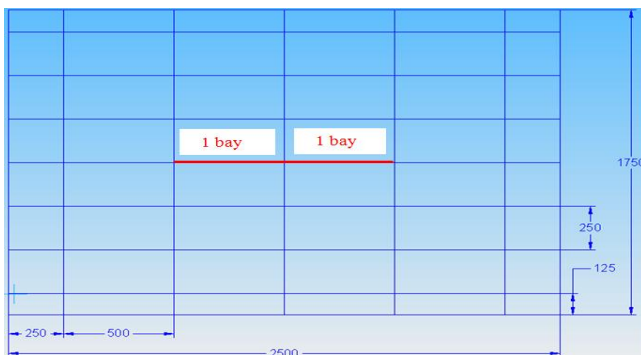
Figure 9 : Crack iniation in the stiffened panel

V. ESTIMATION OF FATIGUE CRACK GROWTH IN STIFFENED PANEL

The crack propagation stage is studied by using stress intensity factor approach. The stress intensity factor plays major role in crack growth period,

which is determined by using modified virtual crack closure integral (MVCCI) method. The skin is meshed by four noded shell elements shown in Fig. 10. Fine meshing is carried out near the crack upto crack length of 1000 mm to get crack propagation results. For mesh continuity from fine mesh to coarse mesh different four noded and three noded shell elements are used. The elemental edge length 1.5625 mm is maintained at crack region.
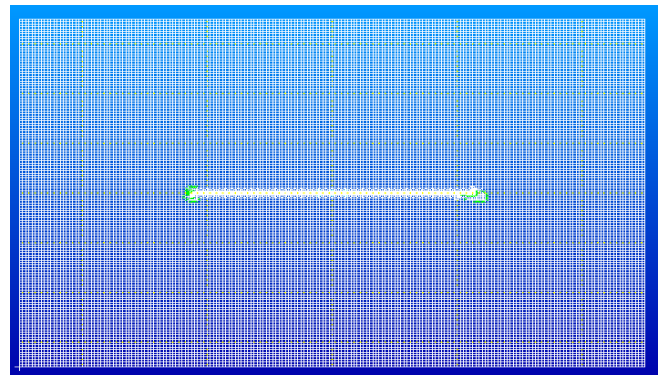
Figure 10 : FE Model of the stiffened panel skin near the crack

a) MVCCI method for calculation of SIF

Modified Virtual Crack Closure Integral (MVCCI) method is used to determine stress intensity factor for different crack lengths in the stiffened panel. MVCCI method is based on the energy balance. In this technique, SIF is obtained for fracture mode from the equation.

$$G_i = \frac{k_i^2}{E} \beta \quad (i= 1,2,3) \qquad (2)$$

Where G_i is the energy release rate for mode i, K_i is the stress intensity factor for mode i, E is the modulus of elasticity and β is 1 for plane stress condition.

Calculation of the energy release rate is based on Irwin assumption that the energy released in the process of crack expansion is equal to work required to close the crack to its original state as the crack extends by a small amount Δ a. Irwin computed this work as

$$W = \frac{1}{2} \int_0^{\Delta a} u(r)\sigma(r - \Delta a)dr, \qquad (3)$$

Where u is the relative displacement, r is the distance from the crack tip, Δa is the change in virtual crack length.

Therefore, the strain energy release rate is

$$G = \lim_{\Delta a \to 0} \frac{W}{\Delta a} = \lim_{\Delta a \to 0} \frac{1}{2\Delta a} \int_0^{\Delta a} u(r)\sigma(r - \Delta a)dr, \quad (4)$$

After simplification, modified strain energy release rate is

$$G = \frac{F \times \Delta u}{2 \times \Delta a \times t} \quad N/mm \qquad (5)$$

Where F is forces at the crack tip, Δu is crack opening displacement (COD), t is thickness of the skin and Δa is the elemental edge length near the crack tip. The stress intensity factor value at the crack tip can be calculated as follows: (i) Force at the crack tip is calculated by means of adding two elemental forces above the crack tip, and (ii) Crack opening displacement is calculated by means of subtracting the two elemental displacement values at the crack tip.

From FE software (MSC NASTRAN)

For crack length of 100 mm (2a=100 mm, a=50 mm)

Crack opening displacement (COD), $\Delta u = 0.029099$ mm

Forces at the crack tip opening displacement, F = 889.2991 N

Elemental edge length at the crack tip, $\Delta a = 1.5625$ mm

Thickness of the skin, t = 2 mm

Then, Strain energy release rate, G=4.1408 N/mm

Therefore, Stress intensity factor for mode I loading,

$K_{I\ FEA} = 16.8619$ MPa$\sqrt{m}$
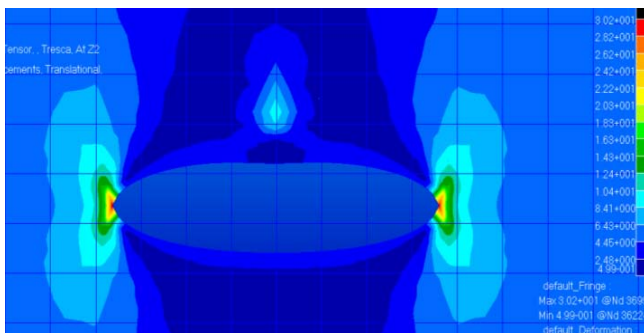
Figure 11 : Close up view of stress contour for skin at crack tip

A linear static stress analysis is performed for the stiffened panels for various crack lengths keeping the same loading condition. Figure 11 shows the stress contour for the stiffened panel skin crack. Orientation of crack is in longitudinal direction and crack widens due to loading in transverse direction. The stresses at crack tip are found maximum and its magnitude is 30.2 kg/mm^2.

The above calculation is carried for different crack length considering a known load. The stress intensity factor value is calculated by using MVCCI method for the stiffened panel. The stress intensity factor is tabulated in steps of 50 mm crack length shown in Table 3.

Table 3 : Stress intensity factor of the stiffened panel

Crack length (2a) in mm	COD (Δu) in mm	Elemental forces at crack tip (F) in N	Strain energy release rate (G) in N/mm	SIF, $K_{I\ FEA}$ in MPa$\sqrt{m}$
50	0.022	695.07	2.502	13.10
100	0.029	889.29	4.142	16.86
150	0.033	1026.3	5.533	19.49
200	0.036	1141.9	6.739	21.52
250	0.041	1245.5	8.172	23.69
300	0.044	1340.6	9.506	25.55
350	0.045	1363.2	9.702	27.16
400	0.049	1512.4	12.08	28.79
450	0.053	1590.9	13.38	30.31
500	0.055	1666.1	14.67	31.75
550	0.057	1736.5	15.96	33.11
600	0.059	1802.1	17.21	34.37
650	0.062	1863.2	18.39	35.54
700	0.063	1918.3	19.50	36.60
750	0.065	1966.7	20.51	37.53
800	0.066	2036.4	21.36	38.31
850	0.067	2037.3	22.02	38.89
900	0.068	2058.6	22.48	39.29
950	0.069	2079.1	22.92	39.67
970	0.066	2017.8	21.39	39.14
1000	0.068	2046.7	22.22	39.06

b) *Damage Growth under Fatigue Loading*

The fatigue strength of a component or structure can be significantly reduced by the presence of a crack or any other sharp discontinuities. More commonly fatigue cracks propagate from the initial to the critical crack size before the final failure occurs. The most common type of sub-critical crack growth is due to fatigue in the presence of an existing crack. In materials science, fatigue is the progressive, localised, and permanent structural damage that occurs when a material is subjected to a cyclic load. In general, the fatigue process is depicted by three distinct regions. Region III is associated with rapid crack growth and as such is typically thought to account for a small fraction of the total life. Region II has received the greatest attention as it is in this region where the ''Paris'' crack growth law [15] can be applied to predict fatigue crack growth propagation.

$$\frac{da}{dN} = C \ x \ (\Delta K)^m \qquad (6)$$

Where, ΔK is stress intensity factor range under cyclic loads, N is the number of cycles, and C and m are the material constants obtained from experiments. ΔK is obtained by:

$$\Delta K = K_{max} - K_{opening} \ \text{MPa}\sqrt{m} \qquad (7)$$

$$K_{opening} = K_{max} (0.5 + 0.4 \ R)$$

$$R = \text{stress ratio} = \frac{\sigma_{min}}{\sigma_{max}} = 0 \ (\text{since} \ \sigma_{min} \rightarrow 0)$$

First step of calculating fatigue crack growth rate [16],

For crack length 2a = 50 mm,

Stress Intensity Factor Range ΔK = 6.55 MPa√m,

Fatigue Crack Growth Rate $\frac{da}{dN} = (5 \times 10^{-11})(6.55)^3$

= 1.405 x 10-8 mm/cycle,

No. of cycles for crack $\Delta N = \Delta a / (\frac{da}{dN}) = 1/(1.405 \times 10^{-8})$

= 71.174 x 10^6 cycles = $(1 \times 10^{-3})/(1.405 \times 10^{-8})$

= 71174 cycles

The above calculation is carried for different crack length considering a known load. The fatigue crack growth rate and number of cycles is tabulated in steps of 50 mm crack length shown in Table 4.

Table 4 : Number of cycles required for crack growth rate

Crack length (2a) in mm	ΔK in MPa√m	$\frac{da}{dN}$ in mm/cycles	No. of cycles for 1mm crack	N = N + ΔN cycles
50	6.55	1.405E-8	71174	71174
100	8.43	2.995E-8	33384	104558
150	9.74	4.627E-8	21611	126169
200	10.76	6.228E-8	16054	142223
250	11.84	8.309E-8	12034	154257
300	12.77	1.042E-7	9592	163849
350	13.58	1.252E-7	7986	171835
400	14.39	1.491E-7	6704	178539
450	15.15	1.740E-7	5745	184284
500	15.87	2.000E-7	4999	189283
550	16.55	2.268E-7	4408	193691
600	17.18	2.537E-7	3940	197631
650	17.77	2.805E-7	3564	201195
700	18.30	3.064E-7	3263	204459
750	18.76	3.303E-7	3026	207485
800	19.15	3.514E-7	2845	210330
850	19.44	3.676E-7	2720	213050
900	19.64	3.791E-7	2637	215687
950	19.83	3.901E-7	2562	218249
970	19.57	3.747E-7	2668	220917
1000	19.53	3.724E-7	2684	223601

VI. Result and Discussion

From the linear static stress analysis of the stiffened panel has been carried out. A differential internal pressure of 6 psi was considered for the current problem. Fatigue crack propagation stage was studied by using SIF approach for the stiffened panel. Fatigue crack growth rate was calculated using Paris law to predict life of the structure. SIF value was calculated for the stiffened panel with different crack lengths.

a) Study of crack propagation in the stiffened panel

Stress Intensity Factor v/s different crack lengths are plotted shown in Fig. 12. It is observed that, SIF increases gradually with increase in the crack length. When the crack reaches nearer to the frame, the value of SIF keeps decreasing. It found that, the value of SIF 13.10 MPa√m at crack length of 50 mm and increases to 39.06 MPa√m at crack length of 1000 mm.

The maximum stress intensity factor is 39.67 MPa√m found at crack length of 950 mm. There is a decrement in SIF value due to presence of frame at 1000 mm. This plot indicates the frame is able to arrest the further crack propagation.
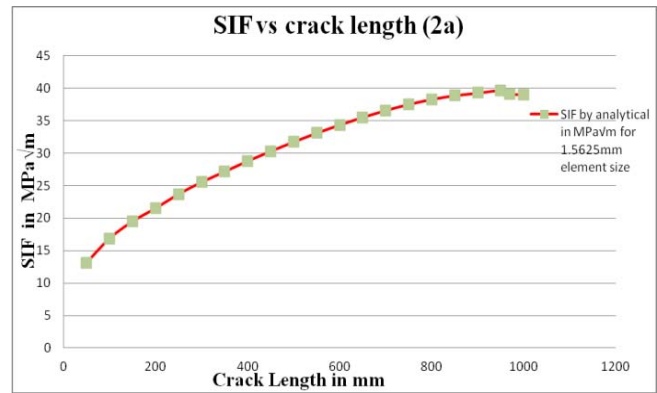
Figure 12 : Variation of SIF as a function of crack length

b) Study of fatigue crack growth rate in the stiffened panel

Fatigue crack growth rate is calculated using Paris law of damage crack growth rate equation. After crack gets initiated from rivet hole location. This was achieved by initiate the longitudinal crack in the stiffened panel with steps of 50 mm crack length. This crack grows as number of cycles increased. The fatigue process is depicted by three distinct regions.
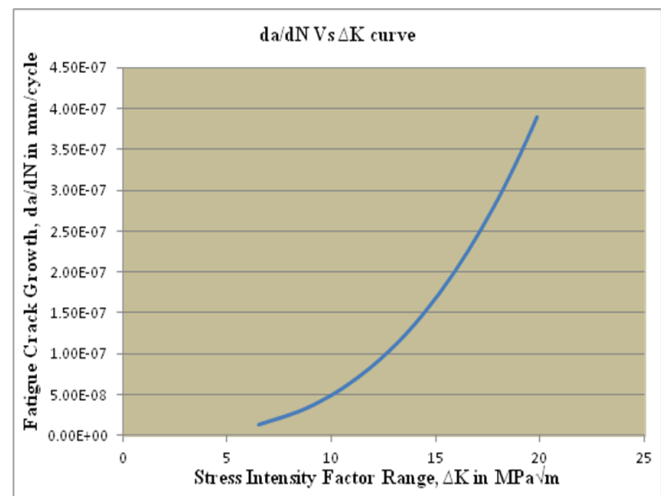
Figure 13 : Variation of Fatigue Crack Growth Rate and ΔK

Region I is associated with slow crack growth, region III is associated with rapid crack growth and as such is typically thought to account for a small fraction of the total life. Region II has received the greatest attention to predict crack growth. The presence of two separate parts, skins and stringers, guarantee the structural integrity of the component when propagating defects and cracks are present and are thus the key

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factor in aircraft structures [17]. Fatigue crack growth rate is found 1.405×10^{-8} mm/cycles for crack length of 50 mm and number of cycles required 71174 cycles for 1mm crack growth. Figure 13 shows Fatigue Crack Growth Rate v/s Stress Intensity Factor Range. Crack growth rate is drastically increases as number of cycles and crack growth rate 3.901×10^{-7} mm/cycles are found maximum at crack length of 950 mm. Finally crack growth rate is reduces to 3.72×10^{-7} mm/cycles at frame location [21]. This predicts frame is able to arrest the further crack growth. Figure 14 gives information regarding number of cycles required to propagate crack. Number of cycles required 2,23,601 cycles are required to grow crack length of 1000 mm.
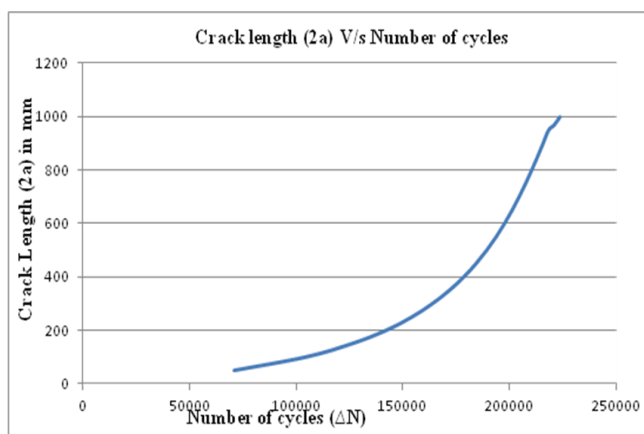
Figure 14 : Variation of crack length and number of cycles

VII. Conclusions

Stress analysis of the stiffened panel was carried out and maximum tensile stress was identified at the rivet hole of skin. Center longitudinal crack was initiated from rivet location of skin. Fatigue crack propagation was estimated by using stress intensity factor approach [22]. Stress intensity factor calculations were carried out for various incremental cracks from 50 mm to 1000 mm. The maximum value of stress intensity factor 39.67 MPa√m was observed at crack length of 950 mm. The value of stress intensity factor 39.06 MPa√m was observed at frame location. The obtained value of stress intensity factor 39.06 MPa√m at crack length of 1000 mm, which is less than fracture toughness of material 72.37 MPa√m. This can conclude that, frame is able to arrest the crack propagation. Fatigue crack growth rate and stress intensity factor range was estimated with of Paris law of damage crack growth.

VIII. Acknowledgment

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Acceptance Testing of Electro Hydraulic based Aircraft Actuator using LabVIEW

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Abstract- This paper presents an approach to perform aircraft actuator Acceptance Testing capability. Efforts include design and development of Test system for Electro Hydraulic aircraft actuator, in nominal condition that may be used along with measurement data to generate effective test results. LabVIEW platform is used for developing the test system.To develop communication between the LabVIEW based Test software and Actuator, Portable Test Controller (PTC), is used.

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GJRE-A Classification : FOR Code: 290501

ACCEPTANCETESTINGOFELECTROHYDRAULICBASEDAIRCRAFTACTUATORUSINGLABVIEW

Strictly as per the compliance and regulations of:

Acceptance Testing of Electro Hydraulic based Aircraft Actuator using LabVIEW

Karthik SP [α] & Vijay Desai [σ]

Abstract- This paper presents an approach to perform aircraft actuator Acceptance Testing capability. Efforts include design and development of Test system for Electro Hydraulic aircraft actuator, in nominal condition that may be used along with measurement data to generate effective test results. LabVIEW platform is used for developing the test system.To develop communication between the LabVIEW based Test software and Actuator, Portable Test Controller (PTC), is used.

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I. Introduction

Being relatively new to the aerospace industry, Electro Hydraulic actuators are being used widely in aircraft. The quantum of knowledge as compared to ones accumulated for the other actuator types are much less and especially when it comes to Acceptance Testing. Lack of health monitoring data from the system installed in field and prohibitive costs of carrying out real flight tests push for the need of building system models and designing affordable but realistic experimental setups.

An electro-hydraulic system comprising an electromagnetic actuator and a hydraulic actuator relatively arranged such that the movement of the hydraulic actuator is controlled by the movement of the electromagnetic actuator.

The electromagnetic actuator is preferably a linear motor with a piston rod arranged to reciprocate in response to electric signal supplied to the electromagnetic actuator. A pump is preferably arranged between the electromagnetic actuator and the hydraulic actuator and causes movement of the hydraulic actuator as a result of the movement of the shaft of the linear motor. [J. Edge, 1978] [G. Daneker, 1973].

