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Performance Analysis of Extraction Condensing Turbine - Unit 1 at PLTU X, Bekasi, West Java

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Abstract: In 2014, Cikarang Listrindo Energy built a steam power plant in Babelan to participate in the government programs. In April 2017, Unit 1 of PLTU Babelan has been operated. After the plant has been in operation for 4 months, the plant will have a performance test for the main part of the steam power plant, one of which is the steam turbine performance test. This performance test purpose is to get actual performance data where it will be compared to the design data, and it willl be used for warranty from the steam turbine contractor. The performance test is using ASME PTC 6 for steam turbine performance test. The steam turbine performance test can be seen from several parameters such as test capability, heat rate and turbine efficiency. The results of the steam turbine performance test based on the design are: the output power is 138,010 MW; the heat rate is 8865 kJ/kWh; and the turbine efficiency is 87.38%. Meanwhile the results of the performance test based on commissioning are: the output power is 139,295 M; the heat rate is 8919 kJ/kWh; and the turbine efficiency is 87.03%. The actual performance test results are: the output power is 137,595 MW, the heat rate is 8830.64 kJ/kWh, and the turbine efficiency is 88.65%. The tolerance given from ASME PTC 6 is 2%. Exhaust turbine pressure affect the turbine efficiency, where as lower exhaust turbine pressure causes higher turbine efficiency.

Keyword: Steam Turbine, Performance test, Capability test, Heat rate, Turbine Efficiency.

INTRODUCTION

In 2014, Cikarang Listrindo Energy built a PLTU in Babelan to participate in the government's program. In 2017, the Babelan PLTU condition was still in the commissioning stage. During this stage, various tests are carried out on each small part of the component, so that the Babelan PLTU can produce electricity. In the same year, April 2017, PLTU Babelan - Unit I started to produce electricity. After the plant is able to produce electricity for 4 months, the performance test for each main component of the power plant begins. One of them is the steam turbine in PLTU Babelan - Unit I, this plant uses an extraction condensing turbine type. The performance test for this extraction condensing turbine is based on the ASME PTC 6 standard, where later the performance test will follow the instructions of the predetermined standards. The results of this performance test will be compared with the initial design data for the manufacture of extraction condensing turbine type steam turbines where the aim is to obtain a warranty value from the contractor.

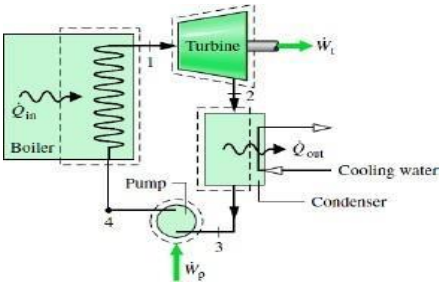
LITERATURE REVIEW

Ideal Rankine Steam Cycle

The Rankine cycle is a thermodynamic cycle used to analyze steam power generation systems. The feature of the Rankine cycle is that the working fluid undergoes phase changes in the cycle. Thermal energy is added to the working fluid by boiling the working fluid. The process of adding the thermal energy is carried out by a steam generator. The thermal energy is then converted into flow energy by the nozzle on the steam turbine which is then converted into mechanical work on the steam turbine shaft.

The process of converting flow energy from the working fluid into mechanical work in the Rankine cycle is carried out by a steam turbine. In the turbine there is an expansion process of the working fluid which will rotate the turbine. The steam turbine rotation will continue through a shaft that is connected to other components, such as an electric generator.

The components used in a simple Rankine cycle are steam turbines, condensers, pumps and boilers. Turbine is a component used to convert the energy of the working fluid flow into mechanical work on the shaft. The condenser is a component for changing the working fluid phase, from water vapor to water which then enters the pump. The pump will increase the pressure of the water working fluid before it enters the boiler. In the boiler, water is heated by burning fuel and boils into saturated steam. The saturated steam will enter the turbine, undergo an expansion process and turn the turbine.

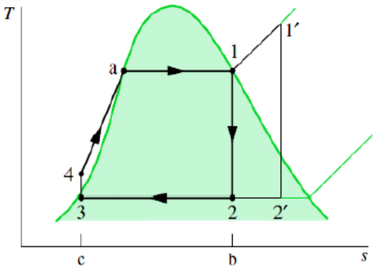


(Source: Fundamentals of Engineering Thermodynamics 5th Edition-Moran & Shapiro)

Figure 1. Simple Rankine Cycle Schematic

(Source: Fundamentals of Engineering Thermodynamics 5th Edition-Moran & Shapiro)

In Rankine cycle analysis, the Ts diagram (temperature versus entropy diagram) is often used to simplify the analysis.



