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Highlights...

- Dynamic Interactions
- Equipments Maintainability
- Hydraulic Turbines
- Sediment Erosion

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Modeling of Inter - Component and Inter - Domain Dynamic Interactions of an Excavator Using Bond Graphs

By Onesmus Muvengei, John Kihiu
Department of Mechanical Engineering, JKUAT

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Keywords : *Actuators, Bond graphs, Forward dynamics, Inter-actuator interactions, Jacobians, Steady-state responses, Transient responses.*

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Onesmus Muvengei[α], John Kihiu[Ω]

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I. Introduction

Most of research work on excavator dynamics has primarily considered the manipulator dynamics (Koivo, et. al, 1996, Vaha and Skibiniewski, 1993, Cannon, 1999). Only a few researchers have considered the interactive hydraulics and mechanical dynamics of excavators (Beater and Otter, 2003, Cheol-Gyu and Kwang-Ho, 2004, Nguyen, 2000). The complication of coupled dynamics and the computational difficulty have prevented the progress of research in this field (Zangh and Duqiang, 1999)

3-dimensional mechanical systems consisting of hydraulic components like excavators are difficult to simulate. Usually two different modeling techniques, one for mechanical dynamics and the other for the hydraulic dynamics, have been used and then coupled to a complete model which is then simulated using a single (Beater and Otter, 2003, Cheol-Gyu and Kwang-Ho,2004, Nguyen, 2000). Cheol-Gyu and Kwang-Ho (Cheol-Gyu and Kwang-Ho, 2004) presented a simulation environment of excavator dynamics by coupling the MSC.ADAMS mechanical dynamic model of the excavator and the Ordinary Differential Equation's hydraulic system model, and then simulating the overall model on SIMULINK. Beater and Otter (Beater and Otter, 2003) demonstrated how to model the dynamics of an excavator by modeling the mechanical part using Modelica language, and modeling the dynamics of the hydraulic system using HYLIB language, then integrating the two models and simulating the output model using DYMOLA 2003 simulation software. Nguyen (Nguyen, 2000) modeled the mechanical dynamics of the excavator using Newton-Euler method and the hydraulic dynamics using ordinary differential method.

The integration of models from different domains have proved to be a complex and time consuming task, because, although powerful simulation libraries exist, they are generally based on different modeling languages, almost invariably not compatible (Ferreira et. al 2000). Also, the integration of two modeling techniques leads to unnecessary numerical problems and the resulting model may contain fragile interfaces which affect the simulation results.

The bond graph method was established as a new approach to model, analyze and control various dynamical systems by Professor Henry Paynter (Paynter, 1961). Through bond graph modeling technique, the problem of coupling several models from different engineering systems has been solved, and now a model representing several sub-models from various engineering disciplines can be simulated using one simulation environment such as MATLAB/SIMULINK, 20-SIM, CAMP-G, et cetera. Since Prof. Paynter introduced the basic concept of bond graph modeling, bond graphs have been a topic of research or are being used in research on modeling and simulation of dynamic behavior of physical systems.

Margolis and Karnopp (Margolis and Karnopp, 1979) contributed to the field of bond graphs by carrying out a comprehensive research, the outcomes of which

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are applicable to areas of robotics, cranes, excavators, wheel loaders, and space vehicles. The study investigated the dynamics of two arms, with articulated joints and actuated on the joint considering actuation unit dynamics, rigid body dynamics and bending vibrations all together. Margolis and Shim, (Margolis and Shim, 2003) used bond graph method to develop a complete pitch/plane model of a backhoe considering the boom dynamics, the hydraulic dynamics of the boom cylinder and valve, the chassis/cab mountings and the control stick dynamics. Using the parameters of a medium size back hoe in simulating the bond graph model, the authors demonstrated the instability of the backhoe in consideration. Also Krishnaswamy (Krishnaswamy, 2004) modeled the boom motion of an excavator to study the passivity of hydraulic systems. The authors only considered the boom motion, but in this research work, three excavator motions, i.e, boom, arm, bucket motions will be considered.

The available literature shows that a lot of emphasis on modeling the dynamics of excavators has been focused on the mechanical dynamics of the manipulator, with less attention to the interactive hydraulic and mechanical dynamics. This has been attributed to the computational difficulty and the complication of coupled dynamics which result when models from different modeling techniques one for mechanical and the other for hydraulic dynamics are integrated together for simulation. In this paper, models of the hydraulic and mechanical dynamics of an excavator are developed using one modeling technique, that is, bond graphs, hence eliminating the problem of coupling models from different techniques.

II. Dynamic Coupling of Mechanical and Hydraulic Bond Graph Models of the Excavator

The bond graph models of mechanical and hydraulic dynamics of the excavating mechanism shown in Fig. 1 have been developed in previous research works (Muvengei and Kihiu, 2009a, Muvengei and Kihiu, 2009b). The objective of modeling the excavating mechanism is to predict its dynamic behavior by combining actuator and manipulator dynamics. Hydraulic cylinders are used to actuate the manipulator joints by generating forces necessary for boom, arm and bucket motion. These forces are determined by the pressures of the chambers in each actuator, and these pressures, in turn, are determined by the velocity and displacement of the actuator which are calculated from the mechanical dynamics of the excavator (Beater and Otter, 2003). Therefore, it is in these actuators where the dynamic coupling between the mechanical and hydraulic system model of the excavator takes place. Figure 2 shows this relationship schematically. From the knowledge of manipulator dynamics, we have the following well known relations.

$$\dot{X} = J\dot{q}$$
$$\tau = J^T F \qquad (2.1)$$

Where X is the vector of piston displacements, is the vector of piston velocities, q is the vector of manipulator joint angles, F includes the forces generated by actuators, and τ is the vector of corresponding torques at the manipulator joints.

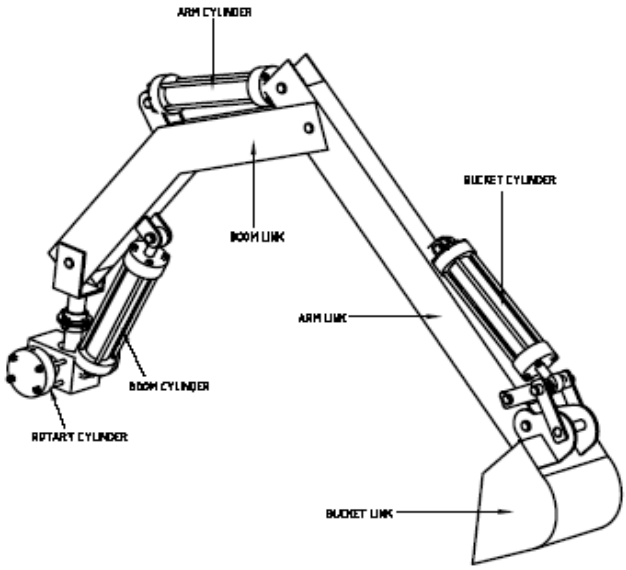
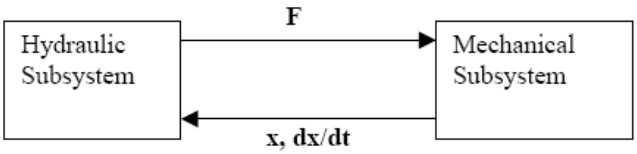


Fig. 1 : Schematic drawing for part of the assembled excavator.



F: Hydraulic cylinder force.
x, dx/dy: Displacement and velocity of the cylinder.

Fig. 2 : Dynamic coupling between the mechanical and hydraulic systems of an excavator.

Since boom, arm, and the bucket links are independently actuated, the jacobian matrix J is a diagonal matrix, and hence equation (2.1) can be written as;

$$\begin{pmatrix} \dot{x}_{bo} \\ \dot{x}_a \\ \dot{x}_{bu} \end{pmatrix} = \begin{pmatrix} r_{19} & 0 & 0 \\ 0 & r_{20} & 0 \\ 0 & 0 & r_{21} \end{pmatrix} \begin{pmatrix} \dot{\theta}_2 \\ \dot{\theta}_3 \\ \dot{\theta}_4 \end{pmatrix} \qquad (2.2)$$

Where $\dot{x}_{bo}$, $\dot{x}_a$ and $\dot{x}_{bu}$ are the velocities of the pistons of the boom, arm, and bucket cylinders respectively.

a) Deriving the Jacobi Expressions for the Manipulator

The diagonal elements of the Jacobi matrix in equation (2.2) can be treated as modulated transformer elements in bond graph method since they relate the

input and output flow variables in a junction, that is, they transform the angular velocities of the links to the linear velocities of the pistons, and their magnitudes depend on the angular positions of the links. The length of a hydraulic actuator can be specified by a line segment between the attachment points as shown in Fig. 3.

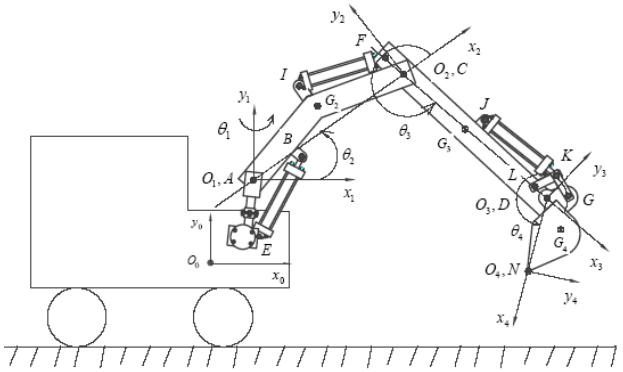


Fig. 3 : Coordinate System assignment for the excavator.

i. *Boom Link*

This is actuated by the boom cylinder which moves joint 2. Consider Fig. 4 which is obtained from Fig. 3.

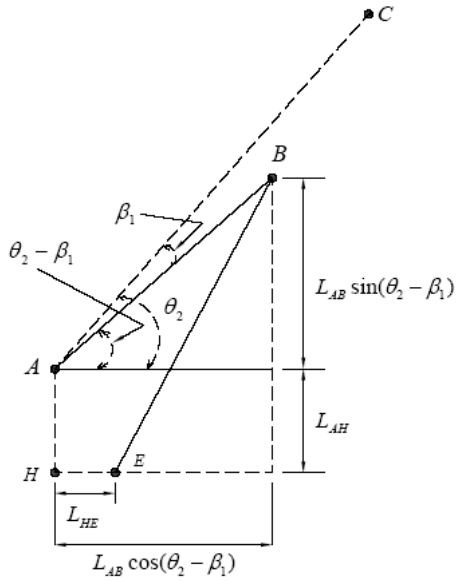


Fig. 4 : Boom cylinder length

Since the rate in which the boom cylinder is changing L_{BE} is technically equal to the piston velocity of the boom cylinder , it can be shown that;

$$\dot{x}_{bu} = r_{19}\,\dot{\theta}_2 \qquad (2.3)$$

Where

$$r_{19} = \frac{L_{AB}L_{AH}\cos(\theta_2 - \beta_1) + L_{AB}L_{HE}\sin(\theta_2 - \beta_1)}{\sqrt{\left[L_{AB}\sin(\theta_2 - \beta_1) + L_{AH}\right]^2 + \left[L_{AB}\cos(\theta_2 - \beta_1) - L_{HE}\right]^2}}$$

β_1 is constant angle <BAC, and L_{AB} , L_{AH} and L_{HE} have constant values obtained from the manipulator's geometry. Equation (2.3) can be represented in bond graphic form as shown in Fig. 5.

$$1:\dot{x}_{bo} \xrightarrow{F_{cy}} MTF : \frac{1}{r_{19}} \xrightarrow{\tau_2} 1:\dot{\theta}_2$$

Fig. 5 : Coupling the hydro-mechanical dynamics of the boom link

ii . *Arm Link*

This is actuated by the arm cylinder which moves joint 3. Consider Fig. 6 which is obtained from Fig. 3.

