Translators

Pratama Irwin Talenta

Latifa Ika Sari

STEAM TURBINES (MAIN ENGINE)

Abdi Seno

STEAM TURBINES (MAIN ENGINE) OPERATIONAL LEVEL

Abdi Seno

Politeknik Ilmu Pelayaran Semarang

TURBIN UAP (MESIN PENGGERAK UTAMA)

Authors:
Abdi Seno

Published by:
Politeknik Ilmu Pelayaran Semarang
Jl. Singosari 2A Semarang

ISBN : 978-602-5694-28-8
e-ISBN : 978-602-5694-52-3

TRANSLATED
STEAM TURBINES (MAIN ENGINE)
Operational Level

Translated by:
Pratama Irwin Talenta
Latifa Ika Sari

Editor: Khaira Dewi

ISBN : -

Published by:
Politeknik Ilmu Pelayaran Semarang
Jl. Singosari 2A Semarang
IKAPI Member, 2021

PREFACE

Praise be to Allah S.W.T., for His mercy and grace so that the preparation of this textbook entitled Steam Turbine Main Engine can be completed. This textbook is intended to complete the material for course of Engine Officer Class II, III, and IV at the operational level on Main Engine subject. The depth of the material in this textbook has been adapted and addressed for those course participants.

The material of this textbook covers the development of turbines steam, the Rankine Cycle, and in the form of the Steam Turbine Ideal Cycle. This section also mentions the steam boiler as a steam generator. The turbine construction section is covers its Components, Working Principles, and Classification of Steam Turbines, and Losses in Steam Turbines.

Another section covers the Characteristics, Velocity Triangle, Zeuner's Equation (SI), Triangle Speed, Blade Performance, Shapes of Turbine Moving Blade - Turbine de-Laval, Zoellly, Curtis, and Parson. Turbine Power discusses Theoretical Power, Blade Power, Indicator Power, and Turbine Effective Power and their technical settings. At the end of this textbook covers the axial forces that occur in turbines and operating procedures and maintaining steam turbines.

The author realizes that this textbook is not perfect yet,so that the author hopes to get suggestions and feedback for improvement. The author would also like to thank all parties for their support and assistance so that the preparation of this textbook can be completed.

Semarang, June 2018

Author

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I.
STEAM TURBINE DEVELOPMENT

The idea of the steam turbine arose in about 120 BC, by a man named Heron of Alexandria who initially made a prototype steam turbine with reaction turbine principle. This installation consists of a pump filled with water which is heated by boilers. The steam is inserted into the sphere of the steam reservoir which is fixed on a pole that has an axis so that the sphere can be rotated. On the rotating sphere, there are several transmitter pipes. Due to the release of steam through the transmitter pipe, the sphere rotates, because of the reaction of the steam coming out.

