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Performance Evaluation of A Steam Turbine Test RIG and Oil Fired Boiler

R.Pachaiyappan[1], Dr.S.Gopalakannan[2], J.Niresh[3], Siddharth Shrivastava[4]
[1] Assistant Professor, [2]Professor, Department of Mechanical Engineering
Adhiparasakthi Engineering College, Melmaruvathur, Tamil Nadu India.
[3] Assistant Professor, [4]PG Scholar, Department of Automobile Engineering
PSG College of Technology, Coimbatore, Tamil Nadu, India

Abstract-The aim of this paper is further the performance improvement of a steam turbine and an oil fired boiler. This paper details the wholesome components of a steam turbine set up such as turbine, steam separator, steam condenser, separating and throttling calorimeter, boiler, and economizer. It also speaks about the performance of each component and efficiency of the system .The heat balance sheet provided fetches a systematic representation of a heat release and heat distribution per hour based on the readily attained value when calculated.
Keywords: Steam Turbine, Oil Fired Boiler, Performance and Efficiency, Heat Balance Sheet.

I. INTRODUCTION

Energy is the heart of universe, and it can't be created or be destroyed it can only change it's from.[1] The efficient transform is the standpoint of system efficiency. There are two types of energy resources available, renewable and non renewable. As far as world is concern we majorly use nonrenewable resources. India's most part of energy comes from coal, oil and LPG[2]. The non renewable energy resources can't be use again. An alarming demand has been dumped on engineers. One is to conserve energy and also produce an alternative energy source. To conserve energy we must know the basics of how energy is produced

A. Steam Turbine

It is a rotary device- where the heat energy of a steam is converted into kinetic energy. On simple explanation it simply breaks down to two parts a nozzle and a blade or a vane or a bucket. The good efficiency starts with a constructional design. A nozzle may be convergent or divergent or convergent divergent nozzle. It depends on the application used. Another important constructional feature is angle of placing, the blades, and the blades placement is important on meeting all the steam entering via nozzle. When steam is generated in the boiler it consists of high pressure and negligible velocity .To hit the blade high velocity is needed, this high velocity is created by nozzle. The nozzle reverses the condition, while entering the nozzle the steam has high pressure and negligible velocity at exit high velocity and low pressure. A pressure drop and a velocity increase are created in the nozzle by its design. The nozzle works under adiabatic expansion. Without any work done the process is changed from one form to another.[3]

B. Forces Acting On Blades

The steam turbine obtains its motive power from the change of momentum. When steam jet strikes the blade it exerts a pressure on the blade, when centrifugal force acts on the blade normal to the blade angle along the whole length of a blade. The effect of steam striking creates a velocity change and the centrifugal force which causes change in momentum which act as a motive force. The static pressure of a steam will not create an impact on blades. The principle is a high velocity steam is obtained by the nozzle and it strikes the blades and produces the kinetic energy so we obtain a mechanical work on rotor blades.[4]

C. Technical Features Of Our Steam Turbine

There are many types of steam turbines, here we use Single stage impulse turbine, condensing type. The blades have large clearance at the sides of the sides of the wheel. The blade is designed in such a way that there is negligible end thrust. The critical speed of the shaft is well above the operating speed. The steam enters the casing through the valve.[5]

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Table 1 *Turbine specifications*

Steam Turbine Type	Single Stage Impulse Turbine
Operating Medium	Steam
Nozzle Angle	32^0
Inlet Pressure	10 Kg\Cm^2
Inlet Temperature	120 To 160^{0}C
Power	500 Watts
No Of Nozzles	3
Steam Flow Rate	0.01 Kg\S\Nozzle
Speed Of Turbine	Not To Exceed 3000rpm

D. Steam Condenser

Steam condenser is a device which helps the exhaust steam from the turbine to condensate into water by exchanging heat into the continuously circulating storage tank. From storage tank it is fed into the boiler. The temperature of condensate water is more than that of storage tank so it is partially used to make steam by the recirculating process.