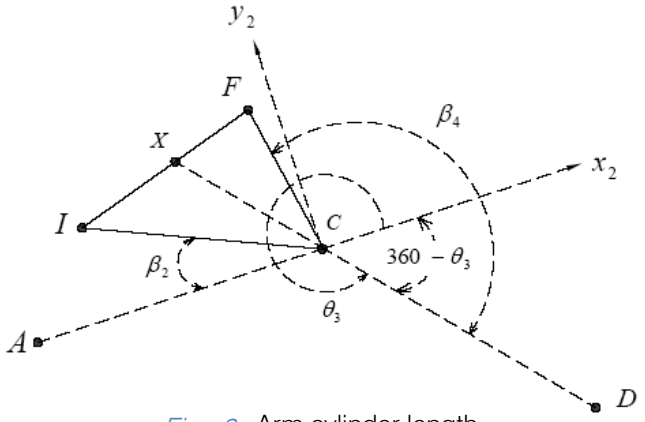


Fig . 6 : Arm cylinder length

Since the rate in which the arm cylinder is changing L_{FI} is technically equal to the piston velocity of the arm cylinder $\dot{x}_a$,it can be shown that;

$$\dot{x}_a = r_{20}\,\dot{\theta}_3 \qquad (2.4)$$

Where

$$r_{20} = \frac{-L_{CI}\sin(540 - \beta_2 - \beta_4 - \theta_3)}{\sqrt{1 + \frac{L_{CI}^2}{L_{FC}^2} - 2\frac{L_{CI}}{L_{FC}}\cos(540 - \beta_2 - \beta_4 - \theta_3)}}$$

$< ACI = \beta_2$ and, $< FCD = \beta_4$. Equation (4) can be represented in bond graph form as shown in Fig. 7.

$$1:\dot{x}_a \xrightarrow{F_{cy}} MTF : \frac{1}{r_{20}} \xrightarrow{\tau_3} 1:\dot{\theta}_3$$

Fig. 7 : Coupling the hydro-mechanical dynamics of the arm link

iii. *Bucket Link*

This is actuated by the bucket cylinder which moves joint 4. Consider Fig. 8 which is obtained from Fig. 3. Since the rate in which the bucket cylinder is changing $\dot{L}_{JK}$ is technically equal to the piston velocity of the bucket cylinder , it can be shown that;

$$\dot{x}_{bu} = r_{21}\dot{\theta}_4 \quad (2.5)$$

Where

$$r_{21} = \frac{-L_{KL}\sin[\nu_1 - (\theta_4 + \pi + \nu_2 + \nu_3 - \varepsilon_2 - \varepsilon_3)]}{\sqrt{1 + \frac{L_{KL}^2}{L_{JL}^2} - 2\frac{L_{KL}}{L_{JL}}\cos[\nu_1 - (\theta_4 + \pi + \nu_2 + \nu_3 - \varepsilon_2 - \varepsilon_3)]}}$$

$\nu_1 =< JLD, \varepsilon_1 =< KLD, \varepsilon_2 =< KDG$, and

$\varepsilon_3 =< LKG$

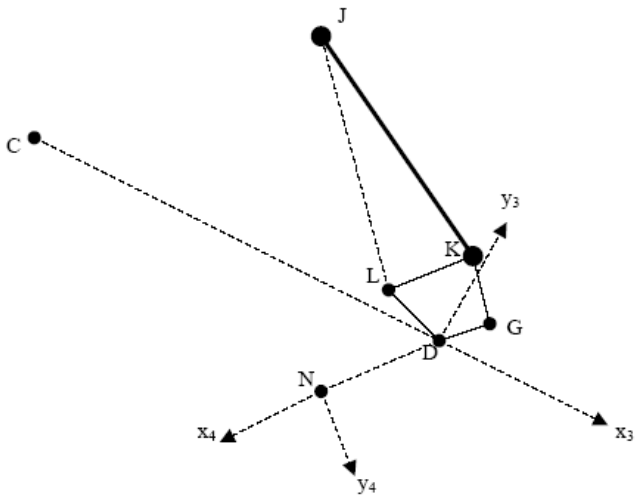


Fig. 8 : Bucket cylinder length

Equation (2.5) can be represented in bond graphic form as shown in Fig. 9.

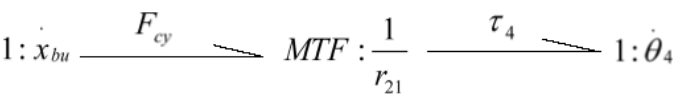


Fig. 9 : Coupling the hydro-mechanical dynamics of the bucket link .

b) Overall Bond Graph Model of the Hydraulic and Mechanical Dynamics

Figure 10 shows the overall causal bond graph model representing the interaction of mechanical and hydraulic dynamics of the excavator. Derivative causality was observed at both the vertical and horizontal momenta of the boom, arm and bucket links. This means that the assumptions made in constructing this model have led to a model that will not compute easily with a computer. To fix this derivative causality problem easily, the Karnopp-Margolis method (Karnopp et. al, 2000) of appending very stiff springs and dampers at the pin joints of the manipulator links was used. These are pointed out in the figure. This allowed a causal bond graph to result with straight-forward simulation properties, that is, integral causality in all the capacitive and inertial elements of the bond graph model. In practice, these additional elements are selected to produce frequencies well outside the range of interest. In this case, elements were chosen to produce 200Hz frequencies since we are interested in frequencies no higher than 20Hz and no modal dynamics have been included for any of the mechanical or fluid parts of the system.

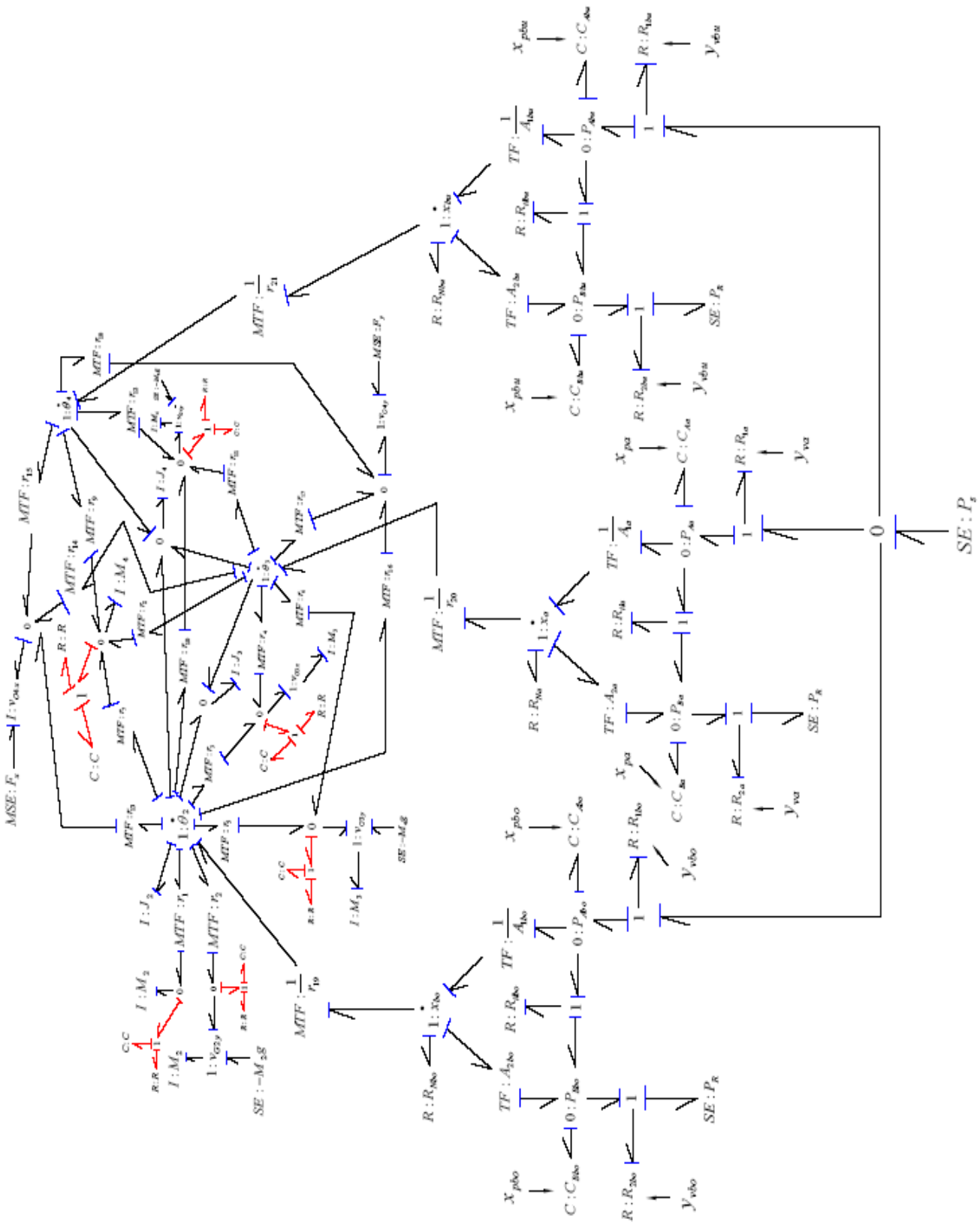


Fig. 10 : Causal bond graph model of the excavating mechanism

III. Results: System Response Using Forward Dynamics

One of the main purposes of modeling a dynamic system is to design appropriate control laws for the system. For a system to be controlled, its model should capture the essential dynamic aspects of the system which include but not limited to, the interaction of the domains involved and also the inter-component interactions. The transient and steady state responses of for the displacements, velocities of the cylinder pistons and manipulator links, flow rates to the cylinders and chamber pressures of the cylinders when all the cylinders are extending simultaneously were simulated to show the dynamic interactions involved in the system. During simulations, one of the links, that is the bucket, was stopped suddenly so as to excite the other links as much as possible, and observed if this excitation was felt in the responses of the other links and the hydraulic system.

a) Link Angular Velocity and Displacement Responses

Figure 11 shows the simulated responses for the angular displacements and velocities plotted in one axis with two y axes for the three links.