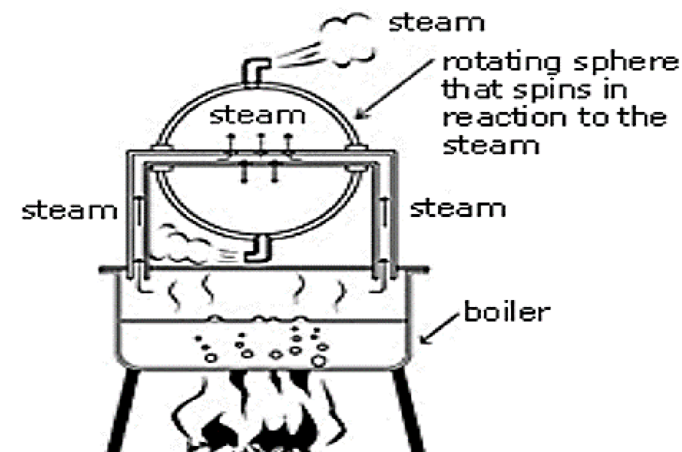


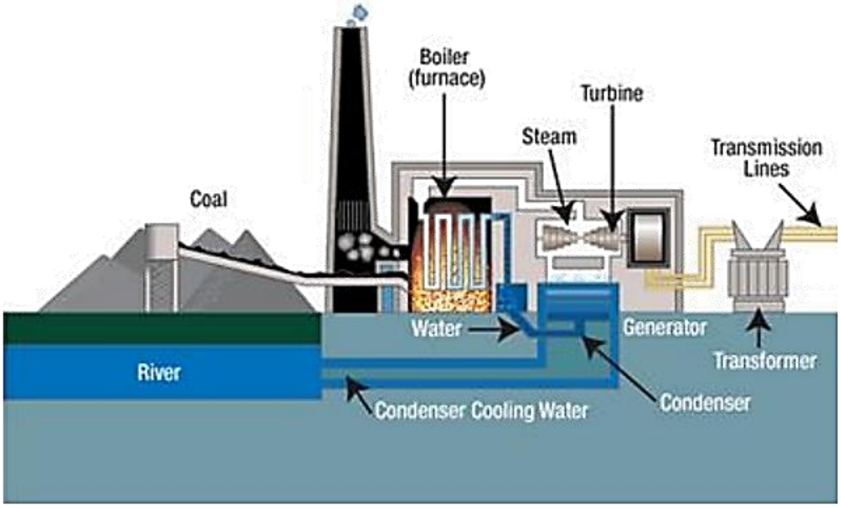
Figure 1. Heron Steam turbine.

In 1890, a Swedish engineer named Gustav de Laval made a single stage turbine, with a capacity of 5 Hp. The successful manufacture of this turbine stems from an early experiment in 1870. Seeing the reaction from the Heron machine, he saw the power created by the transmitter pipe. The first application of the invention is used not for steam turbines but for drying sand. The steam expansion device uses a nozzle connected to a centrifugal separator. The results of this invention produce a turbine that rotates at a speed of 4000 revolutions per minute. In industry, de Laval turbines are widely used to drive generators.

In 1884, an Englishman named CA Parson invented the turbine with the reaction principle. This turbine is used for several needs in the industrial field. The speed of steam flowing through the reaction turbine with many stages is relatively very low, namely 100-200 m/s.

Subsequent developments, continued in 1898. On the basis of the de Laval turbine, Charles Gordon Cutis (America) was able to reduce the turbine rotational speed with an action turbine type made with several levels of one pressure speed. In 1990 this turbine was demonstrated in America. The turbine has two moving blades and between the two blades installed inter-blade mounted on the turbine housing. The blade rotation seems to be opposite to the blade rotation. For turbines with two levels of speed and one level of pressure also made by Lenin Nevsky. Almost all turbines are constructed with radial turbines, meaning that the steam flow is introduced parallel to the turbine shaft.

At this time the steam turbine is used in industry, especially in Steam Power Plants (PLTU). At PLTU, the steam turbines are used in addition to drive a generator as well as a compressor, pump, and others.



Source: http://ptm production.blogspot.co.id

Figure 2. Steam Turbine Installation in PLTU.

CHAPTER II.
RANKINE CYCLE

2.1. Steam Turbine Ideal Cycle

Rankine cycle developed by William John Macquorn Rankine is a steam cycle used to calculate or model the work process of a steam engine/ steam turbine cycle that converts heat energy into work/ motion energy. This cycle works ideally with fluids and is applied to steam power plants and cooling systems (refrigerator plants). Rankine cycles are commonly used in power plants and generally produce ± 90% of the world's electricity. To study the Rankine cycle, you must first understand the Temperature (T) and Enthalpy (h) diagrams for water, as shown in the following figure.