Table 2 *Steam condenser specifications*

Condenser Type	One Shell Two Tube Pass Condenser
Pumping Motor	230 V ,Single Phase, 0.75 Kw
Flow Rate	2 Lps
Head Of The Pump	18 Mwc
Vacuum Pump	Reciprocating Piston Type, 40mm Bore*45mStroke
Capacity	30 Lpm
Condensed Water Measuring Tank	100mm Dia * 0.5 M Height

E. Separating And Throttling Calorimeter

The quality of a steam is an important parameter. Steam quality can be determined by the separating and throttling calorimeter. There are three types of steams, dry steam, wet steam and superheated steam. Consider a system in which steam is flowing, the pressure and temperature can be directly measured by the thermometer and pressure gauges. The saturation temperature can be found out by using the steam tables. If the observed temperature is above the saturation temperature then the steam is said to be in superheated condition. If it is below the steam is said to be in wet or dry state, to find that out separating and throttling calorimeter is used. This type of calorimeter is very efficient and it can be used to find out the dryness fraction of the steam accurately even when the steam is too wet.[6]

F. Working Of Separating And Throttling Chamber

It consists of two parts a separating unit and a throttling unit. Both components consist of a stainless steel tube lagged with a glass wool and a water level indicator. It also consist of a pressure gauge to measure the pressure of the inside steam and a water level indicator to find the amount of water separated from the steam. The water particles are separated in the separating calorimeter and comparatively a dry steam enters the throttling chamber there it is made more dry. The separating and throttling chamber are linked by a narrow aperture.

G. Boiler

The boiler is a device which converts the water into steam. There are many types of boilers and in our set up we use an oil fired boiler. There is much kind of boilers and the aim of every set up is to obtain a good quality and quantity of a steam while utilizing minimum amount of resources. The methods such as recirculating using condensate help in reduced fuel consumption and are therefore used in this setup.

Table 3 Boiler specifications

Type	Non IBR-Automatic, Three Pass, Oil Fired Boiler With Economizer.
Model	SBS 200
Operating Pressure	12 Kg\Cm2
Capacity	200 Kg
Fuel	High Speed Diesel
Calorific Value	10833 Kj\Kg

H. Performance Evaluation Of Each Component

The Performance parameters of a steam condenser and separating and throttling calorimeter are listed below. The core view of this performance evaluation is looking through the test of an impulse steam turbine and test of an oil fired steam generator (boiler).

1) Condenser Efficiency:

Inlet temperature of a cooling water $T_1 = 35^0C$

Outlet temperature of a cooling water $T_0 = 46^0$ C

Vacuum gauge reading = 87mm of Hg

= (760-87)* 0.00136kg/ cm^2

= 0.915kg/ cm^2

Saturation temperature $T_v = 96.22^0C$

Condenser efficiency = T_0-T_1/T_v-T_1 (1)

= 17.96%

2) Calculating Dryness Fraction Using Separating And Throttling Calorimeter:

Pressure inside the separating calorimeter = 7.03kg/cm^2

Corresponding specific enthalpy h_1 = 165.6 kcal/kg

Corresponding latent heat Li = 493.8kcal/Kg

Pressure of a stream after throttling = 0.5Kg / cm^2

Corresponding specific enthalpy h_2 = 642.75 kcal/Kg

Saturation temperature $T_s = 116^0C$

Volume of water collected in separating calorimeter W = 5ml

Volume of condensate water collected from the condenser W_s = 190ml

Dryness fraction for separating X1 = W_s/W+W_s (2)

= 0.9744

Dryness fraction for throttling $X_2 = h_2+C_p (T-T_s) - h_1/L$ (3)

= 0.9721

Dryness fraction for separating and throttling calorimeter $X = X_1 * X_2$

= .9472

H. Performance Of An Impulse Steam Turbine

Total steam consumption (T.S.C)