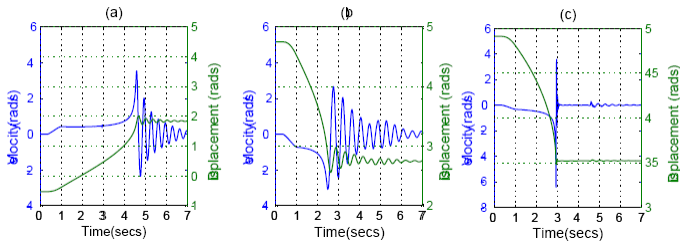


Fig. 11 : The simulated angular velocity and displacement responses for; (a) Boom link (b) Arm link (c) Bucket link.

As clearly seen in Figs. 11 and 12, each manipulator link reaches its final angular position after the piston of the corresponding cylinder completes its stroke (for the case of boom and arm) or is stopped (for the case of bucket). Also, after the final angular position is reached, the velocity response curve of the given cylinder drops and settles to zero value as it is expected practically. The effect of stopping the bucket link suddenly is felt at the velocity response curve of the boom link as an excitement at time 3 seconds as shown in Fig. 11 (a).

b) Piston Velocity and Displacement Responses

Figure 12 shows the simulated responses for the piston displacements and velocities plotted in one axis with two y axes for the three hydraulic cylinders.

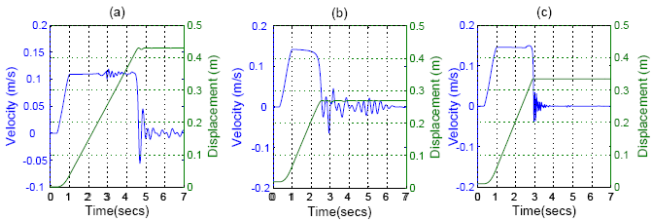


Fig. 12 : The simulated piston velocity and displacement responses for; (a) Boom cylinder (b) Arm cylinder (c) Bucket cylinder

The response curves show clearly that at that time when the piston completes its stroke or stops, the velocity of the piston drops and settles to zero as it is expected practically. The effect of stopping the bucket link suddenly is felt at the velocity response curve of the boom cylinder piston as an excitement in form of damped oscillations at times 3-4 seconds as shown in Fig. 12(a).

c) Flow Rate Responses

Figure 13(a) shows the simulated responses for the flow rates of the three hydraulic cylinders plotted in one axis, while Fig. 16(b) shows the simulated response for the total flow rate.

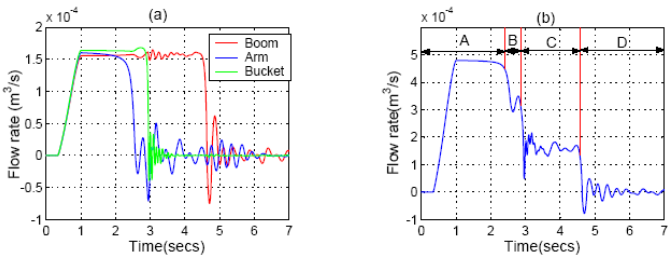


Fig. 13 : The simulated flow rate response; (a) Flow rate responses to individual cylinders (b) Total flow rate.

The flow rate responses for all the cylinders reach the steady state value after 1 second, that is, when the spool valve orifices are completely open. The response curve for the boom cylinder which controls the heaviest link has a lowest steady state value, due to the fact that the cylinder moving the heaviest load offers greater resistance to fluid flow, hence the inter-actuator interaction is captured by the model. The flow rate response curve for the arm cylinder which finishes its stroke first drops to zero value first, then followed by the bucket cylinder which is stopped rapidly after 3 seconds. The excitement caused by stopping the bucket link rapidly is significantly felt at the flow rate response of the boom cylinder at times 3-4 seconds as shown in Fig. 13(a). Since all the manipulator links are extending simultaneously, the total flow rate response which is the summation of the flows to the actuators is simulated and plotted in Fig. 13(b). This curve can be divided into four regions, namely A, B, C and D. In region A the three cylinders are supplied with fluid flow since they are all moving. This is the region of maximum

flow requirement. In region B only the boom and bucket cylinders require fluid flow since already the arm cylinder has completed its stroke. In region C only the boom cylinder requires fluid flow since the bucket cylinder has been stopped. In region D no fluid flow is required since all the links have stopped moving after the boom cylinder has completed its stroke.

d) Pressure Responses at the Cylinder Chambers

Figure 14 shows the simulated pressures in the two chambers of the boom, arm and bucket cylinders plotted in the same axis. It is clearly seen that at the region of ramp input (between 0 and 1 second), the pressures at the two sides of each cylinder increase at the same rate until when the orifices of the valves are completely open. After the cylinder finishes its stroke or is stopped from moving, the pressure at the head side chamber which receives pressurized fluid increases rapidly to the supply pressure of . This is because the control action of a constant pressure hydraulic system which ensures that the pressure supplied to the cylinder drops or increases to an appropriate value rather than to the pump supply pressure when the cylinder stroke is finished, was not included in the model. The effect of this is seen in the rod side chamber pressure responses for all the cylinders in form of significant pressure fluctuations. The effect of stopping the bucket link suddenly is felt at the pressure response curves of the boom and arm links as an excitement at time 3 seconds as shown in Fig. 14 (a) and (b).

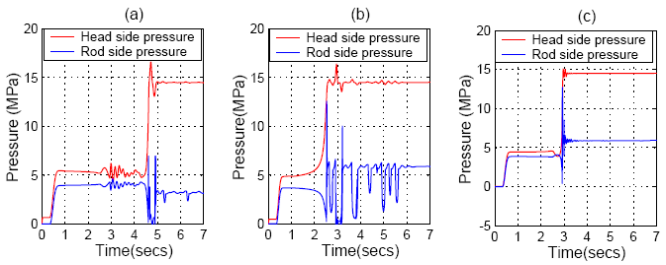


Fig. 14 : The simulated head and rod side pressure responses for; (a) Boom cylinder (b) Arm cylinder (c) Bucket cylinder

From the responses plotted, it is seen that the bond graph model developed captures the interactive dynamics, that is, inter-actuator interactions, inter-link interactions and interaction of the hydraulic and mechanical dynamics.

- Inter-actuator interaction is captured since the cylinder actuating the heavier link receives less fluid flow, and the cylinder actuating the lightest link receives more fluid flow.
- Inter-link interaction is captured since the excitation caused by stopping the bucket link suddenly is witnessed at the response curves of the other links.
- The interaction of the mechanical and hydraulic dynamics is captured since the excitation caused by stopping the bucket link is witnessed at the response curves of the hydraulic system. Also the cylinder actuating the heavier link receives less fluid flow, and the cylinder actuating the lightest link receives more fluid flow.

IV. Conclusion

Dynamic bond graph models representing the mechanical and hydraulic dynamics have been coupled together using appropriate Manipulator Jacobians which were treated as Modulated Transformer. Forward dynamic simulations were then run to determine the open loop transient and steady state responses of the excavator. The bond graph model developed was found to capture the interactive dynamics, that is, inter-actuator interactions, inter-link interactions and interaction of the hydraulic and mechanical dynamics. This is due to the fact that the excitation caused by suddenly stopping the bucket link during simulation, was felt in the response curves of the other links and also of the hydraulic system. Therefore, it can also be concluded that the dynamic model developed in this work can be applied in designing appropriate control laws for the manipulator motions.

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Equipments Maintainability Using Simulation

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Abstract - The challenges of maintenance of engineering equipments and infrastructures are presently attracting researchers' interest. This paper investigates the maintainability of imported "Tokunbo" gear drives in power transmission. In this study, maintainability requirements were quantitatively specified, measured and demonstrated. A combination of Analysis of variance (ANOVA) and Monte Carlo simulation technique were used in this study to determine maintainability of gear drives in power transmission. It was established from the study that gear drives of the same types and condition but from different manufacturing sources have different maintainability. This work provides a useful guide to designers and maintenance engineers in enhancing the maintainability of engineering equipments and systems. This will in no doubt ensure smooth production operations while in service.

Keywords : *Analysis of Variance (ANOVA), Maintainability, Monte Carlo Simulation, Gear drives Power transmission.*

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Equipments Maintainability Using Simulation

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Abstract - The challenges of maintenance of engineering equipments and infrastructures are presently attracting researchers' interest. This paper investigates the maintainability of imported "Tokunbo" gear drives in power transmission. In this study, maintainability requirements were quantitatively specified, measured and demonstrated. A combination of Analysis of variance (ANOVA) and Monte Carlo simulation technique were used in this study to determine maintainability of gear drives in power transmission. It was established from the study that gear drives of the same types and condition but from different manufacturing sources have different maintainability. This work provides a useful guide to designers and maintenance engineers in enhancing the maintainability of engineering equipments and systems. This will in no doubt ensure smooth production operations while in service.

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I. Introduction

Maintainability is an important product characteristic and is also a design parameter (Hao, 2002). Maintainability deals with duration of maintenance outages or how long it takes to achieve with ease and speed the maintenance action compared to a datum. Maintainability is a characteristic of design and installation which is expressed as the probability that an item will be restored to specified condition within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources (David, 2001). Several studies have been done on the maintainability of equipment. *Blanchard et al (1995)* showed that the key feature of merit for maintainability is often the Mean Time To Repair (MTTR) and a limit for the maximum repair time. Quantitatively, it refers to the ease with which hardware or software is restored to a functioning state. Maintainability is usually expressed as in equation 1.

$$M(t) = 1 - \exp(^{-t}/MTTR) \quad (1a)$$

$$M(t) = 1 - \exp(-\mu t) \quad (1b)$$

Where μ is a constant maintenance rate which is equal to the inverse of MTTR. Wanni and Gandhi (2002) explained how maintainability of mechanical equipment based on tribology can be evaluated. The authors developed a model, which is in terms of tribo-maintainability index. This model provides a guide to the designer in enhancing the maintainability of a system. In maintainability test, Roger (1979) described the prediction and allocation techniques that can be used by system designers and planners to determine the maintainability requirements for a system. He concluded from his work that testing whether a system meets maintainability requirements requires a special test that is isolated from other developmental and operational tests.

Many researchers have applied simulation technique in their studies. Houshyar (2003) used simulation in automotive industry to study the impacts of preventive maintenance policy in executing the machinery builder's recommended preventive maintenance policy without adversely affecting the stipulated production quotas. A simulation model was produced that incorporated key characteristics of the actual system. Running the model, the system throughout under two main scenarios was simulated and statistics tests was carried out which indicated that performing the recommended yearly preventive maintenance program would not affect the production quota. Ceric (1990) used simulation to determine vehicle storage space requirements and transportation (performability-Based fleet sizing in a material handling system) *Sean et al (2002)* applied simulation-based methods to develop life cycle analysis in order to aid the department of defence in its management of aging weapon systems. These tools are being used by the US Army, for example to quantify time-dependent life-cycle costs and impacts resulting from proposed aircraft and engine sustainment decisions, specifically, recapitalization maintenance concepts. In a paper presentation, Mart (2000) presented a model and analysis done to predict enemy force closure. The simulation replaces a pencil and ruler method that has been used by Department of defence planners for over a century. Jack (2001) used simulation software to simplify and speed up routine maintenance tasks for the next generation joint strike fighter (JSF).