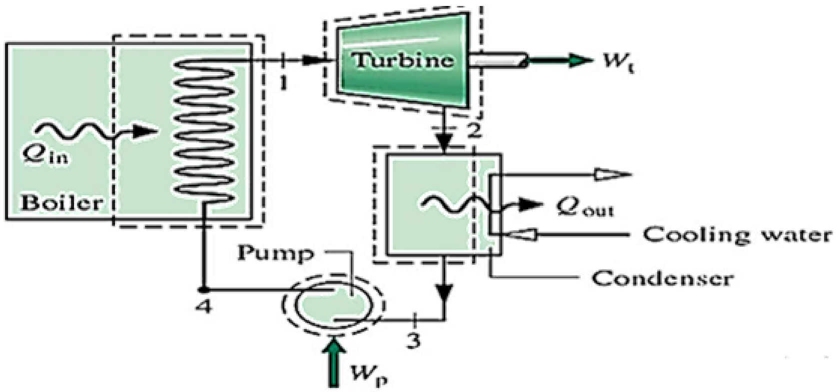
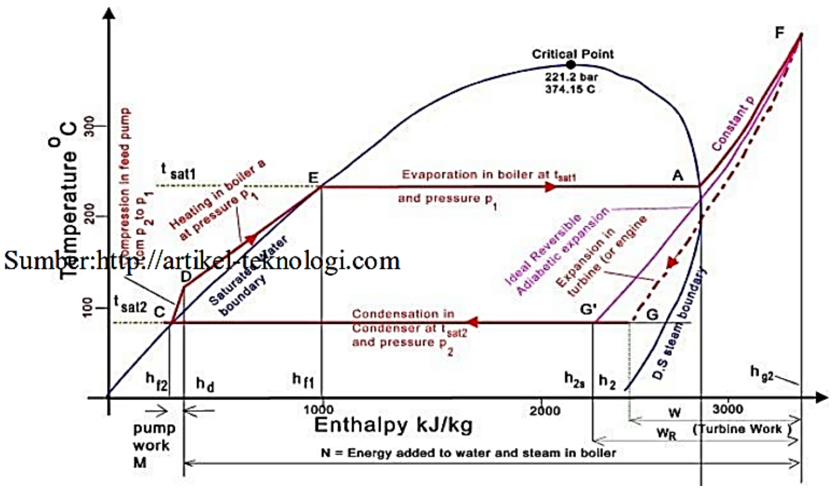


Figure 3. Rankine cycle.



Source: http://article-technology.com

Figure 4. Temperature-Enthalpy Diagram (T-h).

In the picture above, it can be said that water was originally in the form of steam to become a liquid/ fluid, the rankine cycle takes place in a closed-loop cycle, it means that water constantly at the end of the cycle re-enters the process at the beginning of the cycle.

2.2. Rankine Cycle Processes

According to the picture above, the Rankine cycle has four processes, namely:

1. **C-D process**: The working fluid in the form of water is pumped from low to high pressure, and in this process the working fluid is still in the liquid phase so that the pump does not require too much power input. This process is called an isentropic-compression process because when pumped, ideally no entropy change occurs.

2. **D-F process**: High pressure water enters the boiler to undergo an isobaric (constant pressure) heating process. Heat sources are obtained from outside such as burning coal, diesel, or nuclear reactions. In the boiler, the water undergoes a phase change from liquid to a mixture of liquid and steam, and is 100% dry steam.

3. **F-G Process**: This process occurs in steam turbines. Dry water steam from the boiler enters the turbine and undergoes an

isentropic expansion process. The energy stored in the steam is converted into motion energy in the turbine.

4. **G-C process**: Water steam coming out of the steam turbine enters the condenser and undergoes isobaric condensation. The steam is phased back into a liquid so that it can be reused in the cycle process.

The description of the cycle through the T-h diagram is the most basic and simplest Rankine cycle. In its use there are several process modifications so that a higher total thermal efficiency is obtained. Such as the use of a preheater or preheating before entering the boiler, and also the use of reheating water steam coming out of the first turbine (high pressure turbine) so that it can be used again to enter the second turbine (Intermediate pressure turbine). To make it easier to understand, we can see the schematic of the process in the image below.