Volume of a condensate tank for 40mm rise = 0.353

T.S.C = 1271/T_c Kg/hour

Specific steam consumption (S.S.C)

S.S.C = T.S.C/P_d Kg/kW (4)

1) Rankine Efficiency:

$$((T_1-T_2)*(1+h_{fg1}/T_2)-T2*\ln(T_1/T_2))/((T_1-T_2)+h_{fg2}) \quad (5)$$

2) Rankine Engine Efficiency:

$$100*(h_1-h_2)/h_1-h_{f2} \quad (6)$$

3) Brake Thermal Efficiency:

$$100*3600*\text{turbine output power in kW}/T.S.C*(h_1-h_2) \quad (7)$$

4) Relative Efficiency:

$$100*B.T.E/\text{Rankine efficiency} \quad (8)$$

5) Blade Efficiency:

$$100*2*\Delta Cu*U/C^2 \quad (9)$$

6) Gross Or Stage Efficiency:

= work done/enthalpy drop in a nozzle

$$=100*((\Delta Cu*U)/g_c*J)/\Delta h \quad (10)$$

I. Performance Test Of An Oil Fired Generator (Boiler)

Boilers are designed to evaporate steam at different pressures and temperatures, according to the requirements. High pressure super heated steam is used in power generating plants. Low pressure wet steam is used in mainly in chemical and processing industries for heating purpose. The following specifications are provided to give detailed information about boilers. Those are steam pressure, steam quality, type of fuel, type of draught and the firing method. When boilers are generating steam under different working condition, the capacity comparison is the best done by comparing the amount of heat added in the each boiler for steam generation this is known as "Equivalent Evaporation". [7]

*1) Boiler Thermal Efficiency:*The boiler efficiency is the rate of heat absorbed by the steam from the boiler per unit time to the heat liberated by the combustion of fuel in the furnace during the same time.

$$\text{Boiler efficiency} = m_s*(h-h_w)/mf*C.V8$$

2) Heat Losses In A Boiler Plant: There are various ways in which heat is lost in a boiler. Heat lost due to flue gases (Q_g). The flue gases contain many dry product of combustion and steam is generated due to combustion of hydrogen in the fuel.

$$Q_g = m_g*C_{pg}*(T_g-T_a) \text{ kj/hr} \quad \textbf{(11)}$$

Heat losses due to incomplete combustion (Q_{ic}), if the carbon burns as Co instead of Co_2 it is termed as incomplete combustion. In the presence of Co in the flue gas indicates that incomplete combustion is happening in the fuel

$$Q_{ic} = mg*Co*C/Co_2+Co*24800 \text{ kj/hour} \quad \textbf{(12)}$$

Radiation and convection losses (Q_{ua}), if the hot surface of the boiler are exposed to the atmosphere and therefore heat is lost to the atmosphere by convection and radiation. Those heat losses cannot be calculated so it is assumed to be 1% in total efficiency. Boiler efficiency is increased by reducing the amount of losses.

J. Data Collections

There are two types of parameter one is observed readings and another is calculated readings.

Table 4 directly recorded readings for steam impulse turbine

Location	Parameter	Symbol	Unit	1	2	3	4
Ambient	Ambient Temperature	T_r	C	40	41.5	42	42.5
Inlet Steam	Pressure Of Steam At Inlet To Turbine	P_0	Kgf/Cm2	10.4	10.4	10.4	10.4
	Temperature Of Steam At Inlet To Turbine	T_0	C	205	206.5	206	207
Exit Steam	Pressure Of Steam At Exit To Turbine	P_1	Mm Hg	500	500	500	500
	Temperature Of Steam At Exit To Turbine	T_1	C	79	80	81	81
Condensate Tank	Time For 4cm Rise Of Condensate	T_c	S	8.3	8	8	8
	Time Of Condensate	T_c	C	49.5	51	52	52
Condenser Cooling Water	Manometer Reading Of Flow meter	Hm	Cm Hg	30	30	30	30
	Water Temperature At Inlet	T_{w1}	C	34	35.5	35	36
	Water Temperature At Outlet	T_{w0}	C	39.5	41.5	41.5	42
Turbine	Dynamometer Torque Arm Radius	R	Mm	126	126	126	126
	Load On Spring Balance	W_D	Kg	1.8	1.8	1.75	1.7
	Speed On Turbine In Tachometer	N	Rpm	2833	3016	3123	3270