The use of Monte Carlo in simulation is unique. SAFTAC is a Monte Carlo fault tree simulation program that provides a systematic approach for analyzing system, design, performing trade off studies and optimizing system changes (Crosetti, 1971). A combination of Monte Carlo – based Reliability, Availability and Maintainability simulation tools and electronic spreadsheets has been used in the life cycles

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cost analysis of nuclear plant. Monte Carlo simulation has also been used in transportation system. If a simulation method could be developed that can generate a rare event mishap data in lieu of testing prototypes in actual operational environments, the statistical basis for predicting the system risk would exist. The Axiomatic Safety – Critical Assessment Process, ASCAP is such a simulation methodology (Kaufman and Giras, 2000).

This paper seeks to determine the ease of maintainability of imported "Tokunbo"[1] gear drives in power transmission, compare the maintainability of similar gear drives system manufactured by different companies and determine their MTTR using simulation.

II. Methodology

Imported second hand (Tokunbo)[1] gear drives were obtained from two experienced repair technicians who repair and market fairly used gear drives in Nigeria. These gear drives were made by British (A), Japanese (B) and German (C) firms. Ten usual faults or failures of these gears were obtained from these repair technicians who have almost equal training, qualification and experience. They were then used independently to troubleshoot and correct failures in the randomly selected "Tokunbo"[1] gear drives. The time taken by each technician to rectify each failure was noted and recorded. Average time taken to repair each fault or failure by each of these technicians was calculated. The evaluated average time taken to repair each fault for the gear drives of the three sources were combined in a single table and subjected to the Analysis of Variance (ANOVA). The reason was to determine first whether the difference between the time to repair/correct is significant. After it has been determined that the difference between time to repair is very significant, more data were generated using Monte Carlo simulation method for gear drives manufactured by the three sources. The data obtained which represents ten (10) simulated faults and repaired by one hundred technicians were subjected to further analysis using the following models:

$$M_{ct} = \sum_{i=1}^{N} M_{cti} \tag{2}$$

$$MTTR = \frac{\sum_{i}^{N} M_{cti}}{N} = \frac{M_{cti}}{N} \tag{3}$$

$$\sigma = \sqrt{\frac{N\sum_{I}^{N}(M_{ct})^2 - \left(\sum_{I}^{N} M_{ct}\right)^2}{N(N-1)}} \tag{4}$$

$$ERT = \frac{MTTR}{anti\log(1.50\sigma^2)} \tag{5}$$

For a log normal distribution

$$MTTR_G = M_pTR = anti\log\left[\frac{\sum_{1}^{N}\log M_{cti}}{N}\right] \tag{6}$$

$$M_{\max} = anti\log(\log MTTR_G + 1.645\sigma\log M_{cti} \tag{7}$$

Where

$$\sigma\log M_{ct} = \sqrt{\frac{\sum_{1}^{N}(\log M_{cti})^2 - \left(\sum_{1}^{N}\log M_{cti}\right)^{2}/N}{N-1}} \tag{8}$$

$$M(t) = 1 - \exp(4/MTTR) \tag{9}$$

$$M(t) = 1 - \exp(-\mu t) \tag{10}$$

NOTATIONS

M_{ct}	:	Corrective Maintenance Time
MTTR	:	Mean Time to Repair
ERT	:	Equipment Repair Time
$MTTR_G$	:	Geometric Mean Time to Repair
M_{max}	:	Maximum Maintenance Time
M(t)	:	Maintainability Factor or Probability of Maintenance
σ	:	Standard deviation
T	:	specified Time to Repair
SST	:	Total Sum of Squares
SSB	:	Sum of Squares between Samples
SSW	:	Sum of squares within Samples
F	:	Fisher's Test
μ	:	Repair Rate
M_pTR	:	Median Time to Repair

III. Results/Analysis

The experimental results of tests carried out, Analysis of Variance, summary of Monte Carlo simulation results and other analysis carried out are shown in the following tables :

[1] Tokunbo in Yoruba language in Nigeria simply means "imported"

Table 1 : Time taken to repair faults in gear drives from source A

Fault Number	Nature of Fault	Time Taken to Repair (minutes)		Average Time Taken by a Technician to Repair
		Technician I	Technician II	
1	Noise	59	61	60
2	Vibration	73	73	73
3	Overheating	72	76	74
4	Fatigue	88	88	88
5	Plastic flow	81	87	84
6	Tooth breakage	98	90	94
7	Corrosive wear	50	58	54
8	Uneven wear	20	30	25
9	Abrasive wear	65	65	65
10	Scoring	79	71	75
			TOTAL	692

Table 2 : Time taken to repair faults in gear drives from source B

Fault Number	Nature of Fault	Time Taken to Repair (minutes)		Average Time Taken by a Technician to Repair
		Technician I	Technician II	
1	Noise	35	31	33
2	Vibration	89	89	89
3	Overheating	120	124	122
4	Fatigue	102	106	104
5	Plastic flow	80	82	81
6	Tooth breakage	81	81	81
7	Corrosive wear	22	30	26
8	Uneven wear	15	13	14
9	Abrasive wear	30	30	30
10	Scoring	45	51	48
			TOTAL	628

Table 3 : Time taken to repair faults in gear drives from source C

Fault Number	Nature of Fault	Time Taken to Repair (minutes)		Average Time Taken by a Technician to Repair
		Technician I	Technician II	
1	Noise	103	101	102
2	Vibration	120	132	126
3	Overheating	199	201	200
4	Fatigue	210	214	212
5	Plastic flow	182	190	186
6	Tooth breakage	240	246	243
7	Corrosive wear	150	148	149
8	Uneven wear	100	100	100
9	Abrasive wear	98	92	95
10	Scoring	22	18	20
			TOTAL	1433

Table 4 : Average time taken to repair faults in gear drives from sources A, B and C

Fault Number	Nature of fault	A	B	C
1	Noise	60	33	102
2	Vibration	73	89	126
3	Overheating	74	122	200
4	Fatigue	88	104	212
5	Plastic flow	84	81	186
6	Tooth breakage	94	81	243
7	Corrosive wear	54	26	149
8	Uneven wear	25	14	100

9	Abrasive wear	65	30	95
10	Scoring	75	48	20
Total = $\sum m_{ct}$		692	628	1433
Mean $(\bar{x})$		69.2	62.8	143.3
Grand Mean $\left(\bar{\bar{x}}\right) = \frac{69.2 + 62.8 + 143.3}{3} = 91.8 \min utes$				

Table 5 : Total Sum of Square (SST)

Fault Number	Nature of fault	A	$\left(xi - \bar{\bar{x}}\right)^2$	B	$\left(xi - \bar{\bar{x}}\right)^2$	C	$\left(xi - \bar{\bar{x}}\right)^2$
1	Noise	60	1011.24	33	3457.44	102	104.04
2	Vibration	73	353.44	89	7.84	126	1169.64
3	Overheating	74	316.84	122	912.04	200	11707.24
4	Fatigue	88	14.44	104	148.84	212	14448.04
5	Plastic flow	84	60.84	81	116.64	186	8873.64
6	Tooth breakage	94	4.84	81	116.64	243	22861.44
7	Corrosive wear	54	1428.84	26	4329.64	149	3271.84
8	Uneven wear	25	4462.24	14	6052.84	100	67.24
9	Abrasive wear	65	718.24	30	3819.24	95	10.24
10	Scoring	75	282.24	48	1918.44	20	5155.24
			8653.20		20879.60		67668.60
Totals sum of squares = SST = 8653.20 + 20879.60 +B67668.60 = 97201.40							

Table 6 : of Square Between Samples (SSB)

Fault Number	Nature of fault	A	$\left(\bar{x}_A - \bar{\bar{x}}\right)^2$	B	$\left(\bar{x}_B - \bar{\bar{x}}\right)^2$	C	$\left(\bar{x}_C - \bar{\bar{x}}\right)^2$
1	Noise	60	510.76	33	841	102	2652.25
2	Vibration	73	510.76	89	841	126	2652.25
3	Overheating	74	510.76	122	841	200	2652.25
4	Fatigue	88	510.76	104	841	212	2652.25
5	Plastic flow	84	510.76	81	841	186	2652.25
6	Tooth breakage	94	510.76	81	841	243	2652.25
7	Corrosive wear	54	510.76	26	841	149	2652.25
8	Uneven wear	25	510.76	14	841	100	2652.25
9	Abrasive wear	65	510.76	30	841	95	2652.25
10	Scoring	75	510.76	48	841	20	2652.25
			5107.60		8410		2652.250
Sum of squares between samples SSB = 5107.60 + 8410 + 26522.50 = 40040.10							

Table 7: Sum of Square Within Samples (SSW)

Fault Number	Nature of fault	A	$\left(xi_A - \bar{x}_A\right)$	B	$\left(xi_B - \bar{x}_B\right)^2$	C	$\left(xi_C - \bar{x}_C\right)^2$
1	Noise	60	84.64	33	888.04	102	1705.69
2	Vibration	73	14.44	89	686.44	126	299.29
3	Overheating	74	23.04	122	3504.64	200	3214.89
4	Fatigue	88	353.44	104	1697.44	212	4719.69
5	Plastic flow	84	219.04	81	331.24	186	1823.29
6	Tooth breakage	94	615.04	81	331.24	243	9940.09
7	Corrosive wear	54	231.04	26	1354.24	149	32.49
8	Uneven wear	25	1953.64	14	2381.44	100	1874.89
9	Abrasive wear	65	17.64	30	1075.84	95	2332.89
10	Scoring	75	33.64	48	219.04	20	15202.89
			3545.60		12469.60		41146.10

Sum of squares within samples

SSW = 3545.60 + 12469.60 + 41146.10

= 57161.30

Table 8 : Analysis of Variance (ANOVA)

Sources of Variation	Sum of Square	Degree of Freedom	Mean Square
Between samples	40040.10	2	20020.05
Within samples	57161.30	27	2117.09
Total	97201.40	29	

$$F = \frac{\text{Between Sample Variation}}{\text{Within Sample Variation}} = \frac{20020.05}{2117.09} = 9.46$$

Table value of F for $V_1 = V_2 = 27$ at 5% level of significance is 3.35. Since the calculated value of F is more than the one obtained from the table, it can be inferred that the difference between the time to repair, restore or correct failure in the gear drives from sources A, B and C is very significant. Hence there is great difference in the MAINTAINABILITY of gear drives obtained from the three sources. It is therefore important to determine which of these sources has the least Repair or Correct time. More data were generated using Monte Carlo simulation method. The data obtained were subjected to further analysis.