Electro-Hydraulic Actuators (EHA) are presently used in numerous aerospace applications, from robotic applications to thrust vector control of rocket engines, where they accomplish a range of rotational and translational functions [Pawel Rzucidlo, 2006].

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Of the various kinds of actuators, EHAs were chosen for this study because of their growing role in the aerospace field. They are relatively compact and can offer high power-to-weight ratios and motion velocities. [Andrew Goldenberg & Saeid Habibi, 1999].

Actuator Acceptance Testing at Assembly and Production Flooris to determine, if the requirements of a specification or contract are met. It may involve functional tests, physical tests, or performance tests. But for EH based actuator it's a performance testing, which included Testing the aircraft actuator for its basic functionality, including sensors functionality under the hydraulic pressure and real condition environment. [H. Moon and W. Knowles, 1970] [G. McGrath, 1964].

Electrical actuation technologies have to comply with demanding aircraft requirements concerning reliability, performance, weight, and environmental conditions. Electro Hydraulic actuation use comes from customer and airworthiness requirements for clean and more environment friendly aircraft.

The use of Electro Hydraulic actuators helps in aircraft maintenance. Airlines across the globe are looking for more efficient aircraft that can increase their net profit. The increasing fuel price is a major driving factor, forcing the aircraft manufactures to opt for more fuel efficient actuation systems.

With the primary functions in the aircraft more powered by electrical and hydraulic system; rather than conventional Pneumatic system aircraft will be able to achieve reduced fuel burn, higher reliability, reduction in maintenance cost, and more dispatch availability. Many R&D programs are going on in this industry for saving fuel and enhancing operational efficiency.

The instrumentation requirements in the area of automotive testing has increased many folds owing to the increasing and stringent demands imposed by several regulatory bodies such as the BIS, CMVR, EEC, etc. The type of tests to be carried out depends upon the purpose of evaluation such as for certification, design validation, etc. The parameters to be evaluated pertaining to the testing of vehicles are many. Presently, a number of dedicated instruments are being employed for the above purpose, each instrument meant to carry out evaluation of a specific parameter. However, one of the major disadvantages in such instruments is that their functionality is rigid and is difficult for reconfiguration. It

requires the adjustments of many hardware components to achieve the desired functional behavior. It was, therefore intended to have an instrumentation system, which could be completely customized to the users requirements and at the same time be flexible enough to cater for the changing requirements of the test methodologies pertaining to the variation in the test standards.[S V Londhe et al, 1999]In view of this Moog Inc has developed test controller hardware for testing and validating the EH actuators.

A detailed description has been provided about the architecture of acceptance systems and how various cases for acceptance are tested in the test environment and corresponding data is collected to verify the physics based models.

A design and development of test system has been included to outline the details of experimental data collection and calculate the results depending upon the collected data and predetermined data. Furthermore, some idea about how actuator performs in real flight environments through actual flight tests and using real flight data have been presented. Finally, the roadmap leading from this effort towards developing successful Test System for aircraft electro-hydraulic actuators is discussed.

II.   Overview of the System

The Moog Portable Test Controller is made user friendly with only havinga small amount of control keys available. The majority of the functions canbe controlled through the push/turn knob that is located in the middle.

The test system uses PTC,a digital servo controller to command and control the load and position. It is a 1 to 4 channel digital servo controller with Liquid Crystal Display (LCD). This controller gives the flexibility to add additional hardware like the digital and analog inputs and outputs that includes vibration inputs, strain gauge amplifier inputs, remote control units etc.

The connection between the SCU's and the real-time front end is established by using a low-cost real-time Ethernet communication link, enabling the controller to be placed very close to the actuator. The analogue cabling, usually an expensive and noise prone part of a test system, can be kept as short as possible, introducing very high signal-to-noise ratios.

The Test System has capability to measure Linear Variable Differential Transformer (LVDT) sensor on UUT (Unit Under Test), to measure the position and communicate as a voltage signal back to the PTC for the position loop closure. The Acceptance Test Procedure (ATP) test setup is shown in Figure 1.
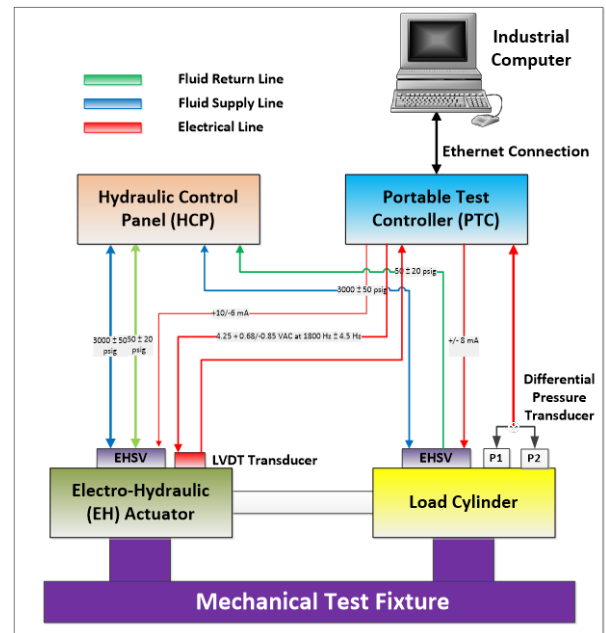
Figure 1 : Acceptance Test Setup

III.   Implementation

a) *Software Implementation*

Acceptance test software has three major parts.

➢ LabVIEW Software Module

➢ Hardware Abstraction Layer(HAL)

➢ PTC Low Level Drivers

Figure 2 shows the interface between the LabVIEW Software Module and PTC Low Level Drivers through HAL layer. The PTC hardware is connected to LabVIEW software through the IP address. Hence, Test System and Host Computer are connected using a Cross Cable or on Local Area Network (LAN).

HAL: A hardware abstraction layeris an abstraction layer, implemented in system software, between the physical hardware of a computer and the software that executes on that computer.

b) *PTC Module has three major functions*

🔸 *Safety Module:* It basically consists of an E-Stop, failsafe conditions.

🔸 *Position Loop:* PTC generally uses the FCSLoop to bind position loop with SCU1.The FCS loop is a Moog unique control loop with dual mode controller, which allows to switch between force and position control modes. The SCU has all necessary I/O hardware to connect a typical actuator. Usually this will be a hydraulic, servo-controlled actuator. Each SCU is connected to its own actuator. It's the job of the controller to modify the output connected to the actuator in such a way that the feedback is always as close as possible to the commanded value.

↯ *Load Loop:* In this the PTC uses the FCS Loop to bind Load loop with SCU 2.

Host Computer gives the input command to PTC low level Drivers which will interact with hardware system and hardware system gives the feedback command to Host Computer through PTC.
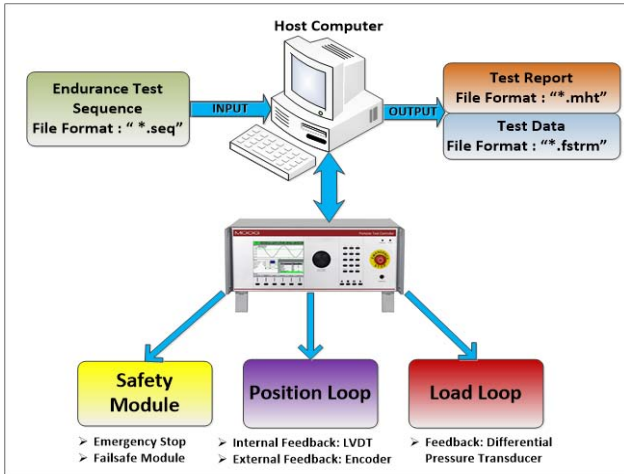
Figure 2 : Acceptance Module Block Diagram

LabVIEW Software Module: This Software interacts with the operators and engineers. The overall functionalityof this module is divide into two major parts, viz; Edit and Graphical User Interface (GUI) window.

Edit Window: The functional logic has four states and every state task is shown in Figure 3.
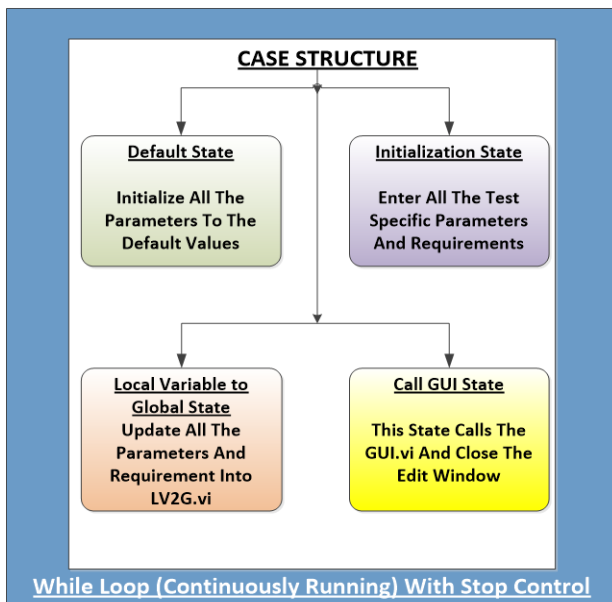
Figure 3 : Edit Window Functional Logic

GUI window: This window has two different while loopswhich are continuously executing andcontrolled with a control button. "While Loop 1"is implemented to execute the Acceptance Test Procedure

and a case structure inside the While loop is execute the logic flow. This case structure states contains the HAL and PTC drivers to make communication with the PTC hardware. While Loop 2 is basically used for plotting the Real Time graphs on the GUI front window by means ofcollecting the data from the PTC hardware through User Datagram Protocol (UDP) communication. Loop synchronization is an important part to plot the real and proper data.

The functional logic of GUI for Air Purging Test is shown in Figure 4. Figure 5 and Figure 6 shows the LabVIEW code of the Air Purging Test for both the loops respectively.
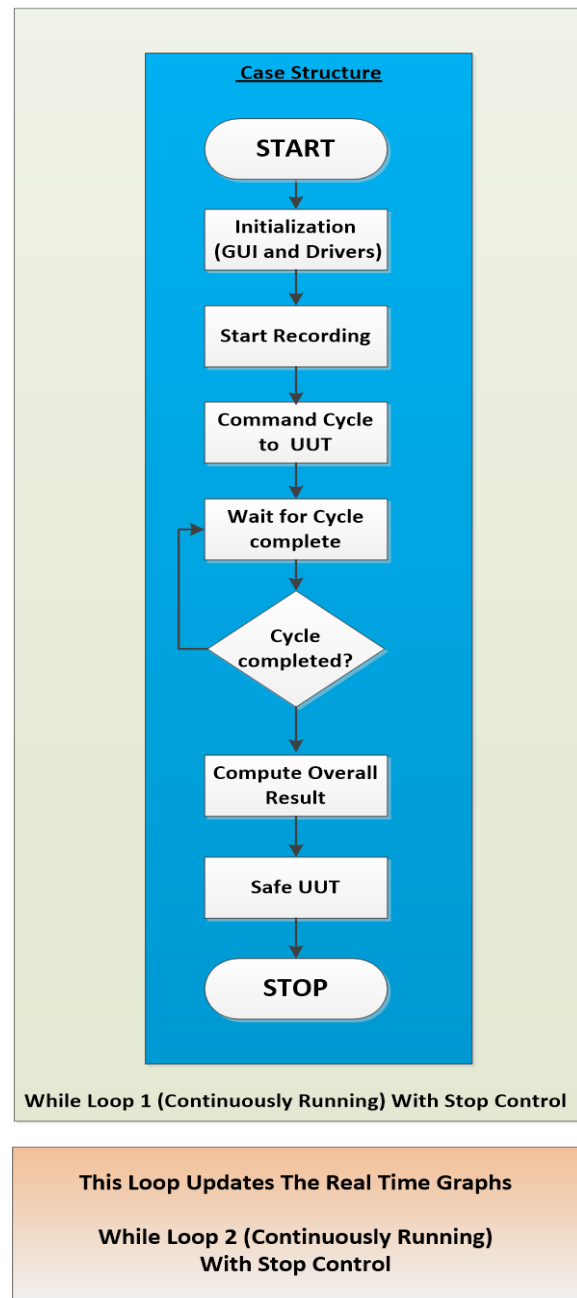
Figure 4 : GUI window functional logic
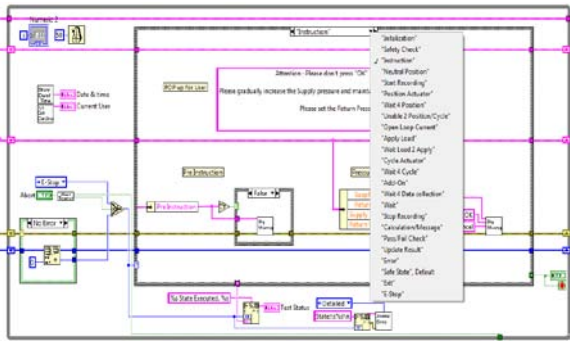
Figure 5 : LabVIEW code of the GUI window with different states
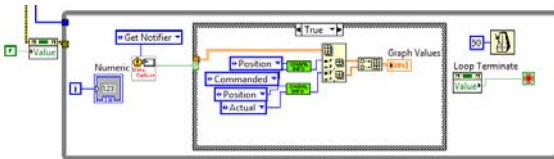
Figure 6 : LabVIEW code for plotting Real Time graph

a) *Hardware Software Integration*

To interface hardware with software, the settings of the PTC need to be changed according to the project requirements.

b) *Loop Configurations*

Two channels are required to bind to open/closed loops.

Channel1 is for Position Loop, which is bound with SCU1 and connected through FCS type Loop.

Channel2 is for Force Loop, which is bound with SCU2 and connected through FCS type Loop.

Figure 7 shows the selected PTC channels and Figure 8 shows how these channels bind with respective SCU's.

Figure 8 : Channel Bindings

c) *Calibrations*

Before calibration and tuning can be performed on a Test controller system, we have to make sure that the channels Loop. Polarity is correct. The loop polarity tuning parameter changes the polarity of the control loop by effectively reversing the connections to the servovalve. LVDT Calibration is performed with the Vendor Calibration report and the PTC calibration utilities. The following figure shows the calibration procedure of LVDT:

i.   Select the LVDT sensor in Figure 9 and press next.

ii. Fill the giving values with the help of vendor calibration report in Figure 10.

iii. Measure the LVDT value at specific points and enter these values in the measured box of Figure 11.

iv. Do the calibration for minimum five points and save the calibration settings.

Figure 7 : PTC Channel Configurations
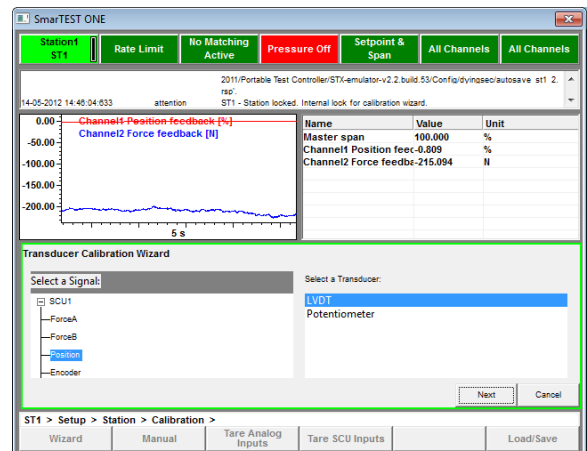
Figure 9 : LVDT Calibration - Step 1
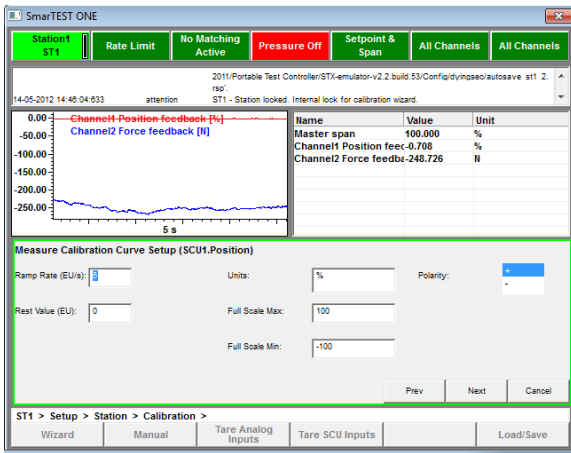
Figure 10 : LVDT Calibration - Step 2
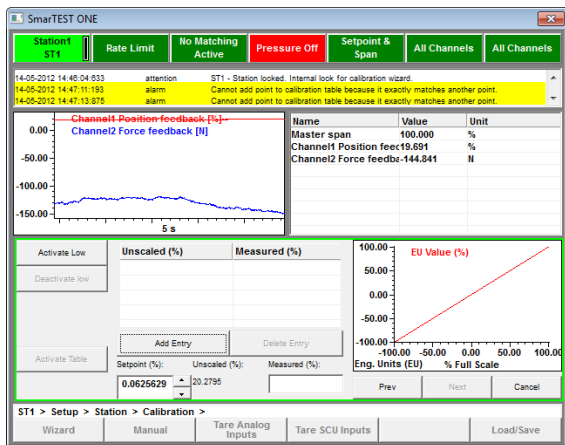
Figure 11 : LVDT Calibration – Step 3

a) Position Loop Tuning

After binding the loop and LVDT calibration, Tuning has to be performed for better output following with respect to input commands. A Proportional–Integral–Derivative controller (PID controller) is uses to control the loop feedback mechanism. PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs. Figure 12 shows the Position loop tuning.

i. Position Loop Tuning procedure

- Set all the PID values to zero, so that the closed loop becomes the open loop.

- Now apply the null bias servo value offset current to the UUT.

- Now slightly increase and decrease the offset current to move the UUT in Extend and Retract direction respectively.