Table 5 Calculated readings of a steam impulse turbine

Location	Parameter	Formula	Unit	1	2	3	4
Turbine	Torque Developed	Tq= 9.81*R*WD/1000	Nm	2.22	2.22	2.16	2.1
	Power Developed	Pd= N*Tq/9554	Kw	0.66	0.702	0.707	0.719
Inlet Steam	Absolute Pressure	P_0= 0.9807*(P0+1.0320)	Bar	11.21	11.21	11.21	11.21
	Enthalpy Hg0	Hg_0	Kj/Kg	2781.5	2781.6	2781.6	2781.8
Exit Steam	Absolute Pressure	P_1= 0.0013332*(760-P1)	Bar	0.3466	0.3466	0.3466	0.3466
	Enthalpy On P1	H_1	Kj/Kg	2400	2400	2400	2400
	Actual Enthalpy	H_{g1}	Kj/Kg	2457.2	2457.2	2457.2	2457.3
Condensate	Enthalpy	H_{fc}= 419-4.2*(100-Tc)	Kj/Kg	206.9	213.2	217.4	217.4

	Mass Flow Rate Of Cooling Water	Mc= 0.285*Hm $^{0.5}$	Kg/S	1.561	1.56101	1.56101	1.56101
	Enthalpy	H_{f1}= 419-4.2*(100-Twi)	Kj/Kg	141.8	148.1	146	150.2
Cooling Water	Enthalpy	H_{f0}= 419-4.2*(100-Tw0)	Kj/Kg	164.9	173.3	173.3	175.4
	Mass Flow Rate Of Steam	M= 0.52/Tc	Kg/S	0.0425	0.04413	0.04413	0.04413
	T.S.C	T.S.C= 1271/Tc	Kg/Hr	153.13	158.875	158.875	158.875
Steam	S.S.C	S.S.C= T.S.C/(Pd/0.746)	Kg/Hp	173.15	168.747	167.622	164.795

Table 6 Heat balance sheet on impulse steam turbine

Parameter	Formulae	Unit	1	2	3	4
Heat Input From Steam Generator	H_{in}= T.S.C*H_0	Mj/H	425.94	441.927	441.943	441.958
Work Done By Turbine	H_{wd}= 3600*Pd	Mj/H	2.38	2.53	2.55	2.59
Heat Carried By Condensate	H_{con}= T.S.C*H_{fc}	Mj/H	31.683	38.8722	34.5394	34.5394
Heat Carried Away By Condenser Cooling Water	H_{cw}= 3600*Mc*(H_{fo}-H_{fi})	Mj/H	129.81	141.61	153.42	141.61
Unaccounted Heat Loss	H_{ua}= By Balance	Mj/H	262.07	263.911	251.442	263.215
Work Done By Turbine	H_{wd}%= 100*Hwd/Hin	%	0.6	0.6	0.6	0.6
Heat Carried By Condensate	H_{con}%= 100*Hcon/Hin	%	704	7.7	7.8	7.8
Heat Carried Away By Condenser Cooling Water	H_{cw}%= 100*Hcw/Hin	%	30.5	32	34.7	32
Unaccounted Heat Loss	H_{ua}%= 100* Hua/Hin	%	61.5	59.7	56.9	59.6