(Source: Fundamentals of Engineering Thermodynamics 5th Edition-Moran & Shapiro)

Figure 2. Rankine Cycle TS Diagram

For an ideal Rankine cycle analysis, there are several simplifications of the Rankine cycle. The simplification is as follows:

1. The expansion process in the turbine is an isentropic expansion process. The process of expansion of the working fluid in the turbine occurs from the saturated vapor phase to the condenser pressure (Process 1-2).
2. The condensation process in the condenser occurs under conditions of isobaric / constant pressure (Process 2-3).
3. The compression of the working fluid by the pump occurs isentropically. This process occurs in a compressed liquid condition (Process 3-4)
4. The process of adding heat to the working fluid in a heat generator occurs under constant pressure conditions (Process 4-1)

Additionally, further simplifications could include:

1. There is no pressure drop in the piping system.
2. No heat is dissipated to the environment apart from the condenser.

The energy equation for the control volume system is: $Q - W = m\,(hout{-}hin)$

1. Steam turbine

   Q = 0 (no heat loss or heat gain)

   $Wturbin = m(h1{-}h2)$
2. Condenser

   W = 0

   $Qout = m(h2{-}h3)$
3. Pump

   Q = 0 (no heat loss or heat gain)

   $Wpump = m(h3{-}h4)$
4. Boilers

   W = 0

   $Qin = m(h1{-}h4)$

Performance Analysis Calculation Steps

1. Capability test

   The capability test is a comparison test between the output power generated by actual conditions and the output power derived from the design.
2. Heat rate

   Heat rate is the rate of heat entering the turbine to produce output power.

$$THR = \frac{Q}{Pgenerator} x\ 3600$$

$$Q = (min.hin) - (mfw.hfw) + (mblow.hblow) - (mdesu.hdesu$$

Where :

THR = Turbine Heat Rate, kJ/kWh
Pgen = Generator output power, kW
Q = Heat input, kJ/s
Min = Main steam flow, kg/s
hmm = Turbine input enthalpy, kJ/kg
mfw = Feedwater flow, kg/s
hfw = feedwater flow enthalpy, kJ/kg
bro = Steam blowdown flow, kg/s
hblo = Blowdown enthalpy, kJ/kg
mdes = desuperheater flow, kg/s
hdes = enthalpi desuperheater, kJ/kg

3. Exhaust Enthalpy Determination

There are two types of enthalpy determination at turbine exhaust, namely isentropic enthalpy and adiabatic enthalpy or actual enthalpy of turbine exhaust. Isentropic enthalpy is enthalpy with 100% efficiency, without any losses that occur in the steam turbine. The adiabatic enthalpy can be obtained using the steam table by entering the value of the turbine outlet pressure and the outlet temperature of the turbine.

Meanwhile, to find isentropic enthalpies, you can find them by using the steam table, and to find the enthalpies of saturated water and saturated vapor first.

Then using the formula below will get isentropic enthalpy at the exhaust turbine.

$$h_{adiabatis} = hf + \mathrm{X}.hfg \ \ (\frac{kJ}{kg})$$

Where :

Hadiabatis = enthalpyisentropic, kJ/kg
Hf = enthalpysaturated water, kJ/kg
X = steam quality, %
hfg = enthalpy of saturated vapor, kJ/kg

4. Turbine Efficiency

Calculation of turbine efficiency can be done by using the following equation:

$$T5 = \frac{WTtotal\ actual}{WTtotal\ Isentropis} x\ 100\%$$

Where :

ȠT = turbine efficiency
Actual tot WT = Actual total turbine power, kW
Isentropic WTtot = Isentropic total power of the turbine, kW

This type of steam turbine has 5 extractions which are used for preheating each feedwater line system, to find the work value of each extraction section, the following formula is used:

$$WTeks1 = min(hin - heks1)$$
$$WTeks2 = (min - meks1).(heks1 - heks2)$$
$$WTeks3 = (min - meks1 - meks2).(heks2 - heks3)$$
$$WTeks4 = (min - meks1 - meks2 - meks3).(heks3 - heks4)$$
$$WTeks5 = (min - meks1 - meks2 - meks3 - meks4).(heks4 - heks5)$$
$$WTeks6 = (min - meks1 - meks2 - meks3 - meks4 - meks5).(heks5 - hout)$$
$$WTisent = (min - meks1 - meks2 - meks3 - meks4 - meks5).(heks5 - hisent)$$