- Now Set the PID values in such a way that the system will not go in unstable mode. And set the

optimum PID values so that output signal follows the input command exactly or nearly exact.
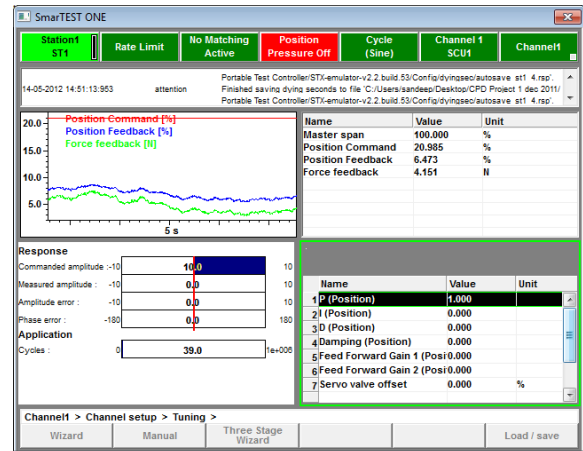
Figure 12 : Position Loop Tuning

IV. TEST RESULTS

Acceptance Testing is used to test the performance of the Electro-Hydraulic actuator in the real environment conditions. For Electro-Hydraulic actuator, there are several tests. All the tests have different test conditions and parameters. The test steps are classified into two categories:

- Open Loop Command Test
- Closed Loop Command Test

Open Loop Command Test: In this, servo current is used as an input command and actuator will move according to the amount of current giving to the EHSV. Electrical Phasing Test comes in this category.
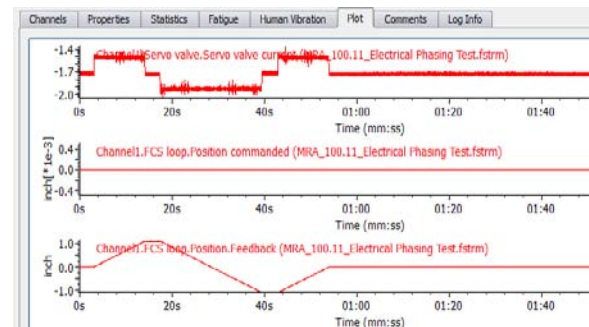
Figure 13 : Electrical Phasing Test Result

- *Analysis*

In Figure 13, the Servo valve current is changing +/- from its null bias value. Therefore the actuator is moving in Extend and Retract direction respectively. Position Command signal is not playing any role in this type of test.

Closed Loop Command Test: In this Position Commanded signal is used as an input command and Electro-Hydraulic actuator will move according to the commanded signal position value. Air Purging Test comes in this category. And actuator shall cycle

smoothly throughout the entire stroke range after the fourth cycle.

- *Analysis*

In Figure 14, Position Feedback signal is changing according to the Position Commanded signal. Actuator is moving smoothly after the 4th cycle.
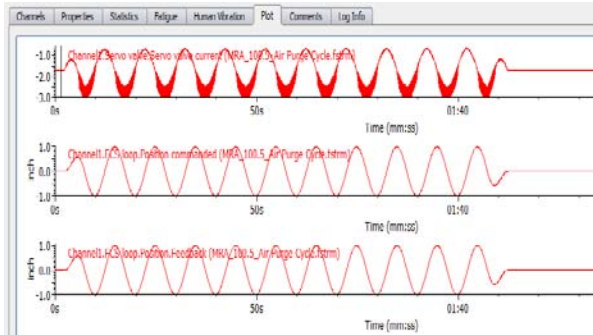
Figure 14 : Air Purging Test Result

V. Conclusion

The intended test equipment has been built and system software for controlling the test equipment has been developed in LabVIEW. A new approach used in this paper to test the actuator using PTC hardware. The advantage of PTC used in Acceptance software is cost reduction of the Testing and the reduction in the development time. On the basis of this approach and its derivative system design, we can further make different test system with large scale testing, which is going to be applied widely in the automation and industrial field.

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Effect of Heat Treatment on Crack Initiation & Propagation of Stainless Steel (Ss-304)

By Soumya Mandal, Tonmoy Karmaker & Dr. Md. Nurul Islam

Rajshahi University of Engineering & Technology, Bangladesh

Abstract- Cyclic loading is common experimental practice for investigations of large structures like vehicles. Numerical analysis of cyclic loading conditions is also a well-established field of research and application. Theoretical and practical support is rare for evaluating growth of fatigue cracks under cyclic loading conditions. Cracks can occur naturally in engineered components due to combination of environmental effects and materials and geometric properties. In this study, the effects of heat treatment on crack initiation & propagation of stainless steel (SS-304) are investigated. The specimens are subjected to different cyclic load. The crack initiation & propagation and final fracture behavior are observed microscopically. The specimens are kept in the furnace at 500℃ at a constant time 1 hour where cooling medium is used as air for heat treatment & the effects of heat treatment are investigated. The fatigue life of the tested specimen at 400MPa stress before & after heat treatment are 54900 cycles & 61000 cycles respectively. So, a better fatigue life is found after heat treatment.

Keywords: heat treatment, fatigue crack. fatigue crack growth, fatigue life.

GJRE-A Classification : FOR Code: 091399p

EFFECTOFHEATTREATMENTONCRACKINITIATIONPROPAGATIONOFSTAINLESSSTEELSS304

Strictly as per the compliance and regulations of:

Effect of Heat Treatment on Crack Initiation & Propagation of Stainless Steel (Ss-304)

Soumya Mandal [α], Tonmoy Karmaker [σ] & Dr. Md. Nurul Islam [ρ]

Abstract- Cyclic loading is common experimental practice for investigations of large structures like vehicles. Numerical analysis of cyclic loading conditions is also a well-established field of research and application. Theoretical and practical support is rare for evaluating growth of fatigue cracks under cyclic loading conditions. Cracks can occur naturally in engineered components due to combination of environmental effects and materials and geometric properties. In this study, the effects of heat treatment on crack initiation & propagation of stainless steel (SS-304) are investigated. The specimens are subjected to different cyclic load. The crack initiation & propagation and final fracture behavior are observed microscopically. The specimens are kept in the furnace at 500°C at a constant time 1 hour where cooling medium is used as air for heat treatment & the effects of heat treatment are investigated. The fatigue life of the tested specimen at 400MPa stress before & after heat treatment are 54900 cycles & 61000 cycles respectively. So, a better fatigue life is found after heat treatment.

Keywords: heat treatment, fatigue crack. fatigue crack growth, fatigue life.

I. Introduction

Ultra-fine grained metals are becoming promising for engineering applications due to the recent progress in technology. Therefore, for envisaged structural applications of Ultra-fine grained metals, attention has been paid to fatigue performance, such as cyclic properties, S-N characteristics, the formation of shear bands (SBs) and persistent slip band (PSBs) [1].

In order to quantify the fatigue damage, it is important to understand what kind of change is brought about by cyclic loading, and to know the critical conditions for fatigue life. Using carbon steel (S45C) specimens, Murakami and Miller showed that crack initiation and growth could be regarded as the damage caused by fatigue loading and that fatigue life was almost equivalent to the number of cycles for the initiated cracks growing to the critical size[2]. Kamaya had done a research based on observation of Fatigue Crack Initiation and Growth in Stainless Steel [3]. The fatigue loading causes various microstructural changes such as an increased number of dislocations, formation of cell structures, and alternation of deformation properties. However, these changes have minor influence on the fatigue life under the same strain range. Therefore, the fatigue damage can be correlated to the crack size. It is possible to measure the fatigue damage by investigating the size of a crack initiated in components, or if no crack is found, it can be confirmed that damage has not been accumulated yet [3]. The fatigue life can be divided into two phases: the number of cycles to crack initiation (hereafter called initiation life) and the remaining life until the failure of the specimen (hereafter called growth life) [4].

In this study crack initiation and propagation behaviour are observed before and after heat treatment.

Cyclic loading is a common phenomenon for different structures. When cyclic loading is applied on metallic structures a common incidence occur called fatigue failure. Fatigue failure is a continuous process which starts with a small crack. The crack propagates up to failure of the structure. Sometimes it is seen then there are more than one cracks initiate and propagate, but their initiation time is not same for all, and the propagation is not homogenous for all of them. Some cracks propagate up to certain cyclic loading and then remain unchanged. They are not directly responsible for the failure of structure, although they weaken the structure and cause more cracks to initiate. Even the crack initiation and propagation nature of cracks are not same before and after the heat treatment. From this study it is found that, crack propagation time is greater after heat treatment i.e. fatigue life is better after heat treatment.

II. Test Material & Experimental Procedure

a) Material Properties

The material used for the fatigue test was Type 304 austenitic stainless steel, which was provided in a cylindrical bar shape. Its chemical composition (in mass %) was: C, 0.07; Si, 1.0; Mn, 2.0; P, 0.05; S, 0.02; Ni, 10.5; Cr, 19.5 and balance Fe. The ultimate tensile strength, yield tensile strength is 600MPa and 300MPa respectively. The material had an approximately equiaxial grain structure.

b) Procedure

The working procedure of this study is shown below-----

➤ The required metal (ss-304) was collected.
➤ The metal was assured by determining ultimate and yield strength by using universal testing machine.
➤ The suitable shape was given to the metal according to the requirement. Fig 2.1 shows the schematic diagram of the tested specimen.

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e-mail: rusho_moran@yahoo.com

D14 mm   D19n   D14m

8mm

31mm   10mm   100mm
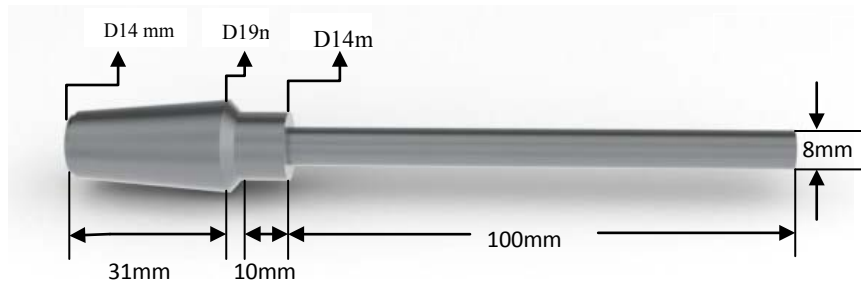
Figure 2.1 : Schematic diagram of Fatigue testing specimen

➤ By using various grades of emery paper such as P320C, 600AW, P1000C, P1200C, C1500CW, C2000CW specimen surface were polished smoothly.

➤ After polishing by the emery papers, Aluminum oxide (AL_2O_3) powder was used for fine polishing and ethanol was used to remove the black spots from the specimen.

➤ A load was chosen for which the stress was produced on the tested specimen lies between the ultimate (600MPa) and yield strength (300MPa).

σ = Stress

M = Moment

Moment of inertia, $I = \frac{\pi d^4}{64}$

$C = \frac{d}{2}$ = Perpendicular distance to neutral axis.

F = Load.

x = Distance between the load applied & stress developed point.

So stress, $\sigma = \frac{Mc}{I} = \frac{64Fx}{2\pi d^3}$

➤ By using this selected load the fatigue life (the number of cycle at which the structure fully fractured) of the tested specimen was determined with the help of fatigue testing machine.

➤ By selecting 10% of the fatigue life the specimen was examined with the help of fatigue testing machine.

Spring balance Specimen **Bearing** Motor   Base
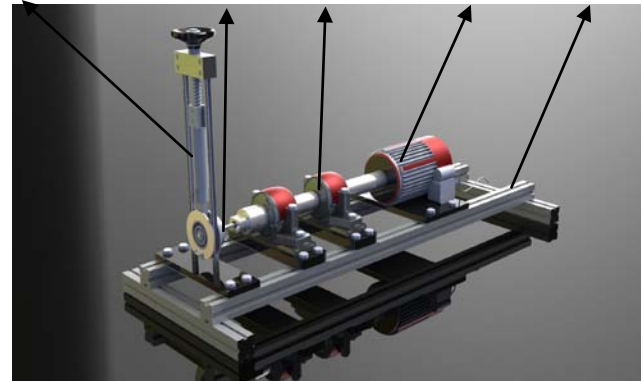
Figure 2.2 : Fatigue testing machine

The predicted space of the specimen was inspected microscopically to observe the crack initiation.

➤ The previous two steps were followed until the final crack of the tested specimen was occurred.

➤ Every times crack propagation of the tested specimen was observed microscopically.

➤ The above steps were performed after heat treatment of the tested specimen.

III.   Results and Discussion

a)   Observation of Crack Initiation & Propagation

Cyclic loading is one of the main reasons for crack initiation and propagation. Crack is microscopic in nature. For stainless steel (SS-304) the change of length of PSBs due to fatigue is observed by using Metallurgical Microscope. In optical microscopic image, it is shown that the PSBs length is increased with increasing cyclic load after starting the crack growth. Fig 3.1 represents the calibration scale through which the length of slip band is measured. Fig 3.2 represents the surface of the specimen before polishing. Fig 3.3 represents the surface of the specimen after polishing.
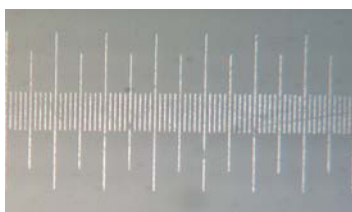
Figure 3.1 : Calibration scale

100μm

Figure 3.2 : Surface of the Specimen before polishing

100μm

Figure 3.3 : Surface of the Specimen after polishing

b) *Changing behavior of slip band length at 400MPa before heat treatment*

Fig. 3.4 represents the optical microscopic images at a stress of 400MPa before heat treatment under different cycles. From the figure it is shown that,

at N=0 cycle there is no crack in the tested specimen surface. At N=45750 cycles a crack is appeared on the surface of the tested specimen. At N=51850 cycles the crack propagates and after that at N=54900 cycles fatigue failure occurs.

N=0 cycle   N=45750 cycles   N=51850 cycles
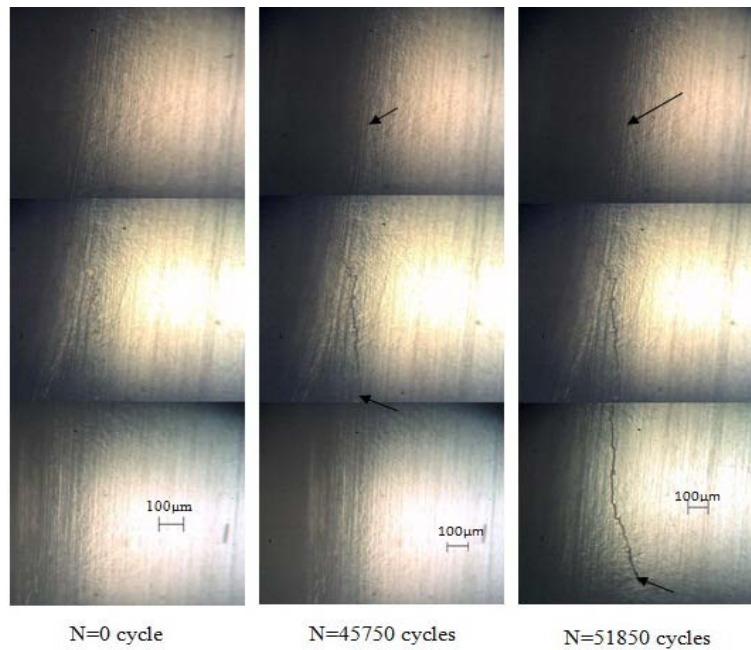
Figure 3.4 : Optical microscopic images at different cycle before heat treatment

Fig. 3.5 represents the number of cycle vs. length of slip band curve under 400MPa stress before heat treatment of the specimen. The length of slip band is determined with the help of calibration scale whereas the number of cycle is directly found from the fatigue

testing machine. From the Fig. 3.5, it is shown that crack 1, crack 2, crack 3 propagates up to certain cycle but they do not cause the final fatigue failure. On the other hand, crack 4; crack 5 propagates up to the fatigue failure.
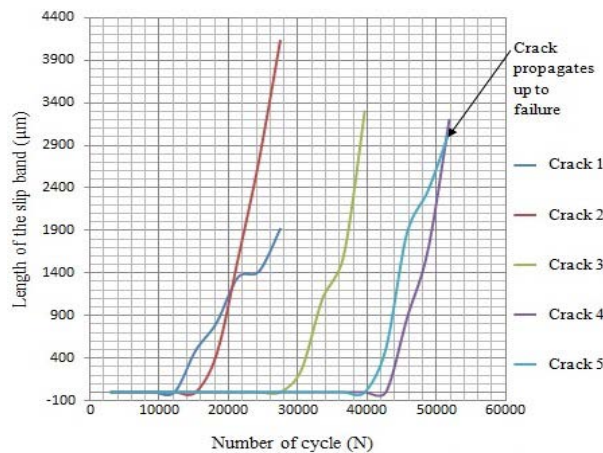
Figure 6.12: Number of Cycle Vs length of the slip

Figure 3.5 : Number of cycle vs. length of slip band curve

c) *Changing behavior of slip band length at 400MPa after heat treatment*

Fig. 3.6 represents the optical microscopic images at a stress of 400MPa after heat treatment under different cycles. From the figure it is shown that, at N=0

cycle there is no crack in the tested specimen surface. At N=42700 cycles a crack is appeared on the surface of the tested specimen. At N=57950 cycles the crack propagates and after that at N=61000 cycles fatigue failure occurs.