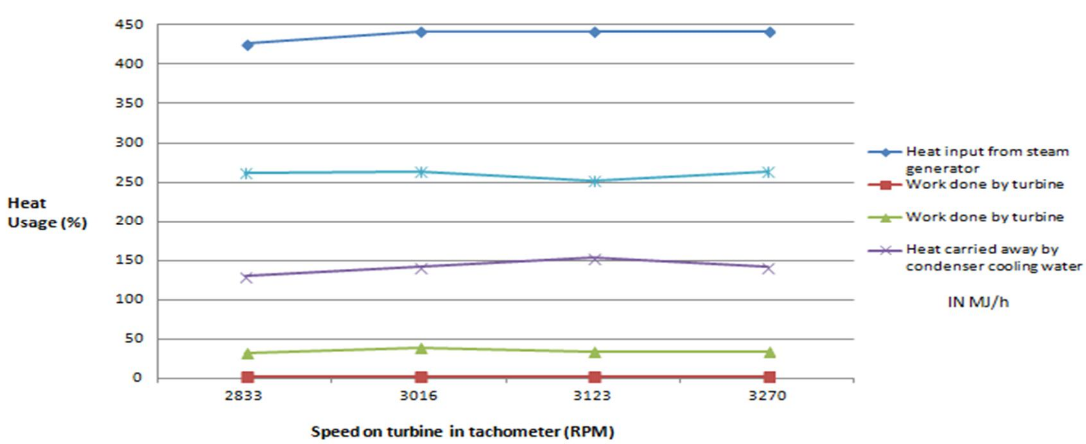

Fig. 1 Heat Balance Sheet on Impulse Turbine

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Table 7 Performance evaluated values of oil fired steam generator (boiler)

Parameter	Symbol/Formulae	Unit	1	2	3	4
Clock Time	T_c	hour	2 .18	2 .35	2 .5	3. 05
Initial Level Of Water	Wh	mm	4 90	4 05	3 15	2 90
Fall In Level Of Water	ΔWh	mm		8 5	9 0	2 5
Initial Level Of Oil	Dh	mm	3 10	2 90	2 60	2 35
Fall In Level Of Oil	ΔDh	mm		2 0	3 0	2 5
Air Orifice Meter Manometer Reading	Ah	mm	3 3	2 7	2 5	3 0
Steam Pressure	P	Kg/c m2	1 2.5	1 2.5	1 3	1 2.75
Ambient Temperature	t_R	C	4 4	4 3	4 3	4 3
Flue Gas Temperature	T_g	C	2 55	2 56	2 58	2 58
Water Inlet Temperature	T_s	C	5 5	5 6	5 6	5 6
Steam Temperature	T_w	C	2 19	2 19	2 19	2 19

Table 8 Calculated values of oil fired boiler

Parameter	Symbol/Formulae	Unit	Result
Duration of test	Td	min	47
Average steam pressure	P	kg/cm^2	12.69
Absolute steam pressure	p= 0.9807*(p0+1.032)	bar	13.45
Dryness fraction	X		0.85
Sp. Enthalpy of sat. liquid at pressure P	Hf	Kj/Kg	822
Sp. Enthalpy of sat. Steam at pressure P	Hfg	Kj/Kg	1966
Average feed water temperature	Tw	C	219
Average Room Temperature	Tr	C	43.25
Average Flue Gas Temperature	Tg	C	256.75
Average Manometer Reading	ΔAh	mm	28.75
Mass Of Steam Generated Per Hour	ms= (∑ΔWh/1000)*1.252*0.602*1000*60/td	Kg/hr	192.4
Mass Of Fuel Oil Burnt Per Hour	mf= (∑ΔDh/10000*0.4*0.4*950*60/td	Kg/hr	14.6
Mass Of Air Supplied Per Hour	ma= 1.23*0.62.0.00785*(2*g*814*Ah)5*3600 *60/td	Kg/hr	589.53
Enthalpy Of Steam Per Kg At Pressure P	h= hf+X*hfg	Kj/Kg	2493.1
Sp. Enthalpy Of Feed Water At Tw	Hfw	Kj/Kg	174