Table 9 : Average time taken (minutes) data used for Monte Carlo Simulation

Fault Number	Nature of Fault	A	B	C
1	Noise	60	33	102
2	Vibration	73	89	126
3	Overheating	74	122	200
4	Fatigue	88	104	212
5	Plastic flow	84	81	186
6	Tooth breakage	94	81	243
7	Corrosive wear	54	26	149
8	Uneven wear	25	14	100
9	Abrasive wear	65	30	95
10	Scoring	75	48	20
INTERVAL		25-94	14-122	20-243

The summary of Monte Carlo simulation of 1000 corrective time by 100 technicians and 10 faults for gear drives of sources A, B and C is given in table 10

Table 10 : Monte Carlo Simulation Results Summary

Fault Number	Nature of Fault	Simulation of time taken in minutes for 100 technicians			Average corrective time in Minute by a technician (M_{ct})		
		A	B	C	A	B	C
1	Noise	6057.112	6739.729	13717.93	60.57	67.40	137.18
2	Vibration	6053.265	7035.493	12999.68	60.53	70.35	130.00
3	Overheating	5933.154	6945.334	11544.56	59.33	69.45	115.45
4	Fatigue	5942.722	6379.348	13875.86	59.43	63.79	138.76
5	Plastic flow	5960.289	6785.992	13440.11	59.60	67.86	134.40
6	Tooth breakage	6233.922	6801.318	12660.45	62.34	68.01	126.60
7	Corrosive wear	5867.79	6213.58	13767.84	58.68	62.14	137.68
8	Uneven wear	5785.665	6698.434	12755.07	57.86	66.98	127.55
9	Abrasive wear	6193.47	6773.705	13021.72	61.93	67.74	130.22
10	Scoring	5862.941	6822.502	13865.23	58.63	68.23	138.65
Total		59890.34	67195.44	131648.50	598.90	671.95	1316.49

The mathematical models in equations 2 to 10 were applied to the results of table 10 for the purpose of determining M_{ct}, MTTR, σ, ERT, $MTTR_G$, M_{max} and $M(t)$.The results obtained from the models are shown in table 11, 12, 13 and 14.

Table 11 : Demonstration-test data for gear drives from source A

Fault Number	Nature of fault	M_{ct}	Log M_{cti}	$(\text{Log } M_{cti})^2$	$(M_{cti})^2$
1	Noise	60.57	1.782	3.176	3668.72
2	Vibration	60.53	1.782	3.175	3663.88
3	Overheating	59.33	1.773	3.145	3520.05
4	Fatigue	59.43	1.774	3.147	3531.92
5	Plastic flow	59.60	1.775	1.151	3552.16
6	Tooth breakage	62.34	1.795	3.221	3886.28
7	Corrosive wear	58.68	1.768	3.128	3443.34
8	Uneven wear	57.86	1.762	3.106	3347.78
9	Abrasive wear	61.93	1.792	3.211	3835.32
10	Scoring	58.63	1.768	3.126	3437.48
Totals		598.90	17.771	31.586	35886.93

Table 12 : Demonstration-test data for gear drives from source B

Fault Number	Nature of fault	M_{ct}	Log M_{cti}	$(\text{Log } M_{cti})^2$	$(M_{cti})^2$
1	Noise	67.40	1.829	3.344	4542.76
2	Vibration	70.35	1.847	3.412	4949.12
3	Overheating	69.45	1.842	3.392	4823.30
4	Fatigue	63.79	1.805	3.257	4069.16
5	Plastic flow	67.86	1.832	3.355	4604.98
6	Tooth breakage	68.01	1.833	3.358	4625.36
7	Corrosive wear	62.14	1.793	3.216	3861.38
8	Uneven wear	66.98	1.826	3.334	4486.32
9	Abrasive wear	67.74	1.831	3.352	4588.71
10	Scoring	68.23	1.834	3.363	4655.33
Totals		671.95	18.272	33.383	45206.42

Table 13 : Demonstration-test data for gear drives from source B

Fault Number	Nature of fault	M_{ct}	Log M_{cti}	$(\text{Log } M_{cti})^2$	$(M_{cti})^2$
1	Noise	137.18	2.137	4.568	18818.35
2	Vibration	130.00	2.114	4.469	16900.00
3	Overheating	115.45	2.062	4.253	13328.70
4	Fatigue	138.76	2.142	4.589	19254.34
5	Plastic flow	134.40	2.128	4.530	18063.36
6	Tooth breakage	126.60	2.102	4.420	16027.56
7	Corrosive wear	137.68	2.139	4.575	18955.78
8	Uneven wear	127.55	2.106	4.433	16269.00
9	Abrasive wear	130.22	2.115	4.472	16957.25
10	Scoring	138.65	2.142	4.588	19223.82
Totals		1316.49	21.187	44.897	173798.16

Table 14 : Results Summary for Maintainability Parameters

Parameter \ Source	A	B	C
Mct	598.90	671.95	1316.49
MTTR	59.89	67.20	131.65
MpTR	1.45	2.47	7.33
ERT	0.237	0.802	0.00000049
$MTTR_G$	59.85	67.17	131.43
M_{max}	65.43	67.30	131.87
M(t)	0.7106	0.6671	0.4299
	71.06%	66.71%	42.99%

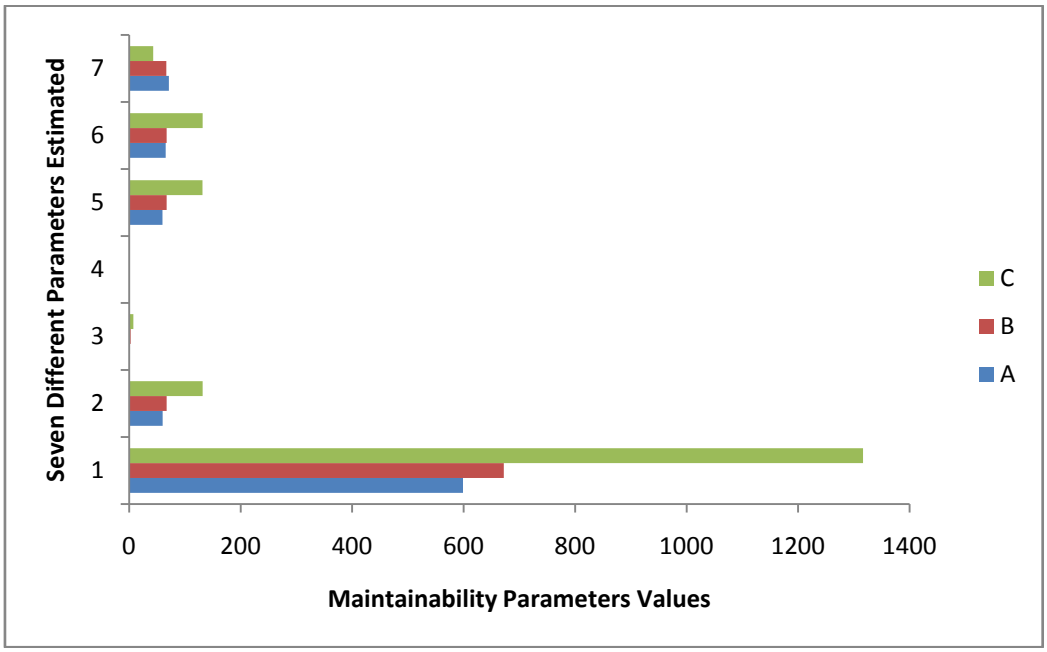

Fig.1 : Bar Charts Showing Summary Results for Different Maintainability Parameters ($M_{ct,}$ MTTR,MpTR, ERT ,MTTRG, M_{max}, $M_{(t)}$)

Chart Key: The following numbers on the vertical axis represents the parameters indicated.
1-M_{ct} 2-MTTR, 3-MpT.R, 4-ERT,5-$MTTR_G$,6-M_{max} ,7 -M (t).

IV. Discussions

As it can be observed at a glance from table 14 and figure 1, Results summary for maintainability parameters, the corrective time for A, B, and C are respectively 598.90 minutes, 671.95 minutes and 1316.49 minutes. It took the least time to correct failure in gear drives sourced in a firm from country A and the highest by a firm from country C. it is also observed that Mean Time To Repair (MTTR) and Geometric Mean Time To Repair ($MTTR_G$) of gear drives from the same source are approximately equal. It can be inferred from this that for a given source, MTTR of gear drives is a representation of its $MTTR_G$.

V. Conclusions

The results of this study have shown that gear drives from source A has the shortest maintenance time. It has the least MTTR, $MTTR_G$ and highest M (t), probability of maintenance (maintenance factor). It is 71.06% maintainable. It can be deduced from this study that the same type of equipment manufactured from different sources have different maintainability. Therefore, before purchase, Maintenance Engineers who are responsible for the purchase of equipment, machine and system should ensure that their maintainability are considered or ascertained in order to ensure smooth production operations while in service.

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Sediment Erosion in Hydraulic Turbines

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Abstract - Sediment erosion not only reduces efficiency and life of hydropower turbines but also causes problems in operation and maintenance. Several factors are responsible for this erosion in hydro turbine components. This paper presents the sediment erosion types in hydraulic turbines and their components based upon an extensive literature review and the field observation at Cahua hydropower plant, Peru. It includes some recommended methods to minimize the effect of sediment erosion in the turbine components. An alternative design of a Francis turbine in sediment-laden water is also briefly discussed.

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Sediment Erosion in Hydraulic Turbines

Hari Prasad Neopane[α], Ole Gunnar Dahlhaug[Ω], Michel Cervantes[β]

Abstract - **Sediment erosion not only reduces efficiency and life of hydropower turbines but also causes problems in operation and maintenance. Several factors are responsible for this erosion in hydro turbine components. This paper presents the sediment erosion types in hydraulic turbines and their components based upon an extensive literature review and the field observation at Cahua hydropower plant, Peru. It includes some recommended methods to minimize the effect of sediment erosion in the turbine components. An alternative design of a Francis turbine in sediment-laden water is also briefly discussed.**

I. Introduction

Hydraulic turbines mainly divided into two groups: Impulse and Reaction. This classification is based upon the principle of energy conversion. Pelton and Turgo are examples of Impulse turbines. Francis, Kaplan and Bulb turbine are examples of reaction turbines. The cross flow turbines are two stage impulse turbine used for smaller units.

In general, a number of factors influence the development of sediment erosion process of hydraulic machinery. These factors include mean velocity of particles, mass of the particle, concentration of the abrasive particles in a liquid flow, grain size and shape of the particles and angle of attack at which the particles collide with the surface etc. In practice, a large number of additional factors involved and further complicated the erosion of hydraulic machinery. In addition, there is no exact mathematical dependence, for the time being, to define them. Variable concentration and structural in homogeneity of suspended particles, continuous alternation and pulsation of both velocities and pressure during the motion of the flow, and variance in operation, and design features of hydraulic machinery itself, caused the actual pattern of the erosion more complicated and different (Duan et al.,2002).

Most often, it is difficult to distinguish the exact type of erosion on the hydraulic machinery. Duan et al., 2002, have described the erosion of hydraulic turbines in six categories as shown in Table 1 based upon the visual appearance. This classification could be use to evaluate the hydraulic patterns.

Table 1 : Turbine erosion categories (Duan et al., 2002)

S.N	Type	Description
1	Metallic luster	A Shining surface with no traces of paint, scale or rust
2	Fine-scaly erosion	A surface with rare, separately located and skin-deep minute scales
3	Scale erosion	A surface entirely covered with skin-deep fine scale
4	Large-sized scaly erosion	A surface entirely covered with deep and enlarged scales
5	In-depth erosion	A surface covered with deep and long channels
6	Through hole or entire erosion	Out of the material

Similarly, B.S. Mann, 1999, collected data on wear patterns of different sediment affected hydro turbine components at various hydropower stations in India in order to analyze the wear patterns. This was compared with the data available with some foreign hydropower stations from Switzerland, Pakistan, and China. It was observed that the wear patterns have a resemblance and there is a significant relevance to the flow characteristics of all the power stations. The wear pattern on a particular component is found to be similar.