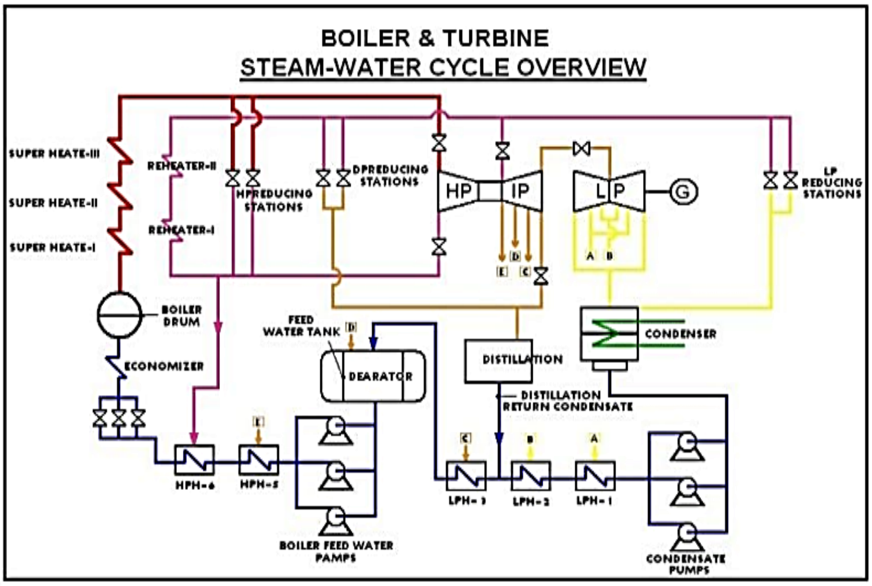


Figure 5. Rankine Cycle with Preheater and Reheater.

In the picture above, the condensate water pumped by the condensate extraction pump from the condenser to the deaerator/ feed water tank goes to the preheating process. And the water pumped by the feed water pump from the feed water tank to the boiler also passes through the preheater. The heat source used by the preheater comes from the extraction of steam taken from the steam turbine at certain stages.

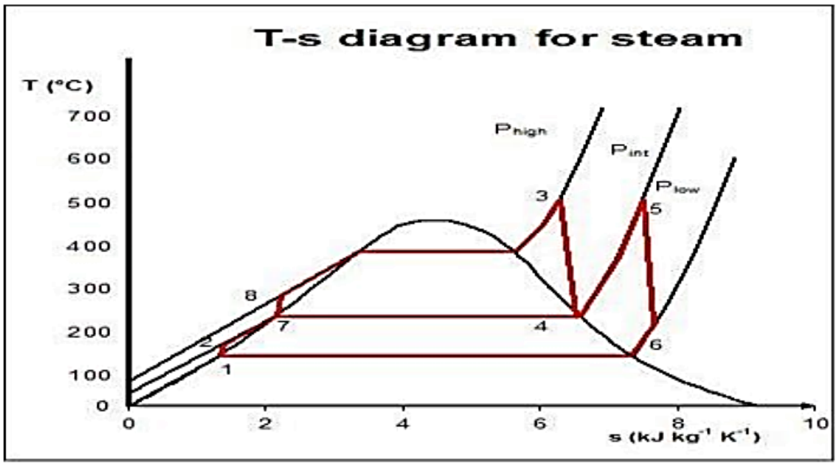


Figure 6. Temperature-Entropy Diagram: Modification h.

In addition, another difference with the conventional Rankine cycle is that there is reheating of water steam coming out of the High-Pressure Turbine by the reheater boiler to return to the superheater phase and the results are fed back to the second turbine (Intermediate Pressure Turbine).

Also, there is also a steam bypass system not to be passed to the steam turbine. The superheater steam leaving the boiler does not enter the turbine and is bypassed to re-enter the boiler side of the reheater. And the steam coming out of the reheater boiler is bypassed to enter directly into the condenser. The function of this bypass system is as a protection system if a problem occurs in the Rankine cycle so that it can avoid serious damage. And also used during the initial startup process of the cycle system and also the process of turning it off.

Chapter III. Steam Boiler

Steam installation consists of four main components. The boiler is used to make superheated steam from the feed water and requires energy obtained from burning fuel with air. Steam turbines with adiabatic expansion of high-pressure steam to obtain output power in the form of work. The condenser receives low pressure steam from the turbine to be cooled and condensed into water. The filling water pump functions to increase the pressure of the water condensation to flow back into the boiler. This section discusses more detail about the steam boiler.