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Heat Gained By Steam Per Hour	Qs= ms*(h-hfw)/1000	Kj/Kg	446.276
Equivalent Evaporation	me= ms*(h-hfw)/2260	Kg/hr	197.5
Heat Released By Burnt Fuel Oil Per Hour	Qf= mf*C.V	MJ/hr	647.617
Heat Lost To Fuel Gas	Qg= ma*cpg*(tg-tr)	MJ/hr	138.5
Unaccounted Heat Loss	Quo= Qf-(Qs+Qg)	MJ/hr	62.891
Evaporation Rate	m= ms/mf	Kg/Kg	13.2

Table 9 Heat balance in percent of heat input for boiler

Parameter	Formulae	Unit	Result
Heat Generated By Burnt Fuel Per Hour	Qf= 100	%	100
Heat Gained By Steam Per Hour	Qs= 100+Qs/Qf	%	68.9
Heat Lost To Flue Gas	Qg= 101*Qg/Qf	%	21.4
Unaccounted Heat Loss	Qua= 102*Qua/Qf	%	9.7

K. Efficiency Values Of Impulse Steam Turbine And Oil Fired Boiler

The efficiency calculation includes the wetness of steam, flue gas exhaust, losses due to convection and radiation. So direct method of efficiency calculation couldn't be applied. The losses are subtracted from the direct method so actual efficiency values are obtained

Table 10 Efficiency values of impulse steam turbine and oil fired boiler

Parameter	Formulae	Unit	1	2	3	4
Rankine engine efficiency	ŋ e= 100*(hg-hf)/hg-hfc	%	14.8	14.9	14.9	14.9
Break thermal efficiency	ŋBte= 100*3600*pd/(T.S.C*(h0-h1))	%	4.8	4.9	4.9	5
Blade efficiency	ŋBe= 100*U*Cu/(Cf^2/2)	%	12.9	13.7	14.2	14.8

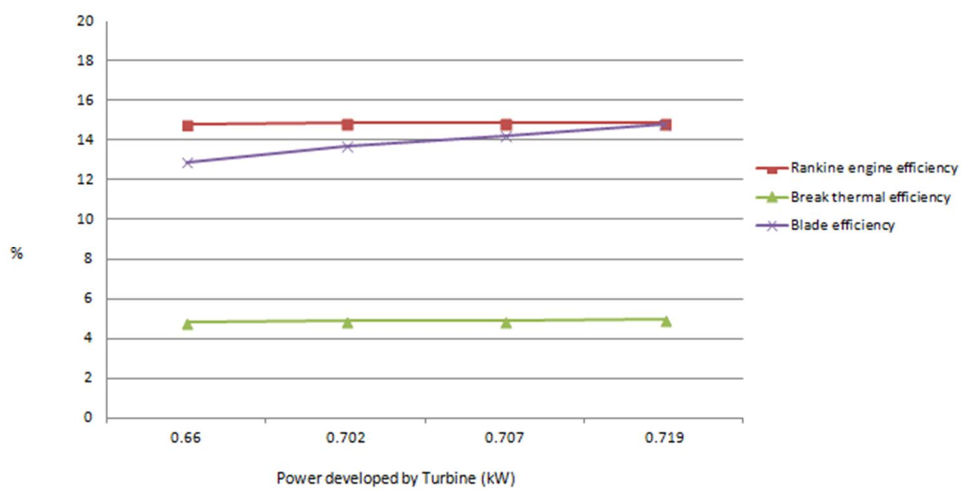

Fig. 2 Efficiency Values of Impulse Turbine and Oil Fired Boiler

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II. CONCLUSION

In this study it can be determined from the performance evaluation of a steam turbine test rig and oil fired boiler the test were done in the laboratory and the resultant data was then tabulated in the above tables. The graphs were drawn based on the the computed data. The performance and efficiency of a steam turbine is determined and the heat release and heat distribution per hour based on the readily attained value is calculated.