As mentioned by Thapa, 2004, Matsumura and Chen, 2002, classified the erosion condition in Reaction turbines in three categories, as I, II and III, based upon difference in flow velocity and impingement angle of particle. This classification is shown in Table 2, which was developed based on erosion test of specimens located at different turbine components. From this classification, it is not possible to interpret the different type of erosion on the same component of turbine, for example, the turbine blade, can have different type of erosion at leading edge and trailing edge.

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Table 2 : Classification of erosion (Matsumura and Chen, 2002)

Type of erosion	Location	Flow velocity	Impingement angle	Type of erosion
I	Spiral casing Draft tube	Low	Small	I
II	Runner blade Guide vane	High	Small	II
III	Wearing ring	High	Large due to vortex and turbulence	III

Brekke, 2002, classified the sediment erosion in hydraulic machinery into three different categories, namely, micro erosion, secondary flow vertex erosion, and acceleration erosion.

Micro erosion is found on the surface of turbine components where fine particles with grains size less than 60 ƒÝm are moving at very high velocity. High shear stress in the boundary layers gives high rotational motion to these particles causing several ripples in the direction of flow. The patterns with such erosion are also compared as fish scale or orange peel. Such type of erosion can appear in guide vane and runner blade in a Francis turbine towards outlet and in the needle of a Pelton turbine.

Obstacles in the flow field or secondary flow in the corners of conduits causes secondary flow vortex erosion. Any obstruction in the flow field causes secondary flow and horseshoe vortex is generated around the cylindrical obstacles like guide vane leading edge. Similarly the needle of the Pelton wheel have vortex behind the ribs supporting needle and hence vortex erosion takes in the straight line downstairs the ribs. The vortices in the corner of conduits like guide vanes-facing plates and blades-band also cause this type of erosion. Such vortices and secondary flow are caused by combined effect of boundary layer and change in flow acceleration. The design of hydraulic machinery working in the range of high Reynolds numbers, (106 - 108) will normally be exposed all three types of erosion.

II. Impulse Turbine: Pelton

Generally, Pelton turbines are designed for low speed number, range from 0.1 to 0.2, the velocity in the jets will be higher than 100 m/s. The acceleration of the particles in the buckets will normally be more than 50,000 m/s2, which depends on the size of the buckets and head of the turbine. The high velocity and acceleration of particles at the buckets are main reasons for the sediment erosion. Brekke, 2002, categorized the Pelton turbine components into four groups in order to study the sediment erosion phenomenon. Those are inlet system, nozzle system, turbine runner and the wheel pit.

a) Inlet system

Inlet system consists of manifold and valve. The velocity at inlet system is normally maintained low. Brekke, 2002, provided the following velocity relations in order to design the inlet system of the Pelton turbines

At inlet manifold, $C = k_i \cdot \sqrt{2 \cdot g \cdot h}$ $[0.08 < k_i > 0.1]$ Equation 1

At valve, $C = k_v \cdot \sqrt{2 \cdot g \cdot h}$ $[0.095 < k_v > 0.12]$ Equation 2

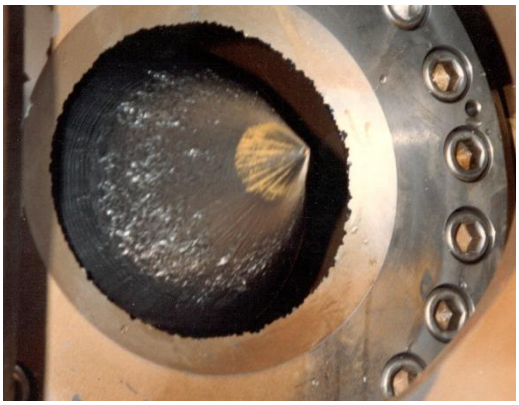
At nozzle, $C = k_n \cdot \sqrt{2 \cdot g \cdot h}$ $[k_n > 0.99]$ Equation 3

Because of the low operating velocity at the inlet, the inlet system or pipes will have only moderate effect of sediment. Hence, application of high erosion resistance rubber, and epoxy based coating or paint may prevent erosion in such pipes. Slight erosion of this system does not affect the performance of the turbine by any means, but severe erosion in bifurcation and bends is likely to increase the leakage and in worst-case rupture of pipe. Regular inspection and maintenance should be carried out to prevent any catastrophic effect.

b) Nozzle system

Nozzle system includes nozzle ring and needle. High head Pelton turbine, for example, 1,200 m head can have jet velocity up to 150 m/s. Such a high velocity can damage both the nozzle and the needle. The flow is accelerated from the outlet of fins supporting needles up to nozzle tip and all the pressure energy available in the water is converted into kinetic energy. High velocity combined with the needle geometry creates strong turbulence in the boundary layer close to needle tip. The fine particles bombarding due to turbulence strikes the needle surface several times and severe erosion can be seen in short time. Cavitation can follow in a short interval of time and severe damage of the needle can take place. The nozzle tips are relatively sharp and less than 1 mm contact between nozzle and needle are maintained to reduce cavitation damage and to obtain highest possible efficiency. This makes the nozzle tip vulnerable to sand erosion. If nozzle diameter increases by 5 % due to erosion at tip, the turbine will run at 10 % load even if needle is at closed position. It may affect entire control system of the power plant.

The photographs presented in Figure 1 illustrate the extent of sediment erosion in Pelton turbine nozzle and needle. These photographs were taken from the lecturer notes provided by professor Ole Gunnar Dahlhaug, NTNU.



(a) Nozzle needle, Mel, Norway

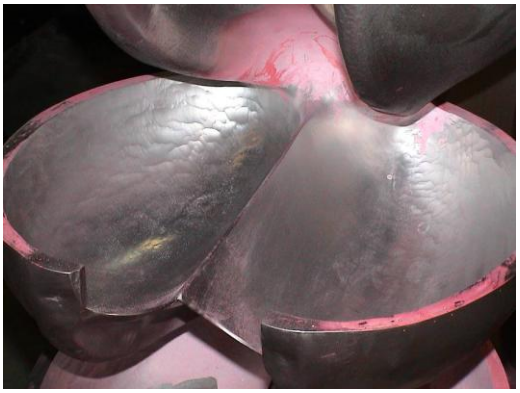
(b) Nozzle ring, Andhi Khola, Nepal

Figure 1 : Sediment erosion at Pelton turbine nozzle and needle

The protection of needle and nozzle surface by applying ceramic-metallic coatings may help to improve erosion resistance. Ceramic coating is not very effective in case of larger size particles. There is very little scope to improve the erosion resistance of needle and nozzle by hydraulic design, but maintainability can be improved by designing replaceable nozzles tip.

c) Pelton turbine runner

Peltion turbine runner consists of splitter, bucket tip and bucket surface. Sediment erosion can be found in all components however, the nature of erosion is different. In high head Pelton turbines, the absolute acceleration range normal to the surface could be 50,000 - 100,000 m/s2. Such a high acceleration is the main reason of sediment erosion in turbine buckets, which has a strong effect on separation of particles from streamline. The characteristics of damage due to fine and coarse sediment are different. With coarse particles, most of the damages are in the area where the jet directly hits at the bucket surface. Surface damage is observed due to the hammering action and not due to the cutting action by sharp edge. Long scars are also seen in the flow direction in each side of the bucket splitter but no damage is observed at the root of the bucket. Splitters and entrance lips are most severely damaged portion of the buckets, because of direct hitting of particles. The photographs presented in Figure 2 illustrate the extent of sediment erosion in Pelton turbine buckets and splitter.



(a) Bucket surface, Khimti, Nepal

(b) Splitter, Rangjung, Bhutan

Figure 2 : Sediment erosion at Runner buckets

The acceleration of particles normal to the flow direction separates the particles from the flow direction and such accelerating particle strikes the surface causing collision in the water conduit surface. Large particles, for instance higher than 0.5 mm, cause severe damage in the Pelton turbine bucket.

Fine particles may glide along with water inside the bucket and strike the surface toward outlet edge, causing severe erosion around the outlet. Due to distortion of bucket profiles near the outlet, but not at the edge where the acceleration is zero, the direction of flow changes bending inward and strike backside of following bucket with braking effect. This phenomenon is schematically explained in Figure 3.

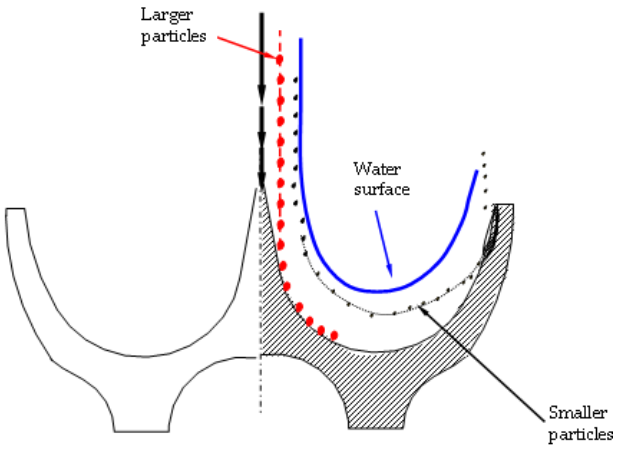


Figure 3 : Illustration of separation of particle in a Pelton bucket (Thapa and Brekke, 2004)

Thapa and Brekke, 2004, have drawn some conclusions based upon the different hydropower plants erosion patterns observations:

- If the particles are fine (silts), then there will be erosion on the needle but not much erosion in the buckets.
- If the particles are coarse (sand), then there will be erosion in the buckets and there is less erosion of needles.
- With medium size particles, both needle and bucket will be eroded.

d) Criteria for Pelton turbine design

Sediment erosion problem cannot be solved completely by hydraulic design alone however, this can be minimised to some extent. The three basic criteria for the design of Pelton turbine to minimize the effect of sand erosion are as follows (Brekke, 2002).

- The radius of curvature should be as large as possible at the location where flow direction changes.
- The number of jets should be as low as possible.
- The hydraulic radius of the bucket and nozzle size should be large. This brings minimum sand particles in contact with the surface.