METHODS

Research Flowchart

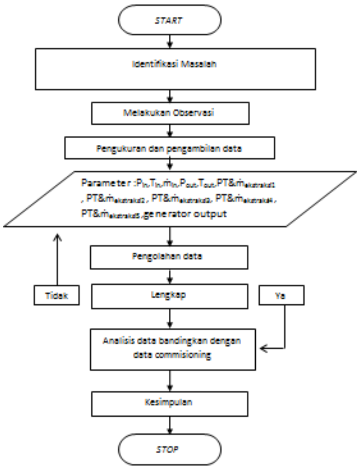


Figure 3. Research flow chart

Data Collection Procedures

Measurement of the parameters needed is by taking data from the initial design of the steam turbine. This data is used as comparative data for actual steam turbine performance testing. After the design data is processed using the equations that have been discussed, the next step is to take a number of parameters that will be used for data processing. The data is taken for 1 week for 4 hours, namely in November, the third week of 2022 according to the minimum data collection from ASME PTC 6. In addition data collection is done when the system is in a state of base load. Base load is a condition where the maximum steam turbine produces output power in the form of electrical power. This is done so that the results of data processing have values under the same conditions so that the results are not ambiguous.

Calculation

1. Heat Rate

By taking one of the research samples, the following calculations are carried out:

min = 134 kg/s
hmm = 3450.5 kJ/s
mfw = 130.304 kg/s
hfw = 924.4 kJ/s
mblow = 0.33 kg/s
hblow = 2662.9 kJ/s
mdesu = 4.021 kg/s
hdesu = 722.3 kJ/s

$$HR = \frac{Q}{Pgenerator} x\ 3600$$

$$Q = (min.hin) - (mfw.hfw) + (mblow.hblow) - (mdesu.hdesu)$$

$$HR = \frac{(134x3450.5) - (130.304x924.4) + (0.33x2662.9) - (4.021x722.3)}{138000} x\ 360$$

$$= 8865 \frac{kJ}{kWh}$$

$$HR\ = \frac{(134x3450.5) - (130.304x924.4) + (0.33x2662.9) - (4.021x722.3)}{138000} x\ 3600$$

$$= 8865\ \frac{kJ}{kWh}$$

2. Turbine Efficiency

min = 134 kg/s
Tin = 540°C
Pin = 125 Bars
hmm = 3450.5 kJ/kg
meks1 = 6.14 kg/s
Text1 = 303.5°C
pack1 = 22.41 Bars
hex1 = 3025.4 kJ/kg
meks2 = 5.61 kg/s
Text2 = 249.9°C
Peks2 = 13.95 Bars
hex2 = 2927.83 kJ/kg
meks3 = 8.32 kg/s
Text3 = 183.8°C

Peks3 = 7.41 Bars
hex3 = 2805.6 kJ/kg
mex4 = 8.7 kg/s
Text4 = 134ºC
pack4 = 3.04 Bars
hex4 = 2725.55 kJ/kg
meks5 = 6.93 kg/s
Text 5 = 92.6ºC
pack5 = 0.77 Bars
hex 5 = 2663.81 Kj/kg
Pout = 0.15 Bars
Tout = 54.5ºC
hout = 2382.5164 kJ/kg

To get the value of isentropic enthalpy, that is by plotting the data on a Mollier diagram or using a steam table. On the Mollier diagram or steam table, you can find it by plotting the value of the steam quality (x) with the exhaust pressure (Pout).

X = 0.83
Hisent = 2194.99 kJ/kg

$$T5 = \frac{WTtotal\ actual}{WTtotal\ Isentropis} x\ 100\%$$

$$WTeks1 = min(hin - heks1)$$
$$WTeks2 = (min - meks1).(heks1 - heks2)$$
$$WTeks3 = (min - meks1 - meks2).(heks2 - heks3)$$
$$WTeks4 = (min - meks1 - meks2 - meks3).(heks3 - heks4)$$
$$WTeks5 = (min - meks1 - meks2 - meks3 - meks4).(heks4 - heks5)$$
$$WTeks6 = (min - meks1 - meks2 - meks3 - meks4 - meks5).(heks5 - hout)$$
$$WTisent = (min - meks1 - meks2 - meks3 - meks4 - meks5).(heks5 - hisent)$$