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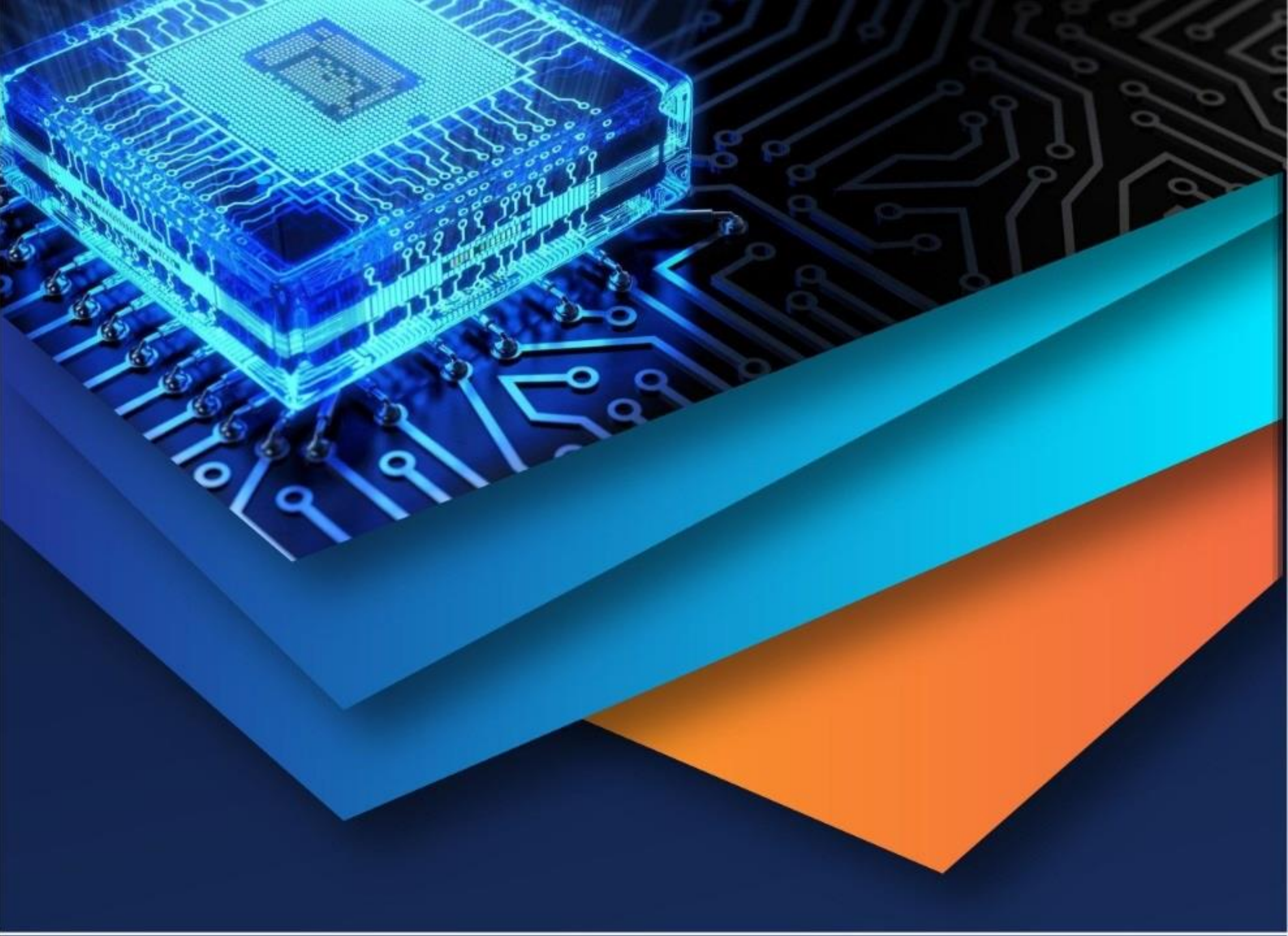

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