N=0 cycle   N=42700 cycles   N=57950 cycles
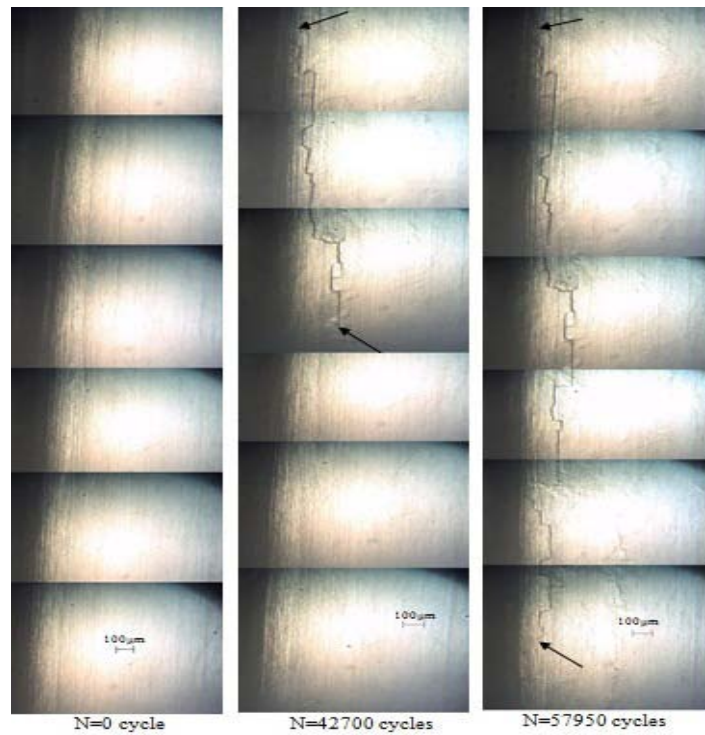
Figure 3.6 : Optical microscopic images at different cycle after heat treatment

Fig. 3.7 represents the number of cycle vs. length of slip band curve under 400MPa stress after heat treatment of the specimen. The length of slip band is determined with the help of calibration scale whereas the number of cycle is directly found from the fatigue testing machine. From the Fig. 3.7, it is found that crack 1, crack 2, crack 3, crack 4 propagates up to certain cycle but they do not cause the final fatigue failure. On the other hand, crack 5 propagates up to the fatigue failure.
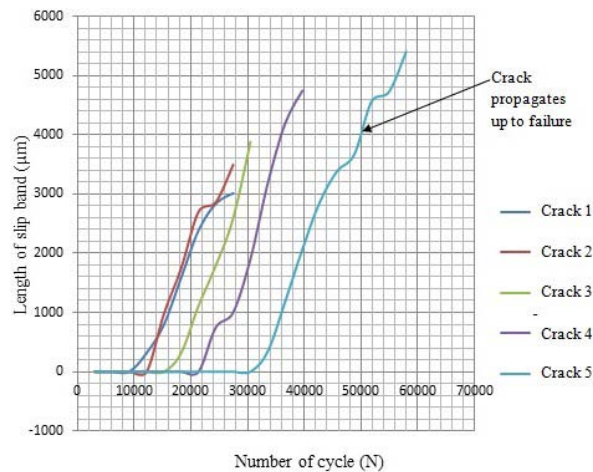
Figure 3.7 : Number of cycle vs. length of slip band curve

IV. Conclusion

Fatigue is one of the primary reasons for the failure of structural component. Fatigue cracks are microscopic in nature. The initiation & propagation of fatigue cracks are observed by optical method. Various stresses are applied on the tested specimen. It is found that, in every case more than one crack initiates & propagates. But the crack initiation & propagation nature are not same for all tested specimen. The fatigue life of the tested specimen at 400MPa stress before & after heat treatment are 54900 cycles & 61000 cycles respectively. The fatigue life reduces with the increasing stresses but for same stress fatigue life increases after heat treatment. So, better life of designed can be provided by considering the phenomenon of crack initiation and propagation. It also provides better longevity of materials.

Appendix A

Table A-1 : Data of length of slip band for 400MPa stress before Heat Treatment [Fig. 3.5]

Number of Cycle(N)	Length of Slip Band(μm)				
	Crack 1	Crack 2	Crack 3	Crack 4	Crack 5
3050	0	0	0	0	0
6100	0	0	0	0	0
9150	0	0	0	0	0
12200	0	0	0	0	0
15250	490	0	0	0	0
18300	820	450	0	0	0
21350	1350	1560	0	0	0
24400	1420	2730	0	0	0
27450	1920	4130	0	0	0
30500			260	0	0
33550			1100	0	0
36600			1600	0	0
39650			3300	0	0
42700				0	510
45750				870	1870
48800				1680	2370
51850				3200	3060

Table A-2 : Data of length of slip band for 400MPa stress after Heat Treatment [Fig. 3.7]

Number of Cycle(N)	Length of Slip Band(μm)				
	Crack 1	Crack 2	Crack 3	Crack 4	Crack 5
3050	0	0	0	0	0
6100	0	0	0	0	0
9150	0	0	0	0	0
12200	317	0	0	0	0
15250	795	976	0317	0	0
18300	1590	1748	1112	0	0
21350	2383	2700	1794	0	0
24400	2837	2860	2588	750	0
27450	3014	3495	3881	1100	0
30500				1950	0
33550				3178	341
36600				4188	1180
39650				4744	2065
42700					2860
45750					3383
48800					3666
51850					4562
54900					4721
57950					5403

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Design of Air Booster for 1200 Ton Mechanical Press

By Ms. Shweta A. Naik & Mrs. Chandrika S. Wagle

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Abstract- A mechanical press is used for pressing of sheet metals to give it the desired shape. Mechanical press is a machine that changes the shape of the work piece by applying tones of load on it for accurate output. Mechanical punch presses fall into two distinct types, depending on the type of clutch or braking system with which they are equipped. Generally older presses are "full revolution" presses that require a full revolution of the crankshaft for them to come to a stop. This is because the braking mechanism depends on a set of raised keys or "dogs" to fall into matching slots to stop the ram. It is a 1200T mechanical press. It consists of a ram, upper die, lower die and cushion. For pressing upper die is pressed on sheet metal and lower die. At that time the cushion gets activated and it holds the lower die. The cushion is supported by hydraulic and pneumatic pressure. The press is a try-out press. It requires pressure up to 7 bar. The pressure provided by the company compressor is 5bar. To increase the pressure there are two options. One is to use compressor for which we have to compress air from atmospheric pressure. So it will consume more power.

Keywords: mechanical press, air booster, air properties, design of air booster, validation.

GJRE-A Classification : FOR Code: 290501p

DESIGNOFAIRBOOSTERFOR1200TONMECHANICALPRESS

Strictly as per the compliance and regulations of:

Design of Air Booster for 1200 Ton Mechanical Press

Ms. Shweta A. Naik [α] & Mrs. Chandrika S. Wagle [σ]

Abstract- A mechanical press is used for pressing of sheet metals to give it the desired shape. Mechanical press is a machine that changes the shape of the work piece by applying tones of load on it for accurate output. Mechanical punch presses fall into two distinct types, depending on the type of clutch or braking system with which they are equipped. Generally older presses are "full revolution" presses that require a full revolution of the crankshaft for them to come to a stop. This is because the braking mechanism depends on a set of raised keys or "dogs" to fall into matching slots to stop the ram. It is a 1200T mechanical press. It consists of a ram, upper die, lower die and cushion. For pressing upper die is pressed on sheet metal and lower die. At that time the cushion gets activated and it holds the lower die. The cushion is supported by hydraulic and pneumatic pressure. The press is a try-out press. It requires pressure up to 7 bar. The pressure provided by the company compressor is 5bar. To increase the pressure there are two options. One is to use compressor for which we have to compress air from atmospheric pressure. So it will consume more power. Moreover the space required for it very large. The another option available for it is to use a compact and power saving device. Such a device is called booster. A booster is a double acting cylinder. It has two chambers. One chamber has bigger area which consist of piston end. Another chamber has small area and it consists of rod end. Large force is applied to piston end by pressurized air. This force is transmitted to rod end of piston. The area at this end is small and hence the air at this end is compressed to very high pressure. Thus pressure rise is obtained.

Keywords: mechanical press, air booster, air properties, design of air booster, validation.

I. Introduction

A booster is a device that amplifies available line pressure in order to perform work requiring much higher pressure. It operates a hydraulic cylinder without the need for a hydraulic power unit. The low pressure is converted by the booster to a much higher hydraulic pressure on the output side.

The principle of the air booster works much the same as our liquid pumps in which a larger air drive piston is directly connected to a smaller pumping piston. The incoming air from the compressor drives the booster and also feeds the supply to the unit. 90% of industrial facilities use compressed air in their process. Unfortunately, most compressed air systems are inherently inefficient, converting less that 20% of their energy input into useable compressed air. Consequently, reducing unnecessary compressed air usage and improving the efficiency of the compressed air systems themselves are excellent energy-saving strategies. Compressed air is often used because it is believed to be convenient, safe, and labor-saving. These advantages may justify the high cost of compressed air, but often more energy-efficient alternatives exist. Air leaks, improper pressure regulation, and airflow restrictions can easily reduce a system's useful capacity by 50% or more. Typically, these problems are "solved" by adding a new compressor, when fixing the problem would be much more cost effective and energy-efficient. The Automatic Airline Booster Pump was designed to boost airline pressure automatically in surge tanks or die cushions, or for any high pressure application, such as testing, where small quantities of high pressure air are needed. To operate this booster you simply pipe airline pressure to the master control valve, to the intake side of the booster, and run a high pressure line from the booster to your surge tank. The booster will then operate automatically to boost pressure in the die cushion or surge tank in the desired ratio. This booster is completely valved, ready to operate, with only three airline connections necessary. The booster is completely air actuated with no electrical connections necessary.

Figure 1 : Image of Booster

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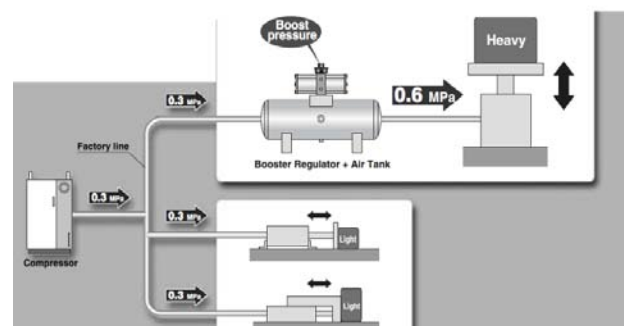
Figure 3 : Layout of executed Air Booster

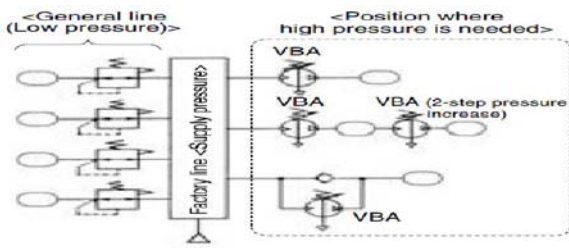## II. Principle & Working of Design Air Booster

Figure 2 : Circuit diagram of Air Booster of single/multistage compression

A booster, or pressure intensifier, is a device that amplifies available line pressure in order to perform work requiring much higher pressure. It operates a hydraulic cylinder without the need for a hydraulic power unit. A booster is basically a cylinder and is similar in internal design, except that the rod end of the piston does not extend outside. The rod becomes a ram for hydraulic fluid. A booster is equivalent to a transformer, or pulley system, in that it changes the ration of pressure input to pressure output but does not amplify power. Low pressure air, as found in most plants or shops, is connected to the large cylinder. Pressures are typically 80 to 100 psi. This low pressure is converted by the booster to a much higher hydraulic pressure on the output side. This discharge has an amplified pressure potential equal to the product of the supply pressure and the booster ratio. Total power is not changed, as the low pressure input air must operate against a large area piston in order to produce high pressure from a much smaller surface area. This total force is exerted by means of piston rod, or ram, to the output section of the booster. The output section contains there hydraulic fluid. Just the end of the rod applies pressure to this fluid.

Low pressure air enters the input section of the booster. It pushes against a large area piston. For example, if a 100 psi air supply pushes against a 4" diameter piston, it is working against an area of approximately 12.6 square inches, for a total force of 1,260 pounds. This total force is exerted by means of the piston rod, or ram, to the output section of the booster. The output section contains a hydraulic fluid. Just the end of the rod applies pressure to this fluid. Let's say that the rod end has a 1" diameter. Its area is about .8 square inches. Divide the .8 square inches into the total applied force of 1,260 pounds and the result is 1,590 pounds per square inch. We have transformed 100 psi into 1,600 psi, or a ratio of 16 to 1. Standard boosters are available in ratios running from approximately 2 to 1 up to 36 to 1. In the selection of a particular booster, not only does the ration have to be taken into account, but also the output volume has to be matched to the cylinder which the booster will drive.

III. Operating Power of Air Booster

In our example above, we have an output of 1600 psi hydraulic pressure. When this 1600 psi is bed to a cylinder, the total area of the piston in the cylinder in now under a pressure of 1,600 psi! Therefore, instead of an air cylinder which would have to work under 100 psi air pressure, we now have a cylinder working under 1600 psi hydraulic pressure. True, this cylinder will only perform work at this pressure through a volume of fluid in the cylinder that is equal to the same volume displacement in the booster, but for many operations, this volume displacement at such increased pressures is completely satisfactory. In shop air is used as the power source, as this is the most common way boosters are used. It is, however, quite possible to use oil as the operating power source, particularly for extremely high pressure applications. For example, if you need to develop 40,000 psi and had a choice of 80 psi air or 3,000 psi oil, the air booster ratio would be 500:1 and the oil only about 13:1. It's obvious that using an oil to oil booster system would be far less expensive. Standard boosters are air to oil only.

IV. Calculations and Graphs

According to the relation

Pressure = force/area; P=F/A;

But, Force=mass flow rate *velocity;

$F = m^{\cdot} * v/A;$

Mass flow rate = density*area*velocity;

$m^{\cdot} = \rho * a * v;$

Therefore;

$P = \rho * a * v * v;$

Therefore according to this relation;

V=620.20m/s;

a) Calculations of Mass Flow Rate

For tank inlet at 5 bar pressure with 2.54 cm diameter of inlet pipe ;

$m^{\cdot} = \rho * a * v;$

Where;

ρ, density of air=1.298;

V, velocity = 620.65;

D, diameter of inlet pipe = 2.54*10E-2;

$m^{\cdot} = 1.298 * \pi/4(2.54*10E-2)E2*620.65;$

$m^{\cdot} = .414$ kg/s;

Mass flow rate = .414 kg/s;

Mass flow rate of air for tank inlet at 7 bar;

At 7 bar pressure, according to the relation;

$P = \rho * a * v^2;$

Velocity, v=734.37 m/s;

Mass flow rate, m˙= ρ*a*v;

Where;

ρ, density of air=1.298;

V, velocity = 734.37;

D, diameter of inlet pipe = 2.54*10E-2;

m˙=1.298*π/4(2.54*10E-2)E2*734.37;

m˙=.48 kg/s;

Mass flow rate through booster at 7 bar pressure;

According to the relation;

m˙= ρ*a*v;

Velocity of flow is given by;

V=734.37 m/s;

Diameter of inlet pipe of booster,

D=0.82*10E-2;

According to the relation;

P= ρ*a*v*v;

Mass flow rate through booster is given by;

m˙=1.298*π/4(0.82*10E-2)E2*734.37;

m˙=0.05031 kg/s;

Therefore, number of booster required is given by the relation;

No. of booster = mass flow rate through tank/mass flow rate through booster;

N= 0.48/0.0503;

N= 10 (approx.);

b) *Calculations for No. of Boosters*

Stroke length of cushion cylinder = 300 mm;

Bore diameter of cushion cylinder, D =1120 mm;

Ram speed, v = 100 m/s;

Reset time, t = 1 minute;

Therefore,

According to the relation, discharge is given by;

Q = π/4*D*D*S/10E6 ltr;

Q = π/4*1120E2*300/10E6 ltr;

Q = 295 ltr;

Flow rate is given by;

Flow rate = Q*60/t ltr/min;

Where,

Time for one stroke, t= 3 seconds;

Therefore flow rate is given by;

Q = 295*60/3;

Q = 5408 ltr/min;

therefore flow rate at 1 bar pressure is given by;

Q = 5408 ltr/min;

Therefore flow rate at 7 bar pressure is given by;

Q = 5408*(0.707 – 0.101/0.101);

Q = 46854 lt/min;
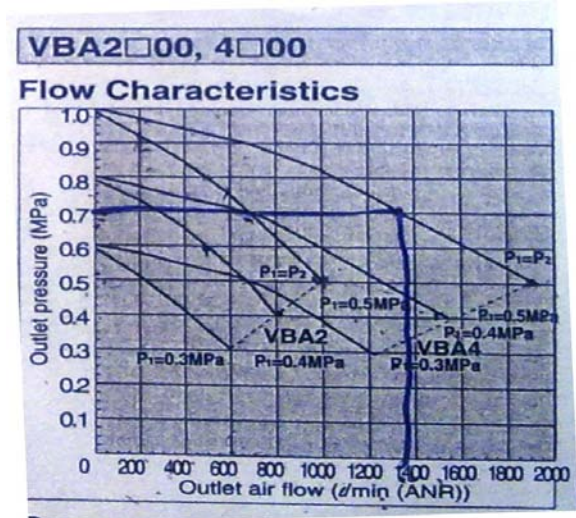
Figure 4 : Plot for output pressure vs flow rate of air

According to the graph;

From 0.5bar to 0.7bar;

Q_b=1350 ltr/min;

Because

$Q > Q_b$;

As the discharge of tank of cushion is more than the discharge through the booster, an extra tank will be installed for the storage of booster output to maintain the pressure.

Tank specifications:

Stroke time, T_c = stroke length/speed;

T_c= 300/100;

T_c = 3 sec;

c) *Calculations for Tank Capacity*

According to the relation;

Volume of tank required, V = (Q-Q_b/2)*(T_c*K/60)/ (P_3-P_2)*9.9;

Where;

K, single side stroke = 1;

P_3, max. Pressure = 10 bar = 1 MPa;

T_c, stroke time = 3 sec;

Q_b, discharge through booster = 1350 lpm;

Q, discharge through the tank = 46854 lpm;

Taking all the values in relation, volume of tank required is given by ;

V =(46854 – 1350/2)(3*1/60)/ (1 – 0.75)*9.9;

V = 777 ltr

d) *Time Required Charging The Tank Is Given By Relation*

$$T = V/10 * (t_2 - t_1)/N;$$

Where,

N, no. of booster required = 1;

$$P_2/P_1 = 0.7/0.5;$$

$$P_2/P_1 = 1.4;$$

From the graph shown;

Time required for 10 litres of tank = 0.5;

$$T = 0.5 * 777/10;$$

$$T = 38 \text{ sec};$$

Therefore time required to fill the tank is 38 seconds.