III. Reaction Turbine: Francis

Generally, Francis turbines are designed for speed number, range from 0.2 to 1.5. High head Francis turbines are mostly affected by sediment erosion. For the high head type of Francis turbine, approximately 50 % of energy is converted in to kinetic energy at guide vane and remaining 50 % is retained as pressure energy. The inlet velocity could reach up to 85 - 95 m/s on high head turbines. Hence, guide vane faces high absolute velocity. The runner outlet has highest relative velocity. The velocity at the runner outlet is normally selected around 40 m/s during design to ensure flow of water out of the turbine. Brekke, 2002, categorized the Francis turbine components in to four groups in order to study the sediment erosion phenomenon. Those are inlet system, guide vanes system, runners and labyrinth seals, draft tubes, and shaft seals.

a) Inlet system: Stay vane

Inlet system of Francis turbine consists of manifold, valves, bypass system, spiral casing and stay vanes. Compared to inlet valve of Pelton turbine, its inlet valve will face 50 % less pressure during closing due to pressure created by spinning runner. Hence inlet valve of Francis turbine have rubber seal against movable steel seal, which has better erosion resistance. It is important to make bypass system larger in order to create higher possible pressure in the spiral casing before opening the valve seals because lower pressure in the spiral casing during opening will increase the damage of the valve seals and bypass valve seals. Hence, bypass system in the Francis turbine has to be stronger than Pelton turbine to create higher pressure in spiral casing. The starting pressure in the guide vane system gives indication of leakage due to sand erosion. The velocity at spiral casing is higher than Pelton turbine manifold because of shorter distance between inlet valve and guide vanes. The velocity at the inlet of the spiral casing is almost same as the meridional velocity at the runner outlet and inlet of valve.

The stay vanes have the main purpose of keeping the spiral casing together. The dimensions have to be given due to the stresses in the stay vanes. The vanes are designed so that the flow is not disturbed, and they direct the flow into the turbine. Because of the secondary flow in the spiral casing, an incorrect flow angle towards the top and the bottom region of inlet of stay vanes in traditional design often cause secondary flow erosion in high head turbines. Similar phenomenon has been observed at Cahua power plant, where paint and material are removed due to the erosion at the stay vane inlet as shown in Figure 4 (a).

(a) Inlet of stay vane

(b) Typical ring grooves near leading edge

Figure 4 : Erosion at stay vane at Cahua power plant

The corrosion followed by removal of paint accelerates the erosion rate. However, modern parallel stay rings reduces incorrect flow and minimizes erosion at stay vane inlet. Under normal condition, erosion resistant paints can be used in spiral casing and stay vane, but for high head turbines, stainless steel stay vanes can be used to reduce the effect of sediment erosion. The mid height of the leading edge part is exposed to less erosion intensity. Near the upper and lower cover at the inlet, ring-shaped erosion grooves, as shown in Figure 4 (b), were observed (Mette Eltvik, 2009).

b) Guide vane system

The guide vane system is highly affected by sediment erosion due to highest absolute velocity and acceleration. For high head turbines, the relative velocity head (C2/2g)/Hn for guide vane increases from 10 % at guide vane inlet to 50 % at runner inlet. At normal speed, pressure drop across the guide vane will be approximately 40 % of net head at full load and 50 % at small opening, which is one of the reason for cross flow and hence erosion takes place at the junction of guide vanes and facing plates. The main reason for cross flow is the pressure difference. The erosion of guide vane due to sand laden water can be classified in following four categories (Brekke, 2002):

- Turbulence erosion at the outlet region and facing plate due to high velocity of fine grain sand
- Secondary flow erosion in the corner between guide vane and facing plates due to fine and medium size particles, which makes horseshoe grooves in the facing plates following contours of guide vanes
- Leakage erosion at the clearance between guide vane and facing plate due to local separation and turbulence increasing the horseshoe vortex in the suction side. The leakage also causes local separation and turbulence at the pressure side at inlet and suction side at outlet of guide vanes causing even a deep groove at the bottom and top of the guide vanes
- Acceleration erosion is caused by separation of large particles from the streamlines of main flow due to rotation of water in front of the runner. This acceleration of particle I s normal to the streamline and strikes guide vane surface causing sevre eroion. This acceleration also creates secondary flow causing erosion at the corner between the guide vanes and the facing plates by fine particles

In Cahua power plant, as shown in Figure 5 (a), more erosion is observed near the transitional zone to the lower cover, due to the high acceleration and absolute velocity in the guide vane cascade. The acceleration erosion in the guide vane in reaction turbine can be reduced by designing the flow with smoothest possible acceleration. The stay vane outlet angle should be carefully chosen so that guide vane will be in neutral position in normal operation condition. Similarly, reduction of clearance between guide vane and facing plate avoid cross flow and secondary flow. Metal sealing are used to reduce gap between guide vane and facing plates with the intention to improve efficiency, but this could be more destructive once damage of such seal commence. The turbulence and secondary flow create dangerous galling in facing plates. It destroys flow pattern and reduces turbine efficiency. The covers will be exposed to erosion since the acceleration normal to the streamline creates secondary flow, especially at the corners between the facing plates and guide vane as clearly seen in Figure 5 (b). This effect occurs because of the horseshoe vortex and heavy erosion grooves are observed.

(a) Eroded guide vanes

(b) Horseshoes vortex of facing plates

Figure 5 : Erosion at guide vane and facing plates at Cahua power plant

The guide vane clearance for new turbine is recommended roughly 0.1 - 0.3 mm in pressurized condition, which is dependent on deflection of the head cover. Low initial dry clearance in the order of 0.05 to 0.1 mm may give low clearance in pressurized condition, but such a low dry clearance may cause abrasion and adhesion between guide vane and facing plates. The facing plates can be improved by cladding underneath the guide vanes, but the difference in hardness between guide vanes and facing plates should be maintained to avoid galling of the surface. The hardness of 16Cr5Ni Guide vanes with 350-400 HB and facing plate of 17Cr1Ni with 300 HB is an example of appropriate combination, which avoids galling and abrasion. The necessary tolerance and surface finish at the mating part of guide vane and facing plate should also be maintained to get rid of these problems. The maintainability of the facing plate is often improved by designing replaceable layer to save maintenance time and expensive bulk material.

c) Runner

In the runner, the highest relative velocity occurs at outlet region while the highest absolute velocity and accelerations may be found at the inlet of the blade. Hence, impact due to kinetic energy is small compared to force exerted by large accelerating particle. Contrary to this, the relative velocity is the highest at the outlet of the runner blade. Hence, turbulence erosion due to fine sand is always susceptible at the trailing edge of the blade. Also because of high relative velocity, most of the particles will move towards outer diameter in the runner outlet and hence more effect of erosion is seen there. Inlet region of the runner is sensitive to incorrect pressure distribution between pressure and suction side and any separation caused by this may cause severe local erosion at the inlet due to fine grain sand. Cross flow from the hub to the shroud caused by incorrect blade leaning will also increase the so-called horseshoe vortex in the blade roots. The erosion at runner outlet of Cahua power plant is shown in Figure 6.

(a) Erosion at runner outlet

(b) Erosion at pressure side of blade

Figure 6 : Erosion at runner at Cahua power plant

The improvement of blade leaning and correct blade loading at inlet may improve performance of Francis turbine against erosion. The splitter blades at the inlet of runner help to reduce damage of flow around leading edge at off design operation, which ultimately improves the resistance to sand erosion and cavitation. Incorrect blade leaning may lead to cross flow between hub to band and such cross flow may intensify erosion effect together with other loss associated with it.

d) Labyrinth seals

The velocity in labyrinth is in order of 45 m/s for high head turbine. Labyrinth seals having small clearance and working with coarse sand may also have erosion as well as abrasion effect. The efficiency of a labyrinth seal is inversely proportional to clearance gap. Hence, gaps should be made the smallest possible to have minimum leakage, but it has to be sufficiently large to avoid any direct contact between rotating and stationary part. The clearance between the stationary and rotating parts is varied between 0.25 to 1.0 mm depending on the size of the turbine. The turbulence erosion due to fine sand is always susceptible in the labyrinth seal because of high velocity in its surrounding. The rotating labyrinth seals are made up of steels to achieve longer life, while stationary seals are normally made of softer materials such as bronze. The replacement cost for the stationary seal is cheaper. However, in the case of high sediment concentration, even the stationary seals can be made up of steel, which has higher erosion resistance than softer material.

e) Draft tube

The draft tube section closer to runner will be exposed to the highest velocity because of high absolute velocity of water coming out of runner and some sediment erosion effect can be anticipated. Apart from this portion, sediment erosion is normally no problem in draft tube.

f) Shaft seal

Mechanical shaft seal will be damaged if the sand-laden water is exposed to it. The damage could be

due to more abrasion than erosion. Shaft seals are normally made up of carbon rings, bronze and steels with lower hardness compared to shaft material. Apart from selection of erosion and abrasion resistance material for seals, insertion of pressurized clean water in the shaft seal also avoids wear.

IV. Turbine Design

The following IEC guidelines explain some recommended methods to minimize particle abrasion and the effects thereof, by modifications to design for clean water. It should be understood that every hydraulic power plant is a compromise between several requirements. While it is possible to design a unit to be more resistant against particle abrasion, this may adversely, affect other aspects of the turbine. Some examples are :

- Thicker runner blades may result in decreased efficiency and increased risk of vibrations from von Karman vortices.
- Fewer runner blades (in order to improve the access to the blade surfaces for thermal spray surface treatment) may result in reduced cavitation performance.
- Abrasion resistant coatings may initially result in increased surface roughness, which may reduce the efficiency.
- Reduced runner blade overhang may result in reduced cavitation performance, which in turn may reduce the output that can be achieved for a turbine upgrade.
- Many abrasion resistance design features will increase the total cost of the power plant.

The optimum combination of abrasion resistant design features must be considered and selected for each site based on its specific conditions.

a) Hydraulic design of turbine

i. *Selection of type of machine*

It is advantageous to select a type of machine that has low water velocity that can easily be serviced and that can easily be coated with abrasion resistant coatings. Some general guidelines are; in the choice between a vertical shaft Kaplan and a Bulb; the Kaplan will normally have lower velocity. The serviceability and ease of coating is approximately equal between the two. In the choice between a Kaplan and a Francis, the Francis will normally have lower velocity. On the other hand, the Kaplan runner has better access for applying abrasion resistant coatings. The serviceability is approximately equal between the two. In the choice between a Francis and a Pelton, the Francis will normally have lower maximum velocity. However, the parts in a Pelton turbine that are subject to the maximum velocity (i.e. the needle tips and seat rings) are small and have better access for applying abrasion resistant coatings. The Pelton turbine is also easier to service.

ii. *Specific speed*

For the same plant, lower specific speed machines are normally bigger and have lower water velocities in the runner outlet. However, the water velocities are not lower in the guide vanes and in the runner inlet. For Kaplan, Bulb and low head Francis turbines, most of the abrasion damage will be in the runner, so the specific speed is important. For high head Francis turbines, much of the abrasion damage will be in the guide vane apparatus, so the specific speed is not so important. For Pelton turbines, the water velocity does not depend on the specific speed. However, a lower number of jets is beneficial for a Pelton turbine since the buckets will be larger which in turn gives less water acceleration in the buckets and thus less abrasion damage. A lower number of jets will automatically result in a lower specific speed.

iii. *Variable speed*

Even though variable speed machines are not frequent, they are less prone to cavitation, even under a wide head range operation. Due to this characteristic, the variable speed machine may better resist particle abrasion.

iv. *Turbine submergence*

Cavitation and abrasion will mutually reinforce each other. For this reason, it is recommended that the turbine submergence is higher for plants where abrasion is expected.

v. *Runner blade overhang*

In case of Francis runner refurbishment, there is sometimes a need to increase the turbine output significantly. One way to do that is to extend the runner band inside the draft tube cone, in order to increase the blade area and to improve the cavitation performance. However, this creates additional turbulences at the top of draft tube cone that will increase metal removal if particles are present in water. A secondary effect of the overhang blades is to create a lower pressure zone downstream of the runner band seal, thus creating higher seal leakage and more particle abrasion at the band seal.

vi. *Thicker runner blades and guide vanes*

Increased runner blade thickness, particularly at the outflow edge, gives some extra margin before the removal of material on the runner blades becomes critical for the structural integrity of the runner. A thicker blade design should be done with care. The thicker blade may result in decreased efficiency and increased risk of vibrations from von Karman vortices. In addition, the risk of cavitation damage on the runner band, downstream of the blade, may increase.

b) Mechanical design of turbine

If abrasion is expected and the turbine type is defined, not only the hydraulic design but also the mechanical design can take some precautions to

reduce the abrasion rate and to allow easy maintenance or replacement of the abraded parts. Generally, for the design, the area exposed to the abrasive wear should be as small as possible. As well, discontinuities and sharp transitions or direction change of the flow should be avoided. The turbine shaft seal should have rubber rigs in place of carbon rings and its design should be such as to allow dismantling and replacement in the shortest possible time. The thickness of the runner blade in the area prone to erosion should be increased. These areas are mainly at runner outlet. Increasing the wall thickness is a method to increase the overhaul interval of a component due to abrasion. For structural components, which do not influence the efficiency, the wall thickness can be increased in critical areas to avoid early failure of the component due to higher stresses.