$$WTeks\ 1 = 134.(3450.5 - 3025.4) = 56963.4 \text{ kW}$$
$$WTeks\ 2 = (134 - 6.14).(3025.4 - 2927.83) = 12475.3\ kW$$
$$WTeks\ 3 = (134 - 6.14 - 5.61).(2927.83 - 2805.6) = 14942.62\ kW$$
$$WTeks\ 4 = (134 - 6.14 - 5.61 - 8.32).(2805.6 - 2725.55) = 9210.1\ kW$$
$$WTeks\ 5 = (134 - 6.14 - 5.61 - 8.32 - 8.7).(2725.55 - 2663.81) = 6496.9\ kW$$
$$\begin{aligned} WTeks\ 6 &= (134 - 6.14 - 5.6 - 8.32 - 8.7 - 6.93).\ (2663.8 - 2382.516) \\ &= 27651.16\ kW \end{aligned}$$
$$\begin{aligned} Wisent &= (134 - 6.14 - 5.61 - 8.32 - 8.7 - 6.93).(2663.81 - 2194.99) \\ &= 46085.006\ kW \end{aligned}$$

Find the actual total steam turbine power

$$WTtotal\ aktual = WTeks1 + WTeks2 + WTeks3 + WTeks4 + WTeks5 + WTeks6$$
$$WTtotal\ aktual = 56963.4 + 12475.3 + 14942.62 + 9120.1 + 6496.9 + 27651.16$$
$$WTtotal\ aktual = 127649.48\ kW$$

Find the total power of an isentropic steam turbine

$$WTtotal\ isent = WTeks1 + WTeks2 + WTeks3 + WTeks4 + WTeks5 + Wisent$$
$$WTtotal\ isent = 56963.4 + 12475.3 + 14942.62 + 9120.1 + 6496.9 + 46085.006$$
$$WTtotal\ isentropis = 146083.326\ kW$$

$$T5 = \frac{WTtotal\ actual}{WTtotal\ Isentropis} x\ 100\%$$

$$T5 = \frac{127649.48}{146083.326} x\, 100\% = 87.38\,\%$$

RESULT AND DISCUSSION

Comparison of Design Output Power, Commissioning Output Power and Actual Output Power

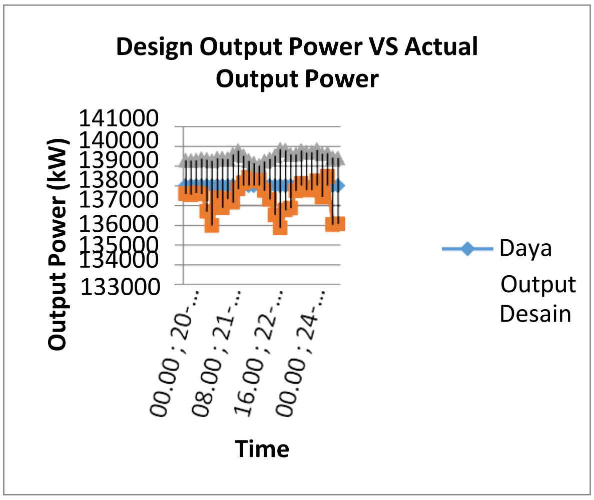


Figure 4. Output Power Comparison Chart

From Figure 4. it can be seen that the output power during commissioning is greater than the output power by design or at the time of actual data collection. The design output power is 138,010 MW, while the output power during commissioning is 139,295 MW or has a deviation of about 0.9% greater than the design data, and the output power when the actual data is taken is 137,595 MW or has a deviation of 0.3% smaller than the design. The output power tolerance given is based on ASME PTC 6 which is 2%. So, the output power during commissioning and when the actual data is collected is still within the given tolerance range. The output power during commissioning is greater because during the performance test, commissioning the incoming steam energy is greater than the design data or when the actual data is collected.

Comparison of Design Heat Rate, Actual Heat Rate, and Commissioning Heat Rate

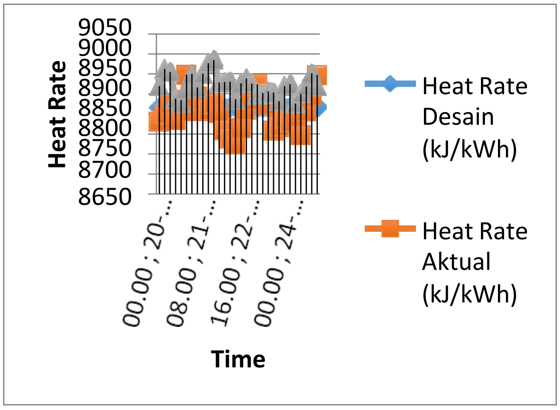


Figure 5. Heat Rate Comparison Chart

From Figure 5 it can be seen that the heat rate during commissioning tends to be greater than the design heat rate and the heat rate when the actual data is collected. The design heat rate is 8865 kJ/kWh while the commissioning heat rate is 8919 kJ/kWh or has a deviation of

0.9% greater than the design heat rate, and for the heat rate when the actual data is collected it is 8830 kJ/kWh or has a deviation of 0.39 % smaller than the design heat rate. For the tolerance of the heat rate itself based on ASME PTC 6 which is 2%. So the heat rate during commissioning and when the actual data is collected is still within the given tolerance range. The greater the heat rate value, the turbine efficiency value will decrease, this causes the fuel consumption to heat water to become steam to increase.