V. Advantages

a) *Long Holding Time*

Another case is where you want to exert a high pressure for a long time, such as maintaining pressures on printing rolls. A booster-cylinder system will maintain a continuous pressure with very little power input. In a pump-cylinder system, the pump must be kept in continual operation. (In order to achieve such holding pressure, there must be a relief valve inserted in the system.

b) *Extreme High Pressure*

Pressures over 10,000 psi can be obtained with special boosters while virtually impossible with ordinary pumps. When you require an inexpensive way of achieving high pressures, even up to 50,000 psi, the booster is the answer.

c) *Cost Ratio*

Another reason for using boosters is the cost ratio of a booster system vs. pump system. You have a machine which requires a linear actuator pressure of 5,000 psi. If you were to design in a complete 5,000 psi hydraulic system into this one machine, it could cost you many times a booster system! Again, remember that we are talking about one machine requiring intermittent high pressure.

d) *Save Space & Weight*

In many applications, booster driven cylinders can replace an extremely large, low pressure air cylinder with a small, efficient, high pressure hydraulic cylinder. Coupled with reduced circuitry, the overall weight of a machine can be reduced, as well as the total space required.

e) *Lower Cost*

A booster system is less expensive than an overall hydraulic system with its pump-motor requirements. They also require only a fraction of the air of a direct air cylinder installation. Hydraulic requirements are also much smaller to operate a given function. This system is a low cost solution when high pressure and relative high volumes of air is required in a pneumatic application. This system can save money when requirements need up to a 600 PSI supply of air with reserve capacity

VI. Applications

a) *High pressure from ship air*

One of the principal applications for boosters is in the conversion of low pressure shop air to high pressure hydraulic operation for a specific function where a hydraulic cylinder is required. Many operations require the smooth power inherent in a hydraulic cylinder, yet do not require the expenditure for a complete hydraulic installation. The small, yet powerful movement of a booster driven hydraulic cylinder can be used to hold a piece for riveting, as a spot welding clamp, for punching, piercing, forming, crimping, bending, stamping, shearing, marking, etc. The complete installation of booster, air-oil tank and cylinder can be mounted directly on the equipment itself.

b) *Testing*

Testing of manufactured parts for physical strength, leaks or burst rating can easily be accomplished with a booster-cylinder combination or a booster alone. A hydraulic cylinder will give a precise, high pressure force for mechanical testing, and a booster can be linked up directly, to a die casting, for instance, to test for leaks.

c) *Fluid Transfer*

Fluids that are difficult or impossible to transfer with a conventional pump can be fed through a valve-booster combination. Depending on the type of fluid, boosters can be produced with special metals, such as stainless steel.

d) *Liquid Injection*

High pressure injection of liquids are readily handled with a booster. Such liquids, injected into high pressure gas lines or containers, might include lubricants, antifreeze or odorants.

VII. Conclusion

I have been successful in implementing the booster system to increase the pressure of press by a desired ratio. For this no extra power input is needed. The pressurized air from the main compressor is taken as input to booster. It saves a lot of power consumption. Further no major modification is required in the circuit. Only small space is required for booster, reservoir and valves.

The press is a try-out press. Now the press can be used for pressure higher than company pressure. Thus various pressures can now be applied for pressing the sheet metal. Thus we can decide for which pressure the sheet gets pressed to desired shape to obtain good

surface finish and wrinkle free surface. Thus the efficiency of pressing operation and machine is increased.

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Study of Environmental Impacts of the Barapukuria Thermal Power Plant of Bangladesh

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Abstract- The generation of electricity and consumption of energy in general, result adverse effects on the environment. Barapukuria is the only natural coalmine reserve in Bangladesh that is currently in operation. Barapukuria thermal power plant produces electricity from the reserved coal. The coal available in Bangladesh is of very high quality, with low ash content and high calorific value. Coal quality plays a great role in environmental impact as well as gaseous emissions. Source of water is the major problem for the Barapukuria thermal power plant and there is a poor disposal system of the waste water. By collecting the secondary data from the authority of the Barapukuria thermal power plant, this study was accomplished at Barapukuria thermal power plant to evaluate the pollutant (SO2) emission rate and its impact on human health due to air pollution. In this study attempts were made to find out the major environmental impacts to Barapukuria thermal power plant and finally showed the possible recommendations to reduce the impacts.

Keywords: emission; health impact; environmental pollution; thermal power plant.

GJRE-A Classification : FOR Code: 859899p, 850506, 091399

STUDYOFENVIRONMENTALIMPACTSOFTHEBARAPUKURIATHERMALPOWERPLANTOFBANGLADESH

Strictly as per the compliance and regulations of:

Study of Environmental Impacts of the Barapukuria Thermal Power Plant of Bangladesh

Mahadi Hasan Masud [α], MD. Nazmus Shakib [σ] & Md. Rokonuzzaman [ρ]

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Keywords: emission; health impact; environmental pollution; thermal power plant.

I. INTRODUCTION

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle [1]. Barapukuria power plant is a power station which follows the Rankine cycle. Barapukuria is the only natural coalmine reserve in Bangladesh that is in currently operation. The overall capacity of Barapukuria Thermal Power Plant is 250MW. Total electricity generation is extracted into two units as 2x125MW. In order to alleviate the electricity crisis in Bangladesh, Barapukuria Coal and Power project is a blessing indeed [2].

Besides the blessing indeed property Barapukuria power plant has some adverse effect also. One of the major effects of the power station is the exhaust emission. Due to continuous & long lasting emission of SO_x & NO_x, which are the principal pollutants coal based plants.. It is also worth to note that very high amount of carbon dioxide (CO_2) emission (0.9-0.95kg/kWh) from thermal power plants contribute to global warming leading to climate change [3].

Also Thermal Power Plants have been found to affect Environmental segments of the surrounding

region very badly. Environmental deterioration is attributed to emission of large amount of SO_x, NO_x & SPM which disperse over 25kms radius and cause respiratory and related ailments to human beings and animal kingdom. The SPM also includes RSPM (respirable suspended particulate matters) and both types of fine particles normally spread over 25kms from the Thermal Power station.

Alam et al. [4] in their study gives emphasis on the evaluation of possible environmental impacts for Barapukuria thermal power plant and coal mine. In his work an attempt was taken to conduct environmental impact assessment of Barapukuria thermal power. Tamim et al. [5] shows the analysis of fly ash of Barapukuria thermal power plant. Fly ash is one of the common residues produced from combustion of coal. But the study was not enough to recommend the possible measurement to reduce the adverse impact of Barapukuria Power Plant. Now the aim is that, to find out the possible environmental impacts by studying the data from water treatment plant, coal handling unit, ash handling unit and I &C department of Barapukuria thermal power plant and recommending the possible way to minimize the impacts.

II. METHODOLOGY

The study was based on field observations, sample collections and data collection. Coal, soil and drain water samples were collected from the study area for sampling. Coal sample and soil data are collected from the authority of Barapukuria thermal power plant.

Overall thesis work was completed by following steps:

Data Collection: The thesis covers both secondary and primary data. Here secondary and primary data sources are used to estimate the emissions and their effects from Barapukuria thermal power plant.

Secondary Data: Secondary data were collected from the authority of Barapukuria thermal power plant, sequentially from the water treatment plant, I&C department, coal & ash handling unit.

Primary Data: Primary data were collected from the analysis of several thesis work based on Barapukuria thermal power plant.

Drain water sample was collected from the Barapukuria thermal power plant and data of drained water collected from the chemistry department to find

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out the level of concentration of different metals or elements.

Exhaust gas emission data was collected from the I&C department of the Barapukuria thermal power plant. Fly ash quantities was calculated from the data given by the authority.
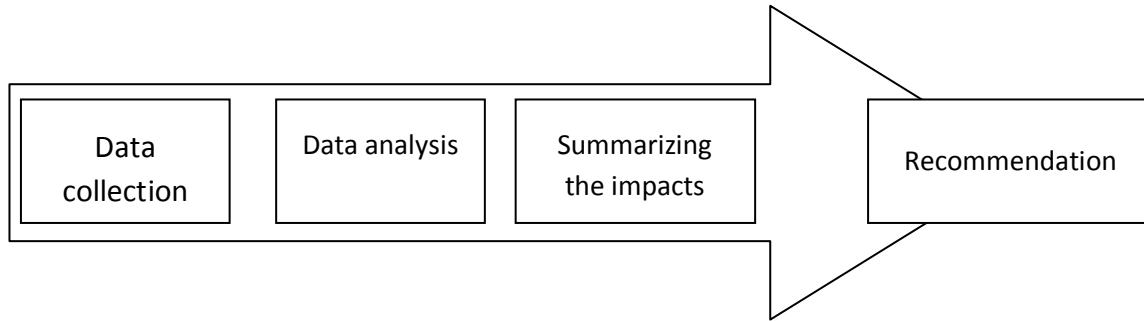
Figure 1 : Methodological Procedures

III. Data Collection and Analysis

As mentioned in the methodology that the data is collected from the different sources.

Survey to the inhabitants: A survey was directed to the surrounding   area within about 5km from the power plant. A conversation was made among 210 people of different profession nearby the plant area to investigate the impact on their health. They informed about their health condition (suffered by the Barapukuria power plant). The survey was based on several questions about asthma, allergy, skin diseases, and other respiratory problems on their health impact. Result of the survey given in table (1).

Table 1 : Health impact on inhabitants (degree of responsive analysis)

Variable	Asthma	Allergy	Skin diseases	Other respiratory problem	Total	Percentages %
Agree	5	7	6	12	30	14
Undecided	35	33	24	28	120	58
Disagree	20	10	30	30	80	38
Total	60	50	60	50	210	100

The above Table 1 reveals that 14% of the inhabitants suffer from allergy, asthma, skin diseases and other respiratory problems and the 58% of the inhabitants were undecided and rest of the 38% were disagreed about the effect of exhaust emission from the Barapukuria thermal power plant.

Conversation was also made with the local doctors about the patient condition around the power plant area. They informed that the skin diseases and the respiratory problems have been increased since when the Barapukuria power plant started operation in 2006.
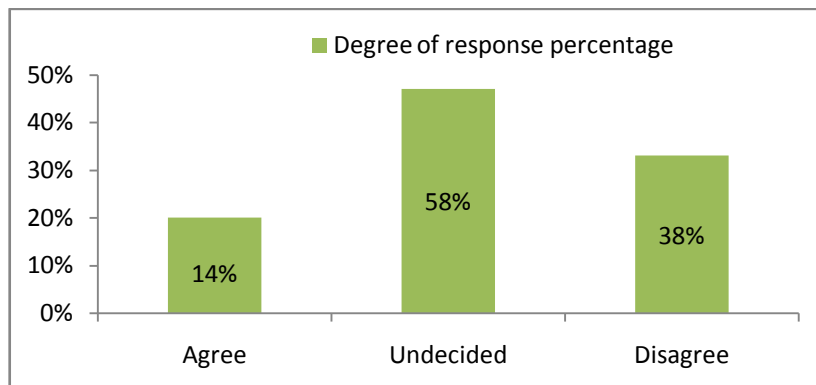
Figure 2 : Percentage of degree of response on health impact

Table 2 : Impact on production and atmosphere

Variable	Less production	Ash in the air	Ash deposited on the leaf	Total	Percentage %
Agree	40	20	30	90	47.36
Undecided	15	15	20	50	26.33
Disagree	15	15	20	50	26.31
Total	70	50	70	190	100

The above Table 2.2 reveals that 47.36% of the inhabitants were agreed that it causes less production, ash in the air, ash deposited in the leaf, and the 26.33% were undecided and the 26.31% were disagreed.
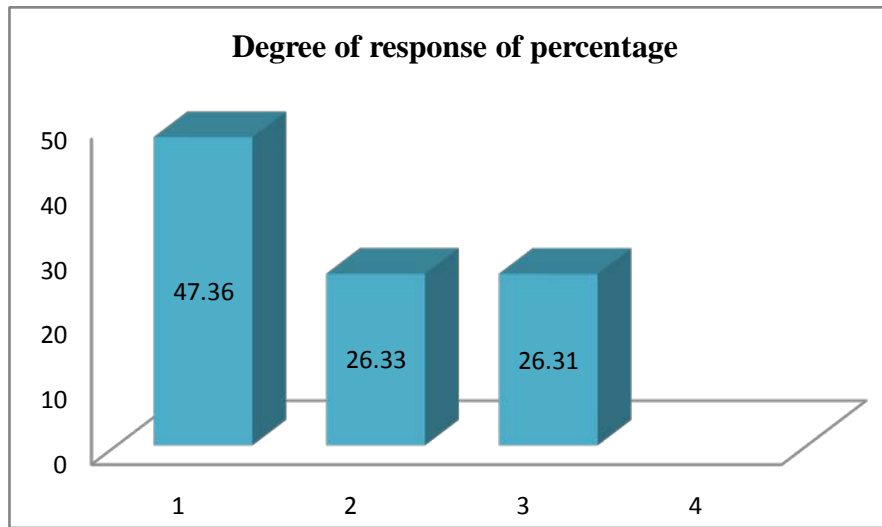
Figure 3 : Percentage of degree of response of production and atmosphere

IV. ANALYSIS OF WASTE WATER (DRAINED)

The test result of drained water sample showed that pH is slightly basic.

Table 3 : Drained water analysis

Water parameters	Gut side boundary drain water	Outside drain water
Mn	0.19 mg/L	0.26mg/L
pH	7.2	7.4
Total count	7.5x10⁴ C.F.U/100mL	10x10⁴ C.F.U/100mL
Total coliform	28	28
Fecal coliform	9	9
As	0	0
SO_4^{2-}	2.4mg/L	3.1mg/L
NO_3^-N	0.4mg/L	1.6mg/L
Fe^{3+}	0.45mg/L	0.61mg/L

It is clear from the analysis that the Mn concentration was found in the range 0.19 to 0.26 mg/L.

The ph was found slightly acidic (7.2 to 7.4). Bacteria is within WHO ranges. The concentration of bacteria was found from 7.5. It is also found that SO_4^{2-} concentration is 2.4 mg/l in gut side boundary drain water and 3.1 mg/l in outside boundary water, which is within the WHO range .NO_3 is slightly varied from the standard range and the concentration of Fe3 was found within the WHO range.

V. COAL ANALYSIS

Coal, the most important fossil fuel remained essential in achieving a diverse, balance and secure energy mix. Barapukuria Coal field has been operating officially since 2004, with a coal reserve of 390 Million Tones. The yearly production is 1 million tones, out of which 65% is supplied to the Barapukuria Coal fired Thermal Power Plant, the only operating thermal power plant of Bangladesh, with a capacity of 250MW [6].

a) *Coal consumption (at rated load)*
- Each unit per day: 1200 M.ton
- Total for 2 units per day: 2400 M.ton
- Coal consumption/kWh: 0.4 kg

- Annual ash generation: 0.08 million M.ton
- Cooling water consumption/h: 800-1200 M.ton

b) *Fly ash analysis*

The ash analysis of Fly ash obtained from Barapukuria Power Plant.

Oxides	Percentage
SiO_2	54.4
Al_2O_3	35.6
Fe_2O_3	2.9
TiO_2	3.2
Mn_3O_4	0.11
CaO	0.56

K_2O	0.66
Na_2O	0.06
MgO	0.18

c) *Fly ash Disposal*

Fly ash disposal is carried out by two techniques, namely dry disposal scheme and Wet disposal scheme. In dry disposal, the produced fly ash is transported from site by various methods (truck, conveyor belt etc.) and disposed into a dry embankment. In wet disposal, the fly ash is mixed with water to form a slurry, which is transported by pipes to be disposed off in a confinement called the 'ash pond'[7].

Figure 4 : Ash pond of Barapukuria Thermal Power Plant

d) *Exaust Gas Emission*

Table 4 : Exhaust gas emission from stack of the power plant (analytic data of I&C department)

Date	Particulates	Units	Time: 12.00	Time: 24.00
12-8-2012	NO_x	mg/Nm^3	182.22	182.26
	SO_2	mg/Nm^3	327.20	327.20
	CO_2	mg/Nm^3	10.48	10.49
	O_2	%	6.37	6.37
	Dust	mg/Nm^3	125.20	125.20
14-8-2012	NO_x	mg/Nm^3	172.42	171.26
	SO_2	mg/Nm^3	357.20	348.29
	CO_2	mg/Nm^3	9.44	10.49
	O_2	%	6.67	6.37
	Dust	mg/Nm^3	122.29	121.22
16-8-2012	NO_x	mg/Nm^3	179.33	180.26
	SO_2	mg/Nm^3	318.23	315.20
	CO_2	mg/Nm^3	11.45	11.33
	O_2	%	6.97	6.87
	Dust	mg/Nm^3	128.20	129.50
18-8-2012	NO_x	mg/Nm^3	168.32	169.26
	SO_2	mg/Nm^3	344.76	344.46

CO_2	mg/Nm^3	9.58	9.79
O_2	%	6.65	6.78
Dust	mg/Nm^3	129.35	129.54

All the reading are taken away from the emission point of power plant, this show that emission is somehow more than allowable limit. When the power plant which are in construction phase when they start their operation then this limit is easily exceeded. So we should take care of all such factors as well as take necessary preventive action to control this emission level .

VI. Summerisation of Impacts on Environment

Figure 5 : Emission from the stack of Barapukuria thermal power plant

Air Quality Around the coal based plants the ambient concentrations of Sulphur Dioxide, Oxides of Nitrogen and SPM are high. Epidemiological Studies have shown that of the area surrounding coal based thermal plants, population living within a 2 -5 km radius of the plant suffers from respiratory disorders. Two other gases, carbon dioxide and ozone are emitted. The high amount of carbon dioxide emission from thermal power plants contribute to global warming leading to climate change is significant Ground level ozone, which is formed due to photolytic reactions of NO_x and its impacts are under study Mercury vapour is also emitted with these gases and its toxicity has far reaching consequences on all life forms.

Impact on water: The water requirement for Barapukuria thermal power plant is 60ton/hr for each unit. Among these water 30 ton/hr is drained and rest of water is recycling. Ash pond decant contains harmful heavy metals like B, As, Hg which have a tendency to leach out over a period of time. Due to this the ground water gets polluted and becomes unsuitable for domestic use. 9m^3/h of industrial waste water is discharged directly into the Tilai River without waste water cleaning.

Figure 6 : Drain water disposal at Tilairiver from Barapukuria thermal power plant

Effect of fly ash on soil environment: Large amount of land is used to dispose fly-ash from the coal based plants. Due to this there is change in natural soil properties. It becomes more alkaline due to the alkaline nature of fly ash. Soft bodied soil workers like earthworms will die out.

VII. Recommendation

a) The drained water which is directly disposed to the Tilai river without cleaning waste water should be cleaned before disposing.

b) There is not any process of reusing the ash, directly thrown in the nearest ash pond. Fly ash can be used in different construction purposes. From the study of this thesis shows that the analyzed fly ash are of useful component for recovery of alumina, opencast mine filling, road reclamation, cement and concrete production, waste water treatment and various agricultural applications.

c) Flue Gas De-sulphurization (FGD) process can be applied to remove sulphar from the flue gas

d) More source of water can be thought not only by using the ground water

VIII. Conclusion

The analysis showed that the emission of SO_x, NO_x and particulates matter is in allowable range but this may cause adverse effect to the environment of the surrounding region.