The material selection for components, which are subject to abrasive wear, is another important criterion. Generally, weldable stainless steel materials are preferred. If both corrosive and abrasive attack anticipated then stainless steel is preferred. Considering the larger hardness, martensitic steel is preferred over austenitic steel. Furthermore, shaft seal with clean sealing water is recommended. Normally, shaft seals in units, which are operated with water and, which contains abrasive particles, have to be fed with clean sealing water. It must be avoided that the contact surface or the wearing surface gets contact with the abrasive particles.

c) Operation of turbine

Operation of a turbine at part load and full load is marked by reduced efficiency, increased flow turbulence and higher relative flow velocities at turbine runner outlet. Presence of secondary flows and accompanying vortices lead to increased local velocities. Since such flow conditions are conducive to increased sediment erosion, attempt should be made to avoid such operations when water carries excessive sediment. The following actions are recommended for consideration during operation of the units.

- Shut down units at higher particle concentration periods. This may avoid considerable wear on the unit for a small amount of lost production. Especially for run of river schemes, where large variation in particle concentration can happen very fast this strategy can be useful.
- Minimize amount of debris passing through unit. Large solid items, for example logs, gravel (larger than 2 mm), etc. may damage the hydraulic surfaces and any abrasion resistant coatings. Damage to hydraulic surfaces may increase the turbulence of the flow, which will increase the abrasion damage. This is especially important for high head Francis and Pelton units, since the water velocities are very high and these units rely on smooth hydraulic surfaces to keep the turbulence low.
- Do not operate the unit in case the abrasion damage jeopardizes the safety of operation. As the abrasion damage progresses, the unit will eventually become unsafe to operate. This could for example be due to seal leakage increasing so much that the axial thrust exceeds allowable limits or that the remaining material thickness of some component falls below acceptable minimum thickness. Regular inspections of critical components should be made at least every year and inspection results must be compared with predefined acceptance criteria.
- Avoid low load operation as much as possible. Low load operations are the worst operating conditions with respect to abrasion for most components and turbine types.
- Close inlet valve at shutdown. With a turbine at standstill and the water shut off only by the guide vanes, the water leaking past the guide vane clearances will have very high velocity, close to the free spouting velocity. This will cause abrasion wear in the guide vane apparatus. By closing the inlet valve, this abrasion is eliminated. To close the inlet valve is especially important for high head units.
- Hard coatings are very sensitive to cavitation. Thus, in machines with such coatings all operating conditions that lead to cavitation must be avoided and strictly stick to the recommended operating range for the turbine.

V. Alternative Design of Francis Turbine

A few instances have been noticed where under identical conditions of sediment, the intensity of damages at different hydropower stations were not identical. While components at a particular power station eroded very fast, damages to components at other power stations were insignificant. This leads one to believe that equipment design has a role to play in influencing the intensity of erosion (Naidu, 1999).

The author earlier designed a Francis turbine for sediment-laden water that considering the erosion of the Francis turbine occurs mainly at the outlet of the guide vanes and at the outlet of the runner blades. In order to reduce the erosion rate of the turbine, the absolute velocity at the inlet of the runner and the relative velocity at the outlet of the runner have to be reduced. In this study, the flow and head were kept constant while the speed, inlet peripheral velocity and outlet runner blade angle were changed according to Table 3.

Table 3 : Variable input parameters

Speed	rpm	n	750	600	500	433	375	333	300	275
Inlet peripheral Velocity, reduced	-	$\underline{U_1}$	0.71	0.74	0.77	0.8	0.83	0.86	0.89	0.92
Outlet blade angle	degree	β_2	17	19	21	23	25	27	29	31

The results show that the outlet diameter changes relatively little while the inlet diameter changes drastically. The reduction of the erosion at the outlet is more than at the inlet. This is shown in Figure 1.7. The inlet angle of the turbine has changed so that the design looks more like a pump-turbine. This means that the turbine will be larger than the traditional design. The reduction of the erosion is linked to the reduction of the velocity and therefore the size of the turbine increases. This result in a higher price of the turbine, but it will reduce the maintenance costs during its lifetime. It has been shown from the calculation that the design of the runner can decrease the sand erosion but it is not possible to avoid this problem completely by design alone.

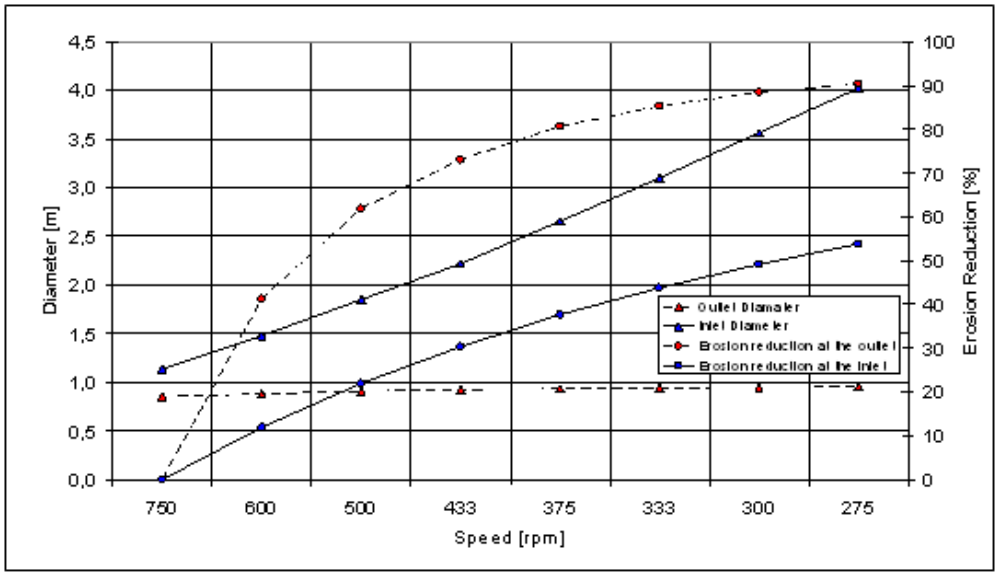


Figure 7 : Variation of diameter for reduction of erosion

However, if a Francis turbine designer combines the hydraulic design and coating of the critical parts, a significant reduction of erosion can be achieved.

VI. Conclusion

Sediment content of water can no more be overlooked in any phase of hydropower project implementation. This includes all the phases like, investigation, design, operation and maintenance, and refurbishment and upgrading. Due consideration of the problem at every stage, would affect economies on one hand and long-term solutions would emerge on the other hand. However, one solution in order to decrease the sediment erosion is to increase the size of the turbine, thereby increases the hydraulic radius of curvature, and thus decreases the accelerations. Furthermore, while it is possible to design a Francis turbine to be more resistant against sediment erosion, this may adversely, affect other aspects of the turbine. It should be understood that every hydraulic turbine is a compromise between several requirements.

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

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

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

6. Use of computer is recommended: As you are doing research in the field of Computer Science, then this point is quite obvious.

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

8. Use the Internet for help: An excellent start for your paper can be by using the Google. It is an excellent search engine, where you can have your doubts resolved. You may also read some answers for the frequent question how to write my research paper or find model research paper. From the internet library you can download books. If you have all required books make important reading selecting and analyzing the specified information. Then put together research paper sketch out.

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

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

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

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.

13. Have backups: When you are going to do any important thing like making research paper, you should always have backup copies of it either in your computer or in paper. This will help you to not to lose any of your important.

14. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several and unnecessary diagrams will degrade the quality of your paper by creating "hotchpotch." So always, try to make and include those diagrams, which are made by your own to improve readability and understandability of your paper.

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

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

17. Never use online paper: If you are getting any paper on Internet, then never use it as your research paper because it might be possible that evaluator has already seen it or maybe it is outdated version.

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.

31. Adding unnecessary information: Do not add unnecessary information, like, I have used MS Excel to draw graph. Do not add irrelevant and inappropriate material. These all will create superfluous. Foreign terminology and phrases are not apropos. One should NEVER take a broad view. Analogy in script is like feathers on a snake. Not at all use a large word when a very small one would be

sufficient. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Amplification is a billion times of inferior quality than sarcasm.

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

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

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

Informal Guidelines of Research Paper Writing

Key points to remember:

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

Final Points:

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

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

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

General style:

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

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page

- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

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

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

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

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

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

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

Title Page:

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

Abstract:

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

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

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to

shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

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

Approach:

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

Introduction:

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

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

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.
- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic

principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

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

Methods:

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

Approach:

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

What to keep away from

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

Results:

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

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

Content

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

What to stay away from

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

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

Approach

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

Figures and tables

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

Discussion:

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

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

Approach:

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

Administration Rules Listed Before Submitting Your Research Paper to Global Journals Inc. (US)

Please carefully note down following rules and regulation before submitting your Research Paper to Global Journals Inc. (US):

Segment Draft and Final Research Paper: You have to strictly follow the template of research paper. If it is not done your paper may get rejected.

- The **major constraint** is that you must independently make all content, tables, graphs, and facts that are offered in the paper. You must write each part of the paper wholly on your own. The Peer-reviewers need to identify your own perceptive of the concepts in your own terms. NEVER extract straight from any foundation, and never rephrase someone else's analysis.

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

- Methods to avoid Plagiarism is applied by us on every paper, if found guilty, you will be blacklisted by all of our collaborated research groups, your institution will be informed for this and strict legal actions will be taken immediately.)
- To guard yourself and others from possible illegal use please do not permit anyone right to use to your paper and files.

Criterion for Grading a Research Paper (Compilation) by Global Journals Inc. (US)

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals Inc. (US).

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

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