Comparison of Turbine Efficiency Design, Turbine Efficiency Commissioning, Actual Efficiency Turbine

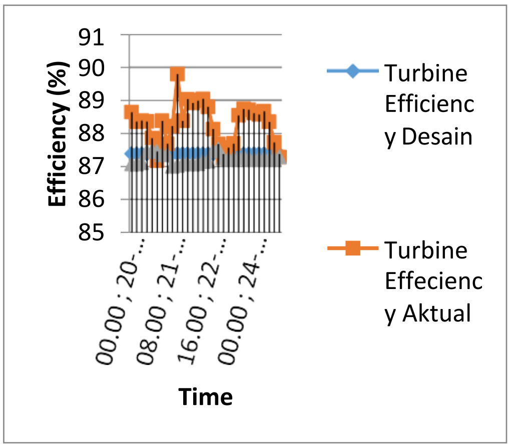


Figure 6. Turbine Efficiency Comparison Chart

From Figure 6 it can be seen that the actual turbine efficiency is greater than the turbine efficiency during commissioning and design turbine efficiency. The actual turbine efficiency value is 88.21%, while the turbine efficiency at commissioning is 87.1% and the design turbine efficiency is 87.38%. The actual turbine efficiency is greater because the exhaust pressure when the actual data is taken is more vacuum compared to the design data and during commissioning. The amount of turbine efficiency is determined based on the vacuum exhaust pressure of the steam turbine. We can see from the data obtained that the design exhaust pressure is 0.15 Bar, while the exhaust pressure during commissioning is 0.15 Bar and the actual data exhaust pressure is 0.126 Bar.

CONCLUSION

From the analysis and calculations that have been carried out on the condensing extraction turbine type steam turbine, it can be concluded that:

1. The design output power is 138,010 MW, while the output power during commissioning is 139,295 MW, and the actual output power is 137,595 MW. The tolerance of the output power based on ASME PTC 6 is 2% of the design data, so that the commissioning output power and the actual output power are still within the given tolerance.
2. The design turbine heat rate is 8865 kJ/kWh, while the turbine heat rate during commissioning is 8919 kJ/kWh, and the actual turbine heat rate is 8831 kJ/kWh. The tolerance given based on ASME PTC 6 is 2%, so that the turbine heat rate during commissioning and when the actual data is taken is still within the given range.
3. The design turbine efficiency is 87.38%, while the turbine efficiency is 87.068% and the turbine efficiency when the actual data is taken is 88.65%. Turbine efficiency is greatly influenced by the vacuum from the turbine exhaust itself.

4. From the results of research on the performance of steam turbines during commissioning and when taking actual data, all the parameters tested were still within the tolerances given based on ASME PTC 6.
5. Steam flow and incoming steam energy affect the efficiency of the turbine, we can see that the steam energy at the time of actual data collection is greater, namely 3463.4 kJ/kg with an efficiency of 88.65%, while the steam energy in the design data is 3450 kJ/kg with an efficiency of 87.38% and steam energy during commissioning of 3445.73 kJ/kg with an efficiency of 87.1%. Maintaining the vacuum from the turbine exhaust or the vacuum from the Air Cooled Condensor is very influential in increasing the efficiency of the turbine.

One of the causes of the decrease in turbine efficiency is the increase in pressure in the air cooled condenser. We can see this in the comparison graph between design, commissioning and actual turbine efficiency, where the more the vacuum exhaust pressure of the turbine or the pressure of the air cooled condenser, the turbine efficiency will decrease. One way to maintain a vacuum in the air cooled condenser so that the turbine exhaust pressure is low requires scheduling the cleaning process of the tubes in the air cooled condenser to avoid the buildup of dirt on the air cooled condenser tubes, which will affect the process of condensing steam output from the turbine, p. This includes efforts to maintain exhaust turbine vacuum and can increase the efficiency of the turbine itself.

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