- Total emissions from the Barapukuria thermal power plant is 1.1ton/hr.

- The high amount of CO_2 emission from thermal power plants before 2009 was 756,020 tons, that make the Barapukuria thermal power plant a red marked power plant in this zone

- Problem associated with ground water is the main challenge of Barapukuria Thermal Power Plant.

- There found poor productivity of cultivating crops due to the lack of water source.

- Upper surface of land become more alkaline due to components of fly ash.

- A significant amount of inhabitants (14%) suffered by the impacts of Barapukuria thermal power plant.

- 47.3 % of inhabitants ensured about less production of their crops, ash in the air, and leaf damage due to fly ash or flue gas.

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Numerical Study of Natural Convection in a Vertical Channel Partially Filled with a Porous Medium

By Samir Amraqui, Nadia Dihmani & Ahmed Mezrha

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Abstract- A numerical study of natural convection in a vertical channel partially filled with a porous matrix is performed. The flow is described using Brinkman-extended Darcy model. The governing equations are solved by using the finite-volume method. The pressure-velocity coupling is provided by the SIMPLER algorithm. The objective of this work is to determine heat transfer and fluid flow characteristics for Prandtl number $Pr = 0.71$. A parametric study was conducted by varying the thicknesses of the porous layers and Darcy Number for two Rayleigh number $Ra = 106$ and $Ra = 107$. The isotherms, streamlines, average Nusselt number and dimensionless temperature are presented for different parametric study.

Keywords: finite volume method; natural convection; porous medium; vertical channel.

GJRE-A Classification : FOR Code: 091399

NUMERICALSTUDYOFNATURALCONVECTIONINAVERTICALCHANNELPARTIALLYFILLEDWITHAPOROUSMEDIUM

Strictly as per the compliance and regulations of:

Numerical Study of Natural Convection in a Vertical Channel Partially Filled with a Porous Medium

Samir Amraqui [α], Nadia Dihmani [σ] & Ahmed Mezrhab [ρ]

Abstract- A numerical study of natural convection in a vertical channel partially filled with a porous matrix is performed. The flow is described using Brinkman-extended Darcy model. The governing equations are solved by using the finite-volume method. The pressure-velocity coupling is provided by the SIMPLER algorithm. The objective of this work is to determine heat transfer and fluid flow characteristics for Prandtl number $Pr = 0.71$. A parametric study was conducted by varying the thicknesses of the porous layers and Darcy Number for two Rayleigh number $Ra = 10^6$ and $Ra = 10^7$. The isotherms, streamlines, average Nusselt number and dimensionless temperature are presented for different parametric study.

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- ## Nomenclature

A	aspect ratio, $A = L/b$
B	channel width [m]
Da	Darcy number, $Da = K/b^2$
e_p	porous layer thickness, [m]
e_p^*	dimensionless Porous layer thickness, e_p/b
K	thermal conductivity [$W\,m^{-1}\,K^{-1}$]
K	permeability
L	channel length [m]
Nuw	average Nusselt numbre
P	pression, [Pa]
P	dimensionless pression, $(p+\rho_o gy)b^2/\rho_o\alpha^2$
Pr	Prandtl number, ν/α
Ra	Rayleigh number, $g\beta(T_h - T_a)b^3/\nu\alpha$
R_k	thermal conductivity ratio, k_s/k_f
T	temperature, [K]
T_o	average temperature, $(T_h + T_a)/2$, [K]
u, v	velocity component along x, y [$m\,s^{-1}$]
U, V	dimensionless velocity components along x, y. $U = ub/\alpha$, $V = vb/\alpha$
x, y	cartesian coordinates [m]
X, Y	dimensionless cartesian coordinates, $X = x/b$, $Y = y/b$
α	thermal diffusivity [$m^2\,s^{-1}$]
β	volumetric expansion coefficient [K^{-1}]
ΔT	maximal difference temperature, $\Delta T = (T_h - T_a)$
λ	dimensionless viscosity ratio, $\lambda = \mu_s/\mu_f$
θ	dimensionless temperature, $\theta = (T - T_0)/(T_C - T_F)$
Θ	dimensionless temperature, $\Theta = T/T_C$
μ	dynamic viscosity

I. Introduction

The study of the natural convection mode in vertical porous channel is particularly developed in recent years because it relates to various applications such as cooling of electronic equipment, nuclear reactors, thermal insulation heat exchangers, building industry, geophysical flows and crystal growth [Chu and Hwang (1977), Nield, Bejan (1992), Mezrhab (1997)].

In recent years, a large number of experimental and numerical researches have been devoted to study the heat transfer in fully or partially porous vertical channels. [Debbissi (2000)] studied the water evaporation by natural convection between two flat plates. A uniform heat flux is imposed on one wet wall whereas the other plate is insulated or heated and supposed impermeable and is kept at a constant flow by taking into consideration the radiation plates.

[Yan and Lin (2001)] studied the combined effects of buoyancy forces and heat and mass diffusion in a laminar natural convection flow inside a vertical pipe. These authors investigated the effects of wet walls temperatures, air humidity and the aspect ratio on the flow and heat and mass transfer. Recently, [Orfi, Debbissi, Belhaj and Nasrallah (2004)] examined the thin liquid film evaporation flowing down on the inner face of a vertical channel plate. The wet wall is subjected to a uniform heat flux and the second plate is insulated and impermeable.

The purpose of this work is to study numerically the natural convection in a vertical channel with two porous layers arranged vertically by examining the effect of the porous layers thickness on the flow structure, the

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average Nusselt number and the temperature distribution within the channel.

II. Formulation Mathématique du Problème

The configuration of the problem studied is depicted in Figure 1. It shows the geometry of a vertical parallel-plates channel partially occupied by two porous layers. The vertical plates are isothermal and kept at the hot temperature T_h. The analysis assumes that the porous media is homogeneous and isotropic. The fluid flow is incompressible, laminar and two-dimensional. The momentum equations are simplified using Boussinesq approximation, in which all fluid properties are assumed constant except the density in its contribution to the buoyancy force.
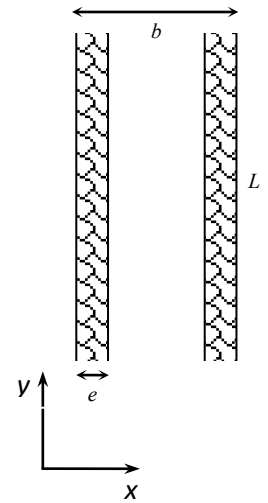
Figure 1 : Schematic configuration of the problem

The two-dimensional governing equations based on the Brinkman–Darcy model can be written in the following dimensionless form:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \tag{1}$$

$$\frac{\partial U}{\partial \tau} + U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \lambda Pr\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) - \frac{Pr}{Da}\frac{U}{K_x} \tag{2}$$

$$\frac{\partial V}{\partial \tau} + U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + \lambda Pr\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) - \frac{Pr}{Da}\frac{V}{K_y} + RaPr\theta \tag{3}$$

$$\sigma\frac{\partial \theta}{\partial \tau} + U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y} = R_k\left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right) \tag{4}$$

Where $\lambda = 1$, $R_k = 1$, $\sigma = 1$ in the fluid region

$\lambda = \infty$, $R_k = k_s/k_f$, $\sigma = \dfrac{(\rho c)_p}{\varepsilon(\rho c)_f}$ in the porous region.

The boundary conditions corresponding to the considered problem are as follows:

- Solid plates boundary conditions: $0 \leq Y \leq 1$, $X = 0$ and $X = 1$

$$U = 0,\ V = 0,\ \theta = 1,\ \frac{\partial P}{\partial X} = 0$$

- Inlet boundary conditions: $0 \leq X \leq A$ and $Y = 0$

$$U = 0,\ \frac{\partial V}{\partial Y} = 0,\ \frac{\partial \theta}{\partial Y} = 0,\ P = \frac{-Q_{in}^2}{2}$$

Where Q_{in} is the mass flow rate at the channel inlet.

$$Q_{in} = \int_0^1 [V(X)]_{Y=0}\, dX$$

- Outlet boundary conditions: $0 \leq X \leq A$ and $Y = 1$

$$U = 0,\ \frac{\partial V}{\partial Y} = 0,\ \frac{\partial \theta}{\partial Y} = 0,\ P = 0$$

III. Numerical Procedure

A series of calculations was done for the set of parameters given in Table 1, to determine the optimum non-uniform grid (i.e. the best compromise between accuracy and computational costs). A numerical simulations of the problem considered for two Rayleigh number $Ra = 1 \times 10^6$ and 10^7, $A = 5$ and $Pr = 0.71$ were performed with six different grids. From the table 1, it was found that the difference in Nusselt number obtained with a 30×140 grid and a 30×160 grid is only 0.1% percent. Therefore, all the computations in the present study were done with a non-uniform 30x140 grid.

Table 1 : Results of the grid independence study for $Pr = 0.71$: $Ra = 10^6$ and $Ra = 10^7$

	$Ra = 10^6$			$Ra = 10^7$		
	Nuw	ψ_{max}	Q	Nuw	ψ_{max}	Q
(14x90)	16.885	389.01	$0.41495.10^3$	18.282	783.18	$0.83540.10^3$
(14x100)	16.891	390.49	$0.41653.10^3$	18.287	790.92	$0.84365.10^3$
(20x100)	17.575	408.209	$0.43542.10^3$	19.125	853.69	$0.91060.10^3$
(20x120)	17.582	410.489	$0.43786.10^3$	19.132	896.143	$0.93509.10^3$
(24x120)	17.847	413.260	$0.44081.10^3$	19.513	882.758	$0.94161.10^3$
(24x130)	17.849	414.15	$0.44176.10^3$	19.517	896.14	$0.95589.10^3$
(28x130)	18.046	415.27	$0.44296.10^3$	19.797	895.557	$0.95526.10^3$
(28x140)	18.047	416.06	$0.44380.10^3$	19.800	908.96	$0.96956.10^3$
(30x140)	18.155	417.57	$0.44541.10^3$	19.907	915.19	$0.97621.10^3$
(30x160)	18.156	418.705	$0.44662.10^3$	19.914	941.68	$1.0045.10^3$

Furthermore, the numerical code has been validated by taking into account some numerical studies available in the literature. Firstly, it was validated on the problem of natural convection in a square porous cavity [Beckermann, Vistkanta and Ramadhyani (1986)]. The results found for the average Nusselt number for different Rayleigh number Ra, the Prandlt number Pr and Darcy number Da are in good agreement with the present results as shown in Table (2).

Table 2 : Average Nusselt number for differents controls parameters and for $A = 1$

Ra	Da	Pr	Beckermann et al.(1986)	Nos Résultats
10^5	10^{-1}	1.0	4.724	4.648
10^5	10^{-1}	0.01	4.724	4.648
10^8	10^{-4}	1.0	24.97	24.891
10^8	10^{-4}	0.01	24.97	24.891
10^{12}	10^{-8}	1.0	48.90	48.854
10^{12}	10^{-8}	0.01	48.90	48.854

Secondly, the code has been tested on the problem of natural convection in an asymmetrically heated vertical channel partially filled with a porous medium. A comparison of the velocity profile for three fluid layer thickness and for $Da = 10^{-2}$ between the predicted results and those obtained by [Paul, Jha, Singh (1998)] is shown in figure 2. Results show an excellent agreement.
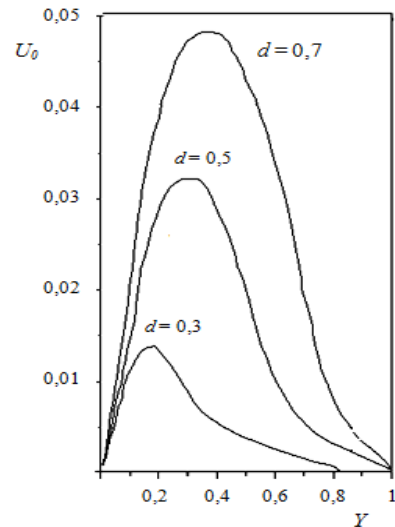
Figure 2 : Velocity profiles for $Da = 10^{-2}$

IV. RESULTS AND DISCUSSION

Numerical simulations are performed for $Pr = 0.71$, $A = 5$, $R_k = 1$ and for Darcy number and porous layer thickness ranged respectively between $10^{-8} \leq Da \leq 1$ and $0.05 \leq e_p^* \leq 0.3$. A survey of the heat transfer and flow overall results obtained is presented and discussed. Some local results are also reported by means of isotherm, streamline, average Nusselt number and dimensionless temperature.

Figure 3 shows the variation of the average Nusselt number Nuw according to Darcy number for different Rayleigh number and for three porous layer thickness: $e_p^* = 0.05$, $e_p^* = 0.1$, $e_p^* = 0.2$.

In general, we observe that for a fixed Darcy number, heat transfer increases with increasing Rayleigh number. However, for a given Ra, there is a significant decrease of Nusselt number Nuw as the permeability decreases. Moreover, from these figures, we can

distinguish three zones: A first zone with low permeability $Da \leq 10^{-6}$: the Nusselt number remains almost constant, in this range of Da, and the porous layers acts as an impermeable wall where the flow is almost zero. A second zone characterized by high Darcy numbers $Da \geq 10^{-3}$: the average Nusselt number is higher and practically independent of Da. The porous layers do not hinder the fluid flow and the heat transfer is more important as Rayleigh number increases. This is due to the fact that the Darcy number becomes negligible compared to the convective terms in the governing equations system. A final intermediate zone $10^{-5} \leq Da \leq 10^{-3}$: we note that the average Nusselt number increases significantly with the permeability. This increase is even higher for $Ra = 10^6$ and $Ra = 10^7$ and for low porous layers thicknesses.
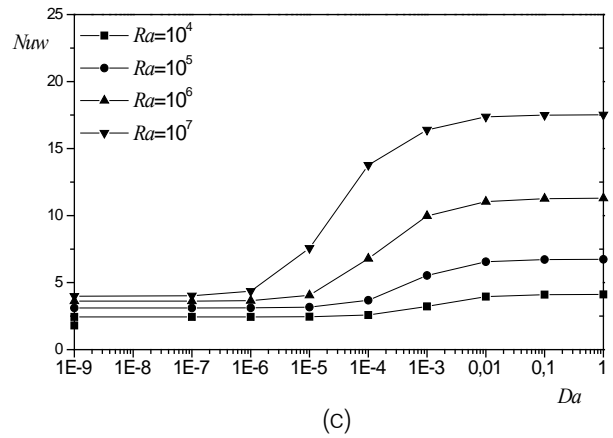
(c)

Figure 4 displays the isotherms and the streamlines obtained for various porous layer thickness and respectively for two Darcy number $Da = 1$ and $Da = 10^{-6}$.

Let us note that for $Da = 1$, which corresponds to a permeable porous layer (Figure 4. a), the variation of the thickness has no significant effect on the streamlines shape. However, for $Da = 10^{-6}$, which corresponds to the porous layers of low permeability (Figure 4. b), we note the absence of flow circulation in the porous media witch behaves like solid walls. The flow is confined in the fluid medium and becomes lower as the thickness increases. The isotherms are parallel to the channel walls and are thinner for $Da = 1$.

(a)

(b)

$e_p{}^*=0.05$ $\quad$ $e_p{}^*=0.1$ $\quad$ $e_p{}^*=0.2$ $\quad$ $e_p{}^*=0.3$ $\quad$ $e_p{}^*=0.05$ $\quad$ $e_p{}^*=0.1$ $\quad$ $e_p{}^*=0.2$ $\quad$ $e_p{}^*=0.3$

(a)   (b)
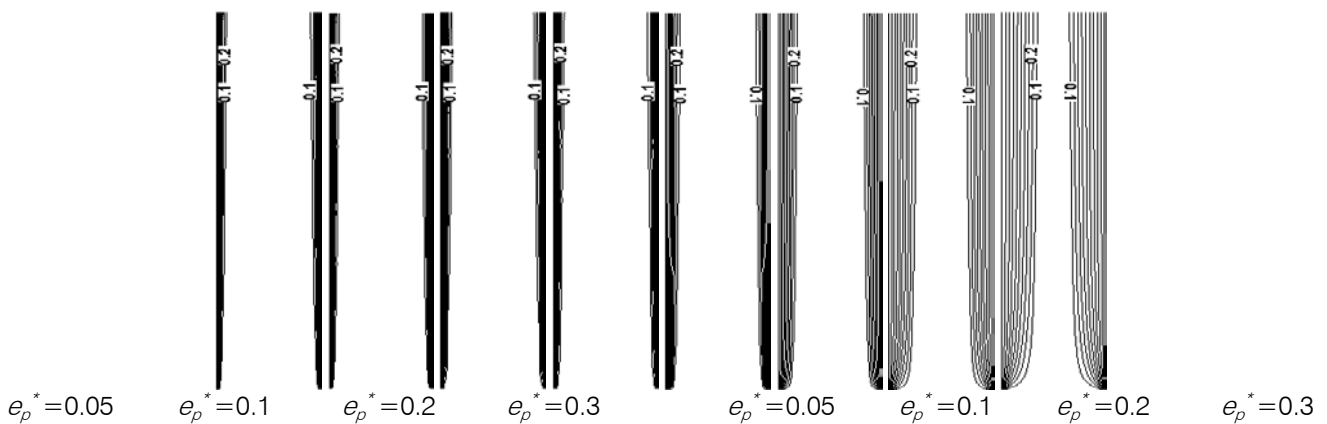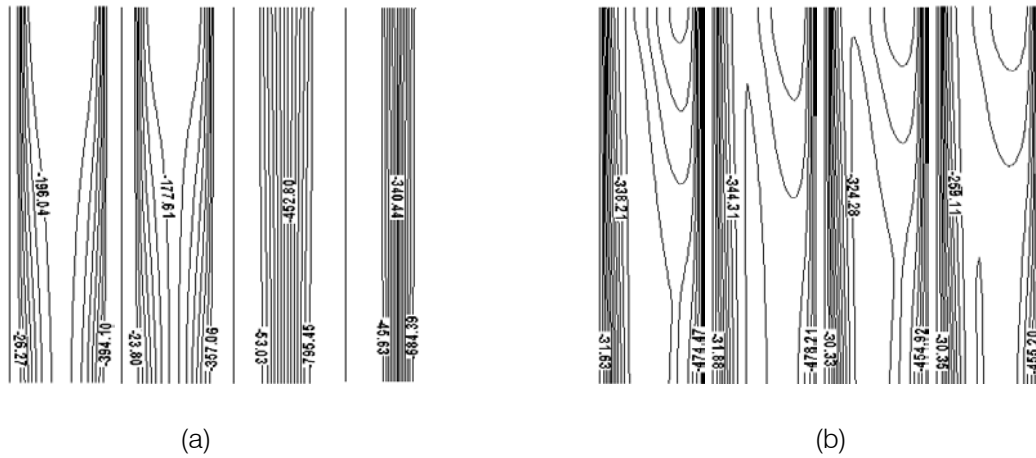
Figure 4 : Isotherms and streamlines for various e_p^* for $Ra = 10^7$: (a) $Da = 1$, (b) $Da = 10^{-6}$

Figure 5 gives the variation of the average Nusselt number Nuw versus the porous layers thickness e_p^* for five different Darcy numbers and for two Rayleigh number $Ra = 10^6$ and $Ra = 10^7$.

As can be seen the different curves are located between two limiting curves corresponding to the fluid and solid behavior of the porous material $Da = 1$ and $Da = 10^{-8}$. It is observed that the heat transfer decreases with increasing the porous layers thickness, which is more important as the Darcy number decreases. Indeed, we note that for sufficiently large permeability ($Da = 1$ and $Da = 10^{-2}$) the influence of the porous layer thickness on heat transfer is negligible and the average Nusselt number remains constant. However, for relatively low permeability the Nusselt number decreases with increasing e_p^*. It should be noted that it is sufficient to introduce porous layers of thickness less than 0.1 to reduce significantly heat transfer.

(b)
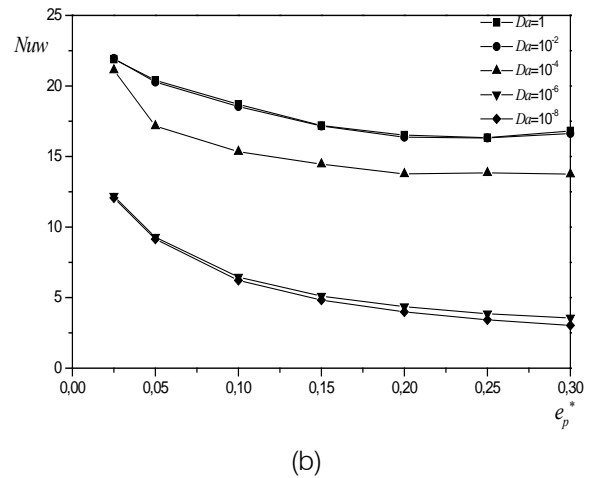
Figure 5 : Evolution of the Nusselt number as a function of e_p^* for different Darcy number: (a) $Ra = 10^6$, (b) $Ra = 10^7$
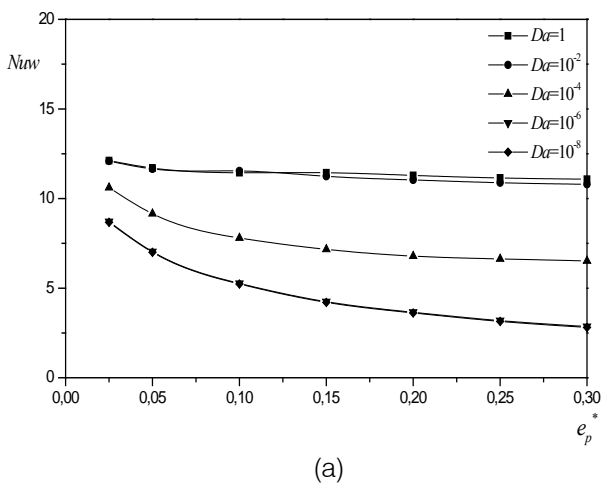
To understand the shape of the isotherms, we plotted in Figure 6 the evolution of the dimensionless temperature profiles θ in the horizontal median plane of the channel for different porous layers thickness and for two Darcy number $Da = 1$ and $Da = 10^{-6}$.

As we have previously reported, for large Darcy number (Figure 6. a), the introduction of porous layers has a negligible effect on dimensionless temperature whatever their thickness. However, for $Da = 10^{-6}$ (Figure 6. b), note that the curves slope decreases significantly for large thickness values and θ is much smaller that the thickness e_p^* is low.

(a)

(b)
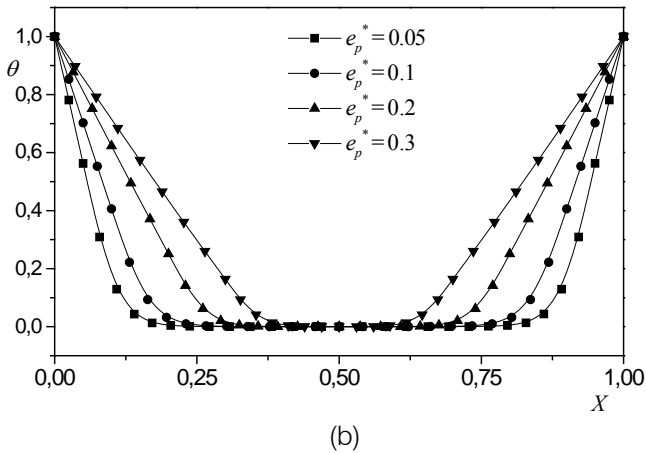
Figure 6 : Evolution of the dimensionless temperature as a function of X for differents e_p^* and for $Ra = 10^7$: (a) $Da = 1$, (b) $Da = 10^{-6}$

V. Conclusion

This paper presents a numerical study of natural convection in a vertical parallel-plate channel partially filled with porous medium. Numerical calculations were performed to investigate the effect of Rayleigh numbers Ra, Darcy number Da and porous layers thickness e_p^* on the flow field and heat transfer. We examined the Rayleigh number effect characterizing the convection intensity and we concluded that the heat transfer increases with increasing Rayleigh number Ra. We also showed that the variation of the porous layers permeability, through the Darcy number, affects significantly the heat transfer. Indeed, we have identified three zones and we found that for a fixed Rayleigh number and high value of Da, the Nusselt number Nuw is nearly constant and the flow is similar to that observed in a fluid channel. Whereas, for small Darcy numbers, the average Nusselt number decreases until it reaches a minimum for $Da = 10^{-6}$ where there is no convective exchange in the porous layers. Results show also that the heat transfer decreases significantly when the porous layer thickness is less than 0.1 ($e_p^* \square 0.1$). Finally, note that the isotherms and streamlines are very sensitive to variation of the porous layers thickness for relatively large Darcy number.

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Analysis of Electro-Thermal Characteristics of a Conductive Layer with Cracks and Holes

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Abstract- Electro-thermal characteristics of conductive layer with edge crack and internal hole subjected to steady current has been studied numerically. In this paper, an attempt has been made to determine the effects of presence of edge cracks or internal hole in conductive layers with different parameters by finite element method using COMSOL Multiphysics Simulation. The characteristics are evaluated in terms of electrical and mechanical parameters that can be expressed in terms of electric potential and temperature at different locations of the layer. The result shows that the generated temperature profiles are affected by edge crack or internal hole in a conductive layer. The effects of practical issues are also being analyzed which include variable crosssection, various materials, variable material properties, electrical and thermal insulation etc.

Keywords: electro-thermal, cracks, holes, comsol, simulation, finite elementary method.

GJRE-A Classification : FOR Code: 290501, 850505

ANALYSISOFELECTROTHERMALCHARACTERISTICSOFACONDUCTIVELAYERWITHCRACKSANDHOLES

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Abstract- Electro-thermal characteristics of conductive layer with edge crack and internal hole subjected to steady current has been studied numerically. In this paper, an attempt has been made to determine the effects of presence of edge cracks or internal hole in conductive layers with different parameters by finite element method using COMSOL Multiphysics Simulation. The characteristics are evaluated in terms of electrical and mechanical parameters that can be expressed in terms of electric potential and temperature at different locations of the layer. The result shows that the generated temperature profiles are affected by edge crack or internal hole in a conductive layer. The effects of practical issues are also being analyzed which include variable cross-section, various materials, variable material properties, electrical and thermal insulation etc.

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I. Introduction

Today's world is extensively and rapidly inclining to miniaturizing of electronic components to meet the demands and flexibility. Miniaturization of electronic devices has led to tremendous integration levels, with complicated network of conductive layer assembled together on a chip area no larger than a few square centimeters [1]. The thermal characteristics of the incorporated conductive layer undergo a huge amount of current [2]. This phenomenon is unavoidable in modern electronics, so it is indeed an urge of time to investigate the electro-thermal problems and determine the associated resultant temperature fields properly, as far as the reliability of electronic devices is concerned. When an electrically conducting material is subjected to a current flow, Joule heating is induced, which eventually leads to the generation of heat in the conductor. This electrical and thermal conduction ultimately causes thermal stress in the materials, which is considered to be one of the major reasons of metal line failure in electronic packaging [3].

The problem of heat conduction in a layer under the influence of current flow has been explained theoretically by Carslaw and Jaeger [4]. Steady temperature distribution near the tip of a crack in a homogeneous isotropic conductive plate was analyzed by Saka and Abe [5] under a direct current field with the help of pathindependent integrals. Further, the analysis was extended by Sasagawa et al. [6] to

determine the current density and temperature distributions near the corner of an angled metal line subjected to direct current flow. Greenwood and Williamson [7] treated the case of a conductor subjected to a direct current flow, in which temperature dependent material properties were considered, and showed that equipotential were isothermals under the assumption that the relationship between the temperature and electrical potential at the positions of current input and output satisfied the condition of zero electro-thermal heat flux vector [8], and the remaining portion of the boundary was insulated both electrically and thermally.

This paper represents a study on the electrical and thermal conduction through a conductive metal layer having edge cracks or internal holes subjected to constant current density. The method of Greenwood and Williamson was extended by Jang [9] is used to obtain a solution to the coupled nonlinear problem of steady-state electrical and thermal conduction across a crack in a conductive layer for which material properties were assumed to be functions of temperature.

The main aim of the current work is focused on conducting a comprehensive numerical modeling of potential distribution and thermal gradient due to the effect of various relevant parameters like varying crack depth and internal holes of different geometrical shapes.

II. Physical Model

The physical model considered in the present study is a two-dimensional rectangular film of copper as shown in Fig. 1. The length and width of the layer is 0.2m and 0.1m respectively. The constant current density, $J_n = 30MAm^{-2}$ is injected from the left boundary (1) which passes through the whole layer and exists from the right boundary (4). The left and right boundaries are kept at temperature $T_i = 328K$ and $T_o = 273K$ respectively while the top (3) and bottom (2) edges are kept both thermally and electrically insulated.

We considered the current and heat balances in a two dimensional approximation of the real geometry, as the thickness considered is negligible.

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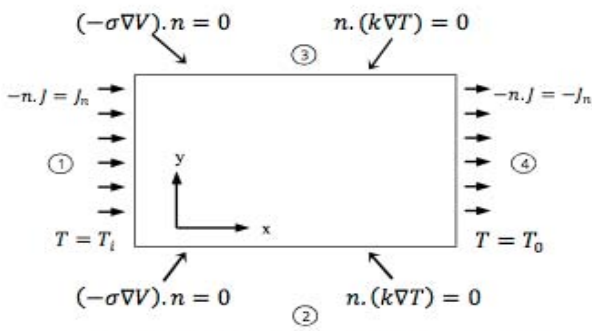*e-mails: palash.me06@gmail.com, aahad16@gmail.com*

Figure 1 : Schematic diagram of the physical domain with boundary conditions

a) Parameters

Table 1 : List of parameters

PARAMETER	UNIT	VALUE
Common Parameters		
Length (L)	m	0.2
Width (W)	m	0.1
Thickness (t)	m	0.001
Current Density (J)	MAm^{-2}	30
Thermal Conductivity (k)	Wm^{-1}K^{-1}	400
Electrical Resistivity (ρ)	Ωm	1.754 e-8
Ambient Temperature	K	298
Inlet Temperature (T_i)	K	328
Outlet Temperature (T_o)	K	273
Edge Cracks		
Crack Width (w)	m	0.001
Varying Crack Depth (d)	m	0.01, 0.02, 0.03, 0.04, 0.05

Internal Holes		
Hole Shape	**Dimension**	**Figure**
Diamond	x= 0.02 m	
	x= 0.04 m	
Circle	r = 0.008m	
	r = 0.016m	
Hole Shape	**Dimension**	**Figure**
Rectangle	a= 0.014m	
	a= 0.028m	
Triangle (J enters from the vertex)	h=0.0187m	
	h=0.0374m	
Triangle (J enters from the base)	h=0.0187m	
	h=0.0374m	

III.   Mathematical Formulation

When a conductive layer is subjected to a constant current, there will be potential difference throughout the layer. The electric potential strongly depends on electrical resistivity of the layer material and the value of injected current. That potential difference affects heat generation, which finally involves in calculating thermal distribution. The energy generation term in the governing equation is calculated based on the distribution of electrical potential, there by leading to a coupled analysis of heat transfer problem with electrical problem.

a) Electrical Problem

At a point in space, the electric potential is the potential energy per unit of change that is associated with a static (time invariant) field. The electric field at a point is equal to the negative gradient of the electric potential over there. In symbols,

$$E = -\nabla\varphi \qquad (1)$$

Where, $\varphi(x,y,z)$ is the scalar field representing the electric potential at a given point and E is the corresponding electric field.

The continuum form of Ohm's law is

$$\nabla\varphi = -\rho J \qquad (2)$$

Which is only valid in the reference form of the conductive material. Equation (2) can be written for orthographic / isotropic material as,

$$iJ_x + jJ_y + kJ_z = -\frac{1}{\rho}\left[i\frac{\partial\varphi}{\partial x} + j\frac{\partial\varphi}{\partial y} + k\frac{\partial\varphi}{\partial z}\right] \qquad (3)$$

If the material is anisotropic, we can conclude as,

$$J_x = -\frac{1}{\rho_x}\frac{\partial\varphi}{\partial x},\ J_y = -\frac{1}{\rho_y}\frac{\partial\varphi}{\partial y}, J_z = -\frac{1}{\rho_z}\frac{\partial\varphi}{\partial z} \qquad (4)$$

According to conservation of current law, for stationary current and no free charge in that region,

$$\frac{\partial J_x}{\partial x} + \frac{\partial J_y}{\partial y} + \frac{\partial J_z}{\partial z} = 0 \qquad (5)$$

From (4) and (5), for the two dimensional analysis,

$$\frac{\partial^2\emptyset}{\partial x^2} + \frac{\partial^2\varphi}{\partial y^2} = 0 \qquad (6)$$

The boundary conditions for prescribed electrical potential distribution are:

$$\varphi(0,H) = \varphi_1, \qquad\qquad \varphi(L,H) = \varphi_2$$
$$\varphi(L,0) = 0, \qquad\qquad \varphi(0,H) = 0$$

And for electrical insulation or prescribed current density,

At $x = 0, \frac{d\varphi}{x} = -\rho J$ $\qquad$ At $x = L, \frac{d\varphi}{dx} = \rho J$

At $y = 0, \frac{d\varphi}{dy} = 0$ $\qquad$ At $y = b, \frac{d\varphi}{dy} = 0$

b) Thermal Problem

The temperature distribution of a conductive layer is easily understood when the wire is subjected to both-endfixed temperature, open to atmosphere at both-ends etc. But if the layer is subjected to Joule heating or heating due to current, temperature distribution largely depends on thermal conductivity, convection co-efficient of a material.

The energy balance equation for the volume element is stated as-

$$\begin{pmatrix} Net\ rate \\ of \\ heat\ gain \\ by \\ conduction \\ (I) \end{pmatrix} - \begin{pmatrix} Net\ rate \\ of \\ heat\ loss \\ by \\ convection \\ (II) \end{pmatrix} + \begin{pmatrix} Rate\ of \\ energy \\ generation \\ \\ (III) \end{pmatrix}$$

$$= \begin{pmatrix} Rate\ of \\ increase \\ of \\ thermal \\ energy \\ (IV) \end{pmatrix}$$

So arranging we get,

$$-\frac{1}{A}\frac{[Aq]_x - [Aq]_{x+\Delta x}}{\Delta x} - \frac{hP}{A}[T(x) - T_\infty] + g = \rho C_p \frac{\partial T}{\partial t} \quad (7)$$

Applying, $\Delta x \to 0$ with the flux by Fourier law

$$\frac{1}{A}\frac{\partial}{\partial x}\left(Ak\frac{\partial T}{\partial x}\right) - \frac{hP}{A}[T(x) - T_\infty] + g = \rho C_p \frac{\partial T}{\partial t} \quad (8)$$

So, the basic governing equation for two dimensional heat problems-

$$\frac{1}{A}\frac{\partial}{\partial x}\left(Ak_x\frac{\partial T}{\partial x}\right) + \frac{1}{A}\frac{\partial}{\partial y}\left(Ak_y\frac{\partial T}{\partial y}\right) - \frac{hP}{A}[T(x) - T_\infty] + g = \rho C_p \frac{\partial T}{\partial t} \quad (9)$$

For variable area and conductivity,

$$\frac{1}{A}\frac{\partial}{\partial x}\left(Ak_x\frac{\partial T}{\partial x}\right) + \frac{1}{A}\frac{\partial}{\partial y}\left(Ak_y\frac{\partial T}{\partial y}\right) - \frac{hP}{A}[T(x) - T_\infty] + g = 0 \quad (10)$$

For constant area and variable conductivity,

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) - \frac{hP}{A}[T(x) - T_\infty] + g = 0 \quad (11)$$

For constant area and constant conductivity,

$$k\left(\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2}\right) - \frac{hP}{A}[T(x) - T_\infty] + g = 0 \quad (12)$$

For variable area, variable conductivity and insulated layer,

$$\frac{1}{A}\frac{\partial}{\partial x}\left(Ak_x\frac{\partial T}{\partial x}\right) + \frac{1}{A}\frac{\partial}{\partial y}\left(Ak_y\frac{\partial T}{\partial y}\right) + g = 0 \quad (13)$$

The boundary conditions are,

$$\left.\begin{array}{l} x=0,\ T(x)=T\_\infty \\ x=L,\ T(x)=T\_L \end{array}\right\} \text{ (For prescribed temperature)!}$$

$$\left.\begin{array}{l} x=0,\ q_0=-kA\frac{dT}{dx} \\ x=L,\ q_0=kA\frac{dT}{dx} \end{array}\right\} \text{ (For prescribed heat flux)}$$

$$\left.\begin{array}{l} x=0,\ A\frac{dT}{dx}=h(T-T_\infty) \\ x=L,\ kA\frac{dT}{dx}=h(T-T_\infty) \end{array}\right\} \text{ (For convection)!}$$

Coupling Electrical and thermal problems,

$$\frac{1}{A}\frac{\partial}{\partial x}\left(Ak_x\frac{\partial T}{\partial x}\right) + \frac{1}{A}\frac{\partial}{\partial y}\left(Ak_y\frac{\partial T}{\partial y}\right) - \frac{hP}{A}[T(x) - T_\infty] + g = \rho C_p \frac{\partial T}{\partial t} \quad (13)$$

And, $g = \rho(J_x^2 + J_y^2) = \left\{\left(\frac{\partial \varphi}{\partial x}\right)^2 + \left(\frac{\partial \varphi}{\partial y}\right)^2\right\}$ (14)

Here, potential distribution, which is found by electrical analysis of a conductive layer, is put in above equation and the heat generation is calculated. Then heat generation is used in thermal analysis where temperature distribution of that conductive layer is evaluated.

c) Electro-Thermal Heat Flux

Electro-thermal heat flux of a conductive layer is the difference between the thermal heat flux and the flux generation by the potential distribution of that layer. Electro-thermal Heat Flux for two dimensional electrothermal problem,

$$P = q - \frac{1}{2k\rho}\ \varphi\left(\frac{\partial \varphi}{\partial x} + \frac{\partial \varphi}{\partial y}\right) \quad (15)$$

d) Solution Procedure

In this study, the Galerkin weighted residual method of finite-element formulation is used as a numerical procedure. The finite element method begins by the partitions of the continuum area of interest into a number of simply shaped regions called elements. These elements may be of different size and shapes. Within each element, the dependent variable is approximated using interpolation functions.

The coupled governing equations (14)-(15) are transformed into sets of algebraic equations using the finite element method to reduce the continuum domain into discrete triangular domains. The system of algebraic equations is solved by iteration technique. The solution process is iterated until the subsequent convergence is satisfied.

$|\psi^{m+1} - \psi^m| \le 10^{-4}$ Where m is the number of iteration and $\quad$ is the general dependent variable.

IV. Results and Discussion

In this study, the electro-thermal characteristics of thin conductive metal layer are measured through a simulation study using the COMSOL Multiphysics software by finiteelement- method (FEM).
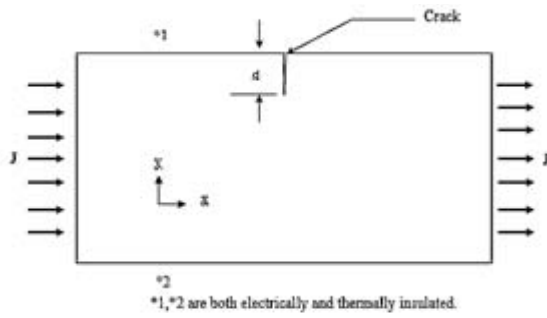
Figure 2 : Geometry of a rectangular copper plate having an edge crack at mid-length position of the layer

Figure 2 shows the geometric configuration of the copper plate and Figure-3 visualizes the generated temperature distribution profile. Figure-6 illustrates the effect of crack depth on the electrical potential. Electrical potential is a function of axial position and it follows a linear shape. We can see that, changing the crack depth increases the maximum electrical potential. When the copper layer with an edge crack at mid-length position of the layer, with constant material property and unchanged boundary conditions is subjected to uniform current density, then Figure 7 depicts the trend of generated temperature along the length.
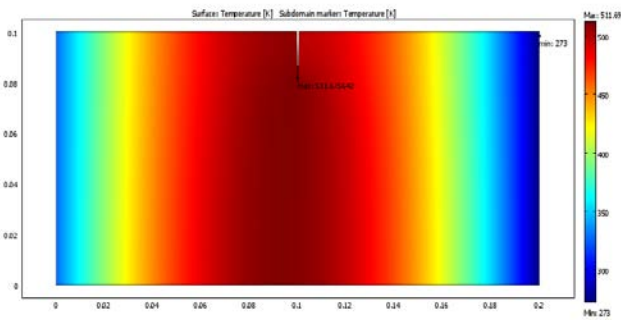
Figure 3 : Temperature profile of a rectangular copper plate having an edge crack at mid-length position of the layer

As the generated temperature is the function of position, so the figure is dome shaped. The temperature increases along length until the center and decreases thereafter. Increasing the crack depth obviously increases the maximum temperature as at the points of crack, the current density increases which raises the temperature. Therefore, the position of maximum generated temperature is at the position of the crack, more appropriately around the tip of the crack. From Figure-7, it is obvious that generated maximum temperature increases proportionally with the ratio of crack depth to crack width, which ultimately depicts that temperature is proportional to crack depth, as crack width is constant.
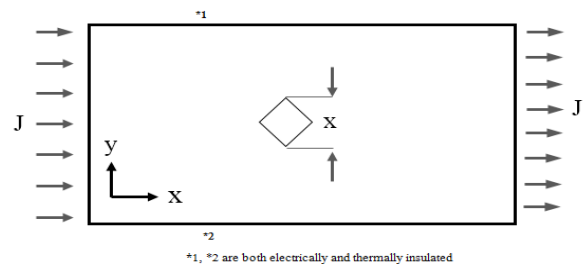
Figure 4 : Geometry of a rectangular copper plate having a right-angled diamond-shaped hole at its center

Figure 8 shows the variation of heat flux when varying the crack depth. It should be noticed that at the position of crack, the shape changes. The heat flux sharply decreases at the crack as the sectional area decreases. Moreover, the minimum heat flux is at the top of the crack.

In case of holes, Figure 5 shows the general trend of temperature distribution of a rectangular copper plate having a right-angled diamond-shaped hole at its center. Figure 10 represents the change of temperature with change of hole shape keeping the boundary condition unchanged.
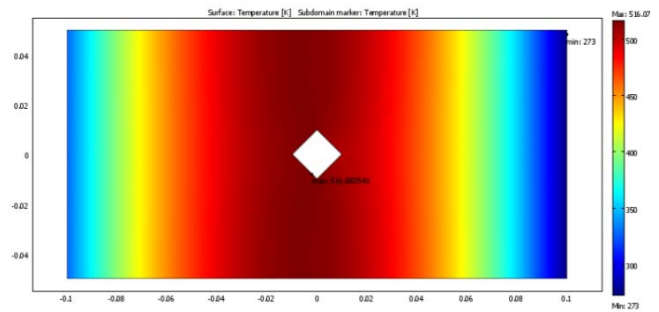
Figure 5 : Temperature profile of a rectangular copper plate having a right-angled diamond-shaped hole at its center
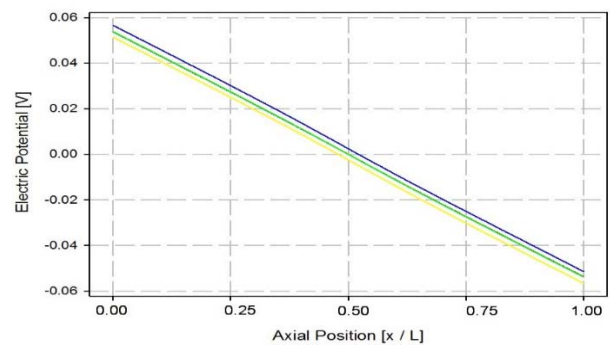
Figure 6 : Comparison of electric potential at the center line along X- axis for various crack depth of a rectangular copper plate having an edge crack at midlength position of the layer
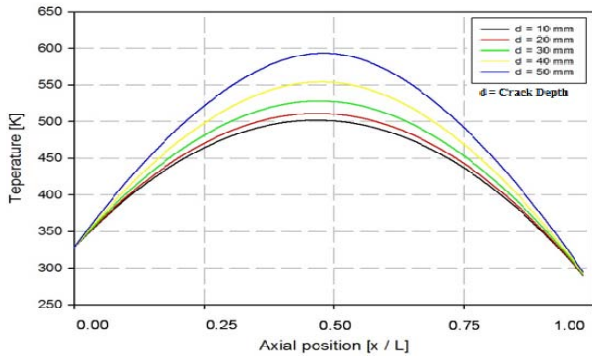
Figure 7 : Comparison of temperature at the centerline along X- axis for various crack depth of a rectangular copper plate having an edge crack at mid-length position of the layer
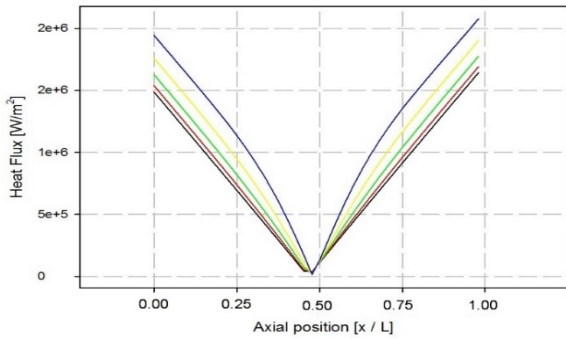
Figure 8 : Comparison of heat flux at the centerline along X- axis for various crack depth of a rectangular copper plate having an edge crack at mid-length position of layer

The temperature is dependent on heat generation and g∝ |∇V| i.e. g is dependent on axial position. The figure shows that the shape is almost same for circle, diamond and rectangle. But with reversed triangle (Vertex is opposite to current input direction) the temperature is little lower.
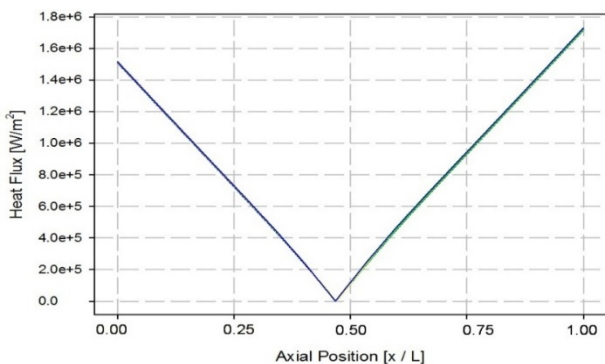
Figure 9 : Comparison of electric potential (developed at the upper edge along X-axis) of a rectangular copper plate having various types of holes at its center
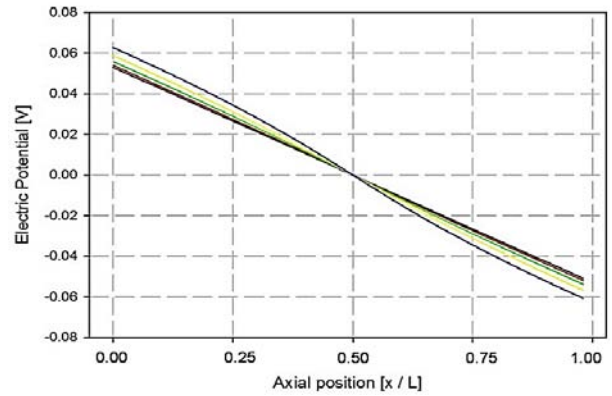
Figure 10 : Comparison of temperature (at the upper edge along X-axis) of a rectangular copper plate having various types of holes at its center
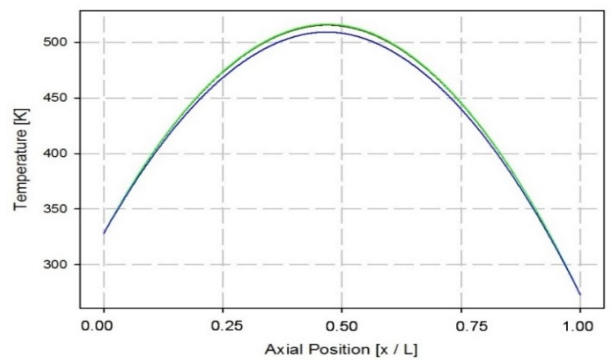
Figure 11 : Comparison of heat flux (generated at the upper edge along X-axis) of a rectangular copper plate having various types of holes at its center

Making the hole diameter as a variable quantity, which shows that with the increment of the size ratio, temperature increases as it withstand the same current input within a smaller region, makes another analysis. Here temperature is a function of size ratio (the ratio of hole diameter to plate diagonal)

Effect Of Crack Depth
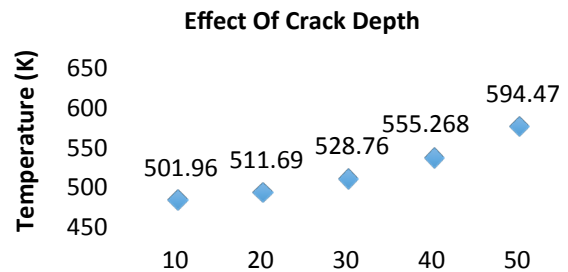
Figure 12 : Temperature (at the center line along X- axis) variation with the ratio of crack depth to crack width of a rectangular copper plate having an edge crack at midlength position of the layer

Table 2 : Effect of varying Size Ratio of the Hole

Shape	Size Factor	Size Ratio	Maximum Temperature (K)
Diamond	Hole Diagonal/ Plate Diagonal	0.089	516.08
		0.134	528.76
		0.179	548.06
		0.224	577.84
Rectangle	Hole Diagonal/ Plate Diagonal	0.089	516.21
		0.179	547.89
Circle	Hole Diameter/ Plate Diagonal	0.071	515.51
		0.143	544.57
Triangle (J enters from the topmost point)	Hole Height/ Plate Diagonal	0.084	499.31
		0.167	535.28
Triangle (J enters from the base)	Hole Height/ Plate Diagonal	0.084	499.32
		0.167	535.03

V. Conclusion

Thermal and electrical characteristics of uniform and non-uniform conductive layers are studied in this research and the analysis was done by computer simulation using COMSOL Multiphysics. In this paper, conductive layers with different types and shapes of internal holes as well as edge cracks are studied.

When analyzing edge crack, it is also seen that crack on conductive layer affects electrical potential and the temperature distribution. An interesting result is found that increasing the crack depth has more significant effect than changing the crack position when other parameters are unchanged. Sharp drop of electrical potential at crack position indicates the sudden change of temperature at that position.

It has been investigated that any kind of hole in a conductive layer increases the temperature. Impacts of circular, diamond-shaped, rectangular and triangular holes are studied. Changing the shape of the internal hole creates little fluctuation on characteristic curves.

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Nomenclature

Symbol	Meaning	Unit
J	Current density	Am^{-2}
k	Thermal conductivity	$Wm^{-1}K^{-1}$
h	Convective HT co-efficient	$Wm^{-2}K^{-1}$
C_p	Specific heat capacity	$KJKg^{-1\circ}C^{-1}$

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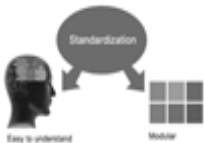
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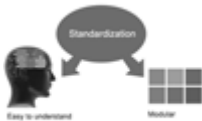
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- Numbering of First Main Headings (Heading 1) must be in Roman Letters, Capital Letter, and Font Size of 10.
- Numbering of Second Main Headings (Heading 2) must be in Alphabets, Italic, and Font Size of 10.

You can use your own standard format also.
Author Guidelines:

1. General,

2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript's Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

1. GENERAL

Before submitting your research paper, one is advised to go through the details as mentioned in following heads. It will be beneficial, while peer reviewer justify your paper for publication.

Scope

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Complete support for both authors and co-author is provided.

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Original research paper: Such papers are reports of high-level significant original research work.

Review papers: These are concise, significant but helpful and decisive topics for young researchers.

Research articles: These are handled with small investigation and applications

Research letters: The letters are small and concise comments on previously published matters.

5.STRUCTURE AND FORMAT OF MANUSCRIPT

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

Papers: These are reports of significant research (typically less than 7000 words equivalent, including tables, figures, references), and comprise:

(a)Title should be relevant and commensurate with the theme of the paper.

(b) A brief Summary, "Abstract" (less than 150 words) containing the major results and conclusions.

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

(d) An Introduction, giving necessary background excluding subheadings; objectives must be clearly declared.

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

(f) Results should be presented concisely, by well-designed tables and/or figures; the same data may not be used in both; suitable statistical data should be given. All data must be obtained with attention to numerical detail in the planning stage. As reproduced design has been recognized to be important to experiments for a considerable time, the Editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned un-refereed;

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

(h) Brief Acknowledgements.

(i) References in the proper form.

Authors should very cautiously consider the preparation of papers to ensure that they communicate efficiently. Papers are much more likely to be accepted, if they are cautiously designed and laid out, contain few or no errors, are summarizing, and be conventional to the approach and instructions. They will in addition, be published with much less delays than those that require much technical and editorial correction.

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It is vital, that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

Format

Language: The language of publication is UK English. Authors, for whom English is a second language, must have their manuscript efficiently edited by an English-speaking person before submission to make sure that, the English is of high excellence. It is preferable, that manuscripts should be professionally edited.

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Abbreviations supposed to be used carefully. The abbreviated name or expression is supposed to be cited in full at first usage, followed by the conventional abbreviation in parentheses.

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

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

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

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

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

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

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

Acknowledgements: Please make these as concise as possible.

References

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

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

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

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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.

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

12. Make all efforts: Make all efforts to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in introduction, that what is the need of a particular research paper. Polish your work by good skill of writing and always give an evaluator, what he wants.

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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.

20. Use good quality grammar: Always use a good quality grammar and use words that will throw positive impact on evaluator. Use of good quality grammar does not mean to use tough words, that for each word the evaluator has to go through dictionary. Do not start sentence with a conjunction. Do not fragment sentences. Eliminate one-word sentences. Ignore passive voice. Do not ever use a big word when a diminutive one would suffice. Verbs have to be in agreement with their subjects. Prepositions are not expressions to finish sentences with. It is incorrect to ever divide an infinitive. Avoid clichés like the disease. Also, always shun irritating alliteration. Use language that is simple and straight forward. put together a neat summary.

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.

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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.

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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.

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

To make a paper clear

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Mistakes to evade

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- Separating a table/chart or figure - impound each figure/table to a single page
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· 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.

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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 <u>definite statistics</u> - 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

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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.

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- 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.

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

Approach:

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

What to keep away from

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

Results:

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

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

Content

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

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.

- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

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

Figures and tables

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

Discussion:

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

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

Approach:

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

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- Do not give permission to anyone else to "PROOFREAD" your manuscript.

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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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