3.1. Definition of Steam Boiler

A steam boiler is a closed vessel that can form steam with a pressure greater than 1 atmosphere, by heating the boiler water inside with hot gases from the combustion of fuel. The steam produced by steam boilers is used for many uses on the ship. As the main installation, it is used to drive steam turbines that rotate the propellers, so that the ship can move forward and backward. As a main installation, it is used to drive pumps, especially cargo pumps on tankers or as a heating medium.

Boiler/ steam boiler is a pump in which it contains water or other fluids to be heated. The heat energy from the fluid is then used for various purposes, such as for steam turbines, space heating, steam engines and so on. In the energy conversion process, the boiler has a function to converts chemical energy stored in the fuel into heat energy which is transferred to the working fluid.

For the use of boilers in large industries, boiler vessels generally use steel with certain specifications that have been determined in the ASME

(Code Boilers) standard. Historically, various types of materials have been used to make boilers, such as copper, brass, and cast iron. However, these materials have long been abandoned due to economic reasons and also the durability of materials that are no longer in accordance with industrial needs.

The heat given to the fluid in the boiler comes from the combustion process with various types of fuels that can be used, such as wood, coal, diesel, other petroleum and gas. With technological advances, nuclear energy is also used as a heat source in boilers.

3.2. Steam Boiler Terms

In order to be used in industry or on ships, especially a steam boiler, it must meet the following requirements:

1. In a certain time can produce steam with a certain weight and pressure greater than 1 atmosphere.
2. The steam produced must be with as little water content as possible.
3. If an advanced heating device is used, then in irregular use of steam, the temperature of the steam should not change much and must be easily regulated.
4. During exercise where the use of steam varies, the pressure of the steam should not change much.
5. Steam should be able to be formed with the lowest possible amount of fuel.
6. The arrangement of fuel packing must be such that the fuel can be burned without requiring too much cost and energy.

3.3. Steam Boiler Type

There are many kinds of Steam Boilers, and their development can follow to the technological advances today. Of the many kinds of boilers, it is necessary to group them into several sections according to the Steam Act, their position, construction and use on ships.

1. Steam boiler according to the act on steam.

   According to Article 9 of the Steam Law, Steam Boilers are divided into three namely:

   a. Fixed boiler or land boiler, namely boilers used on land such as factories, power plants and others that have a fixed foundation.
   b. Ship boilers, namely boilers used on ships. Here the equipment for boiler safety equipment usually has a slightly different construction from other boilers, considering the state of the ships that are always rocking during sail.
   c. Movable boilers, namely boilers that are not included in the two groups of boilers mentioned above, such as train boilers, pile boilers etc.

2. Steam boiler according to its position.

   The boiler is made to produce steam by heating the water in it by hot gases from the combustion of fuel. The boiler should work as efficiently as possible; it means you have to produce as much steam as possible with minimal fuel consumption. Therefore, the boiler construction must be such that the heat from the fuel must be as much as possible to be absorbed by the boiler water to produce steam. To achieve this, the boiler construction is made of an arrangement of pipes that separate the water and the hot gases heat it.

   Seen from the position of the boiler pipe is divided into:

   a. Horizontal Kettle, example: B&W Section.
   b. Vertical Kettle, e.g., Foster Wheeler.
   c. Tilting Kettle, example: B & W Integral.

3. Steam boiler according to construction.

   Seen from the substance flowing in the pipe, the boiler is divided into 3 groups, namely:

a. “Boiler Pot” or “Haycock Boiler”.

Is a boiler with the simplest design in history. It was introduced in the 18th century, using large volumes of water but only producing at low pressures. This boiler uses wood and coal as fuel. This type of boiler does not last long due to its very low efficiency.

b. Fire-Tube Boiler.

In subsequent developments appeared the fire-tube boiler design. This boiler has 2 parts in it, namely the tube/ pipe side and the barrel side. The barrel side contains fluid/ water, while the side of the pipe is a place for combustion or in other words hot gases flow inside the pipe, while the heated water is outside the pipe. Examples of these boilers: Schots Kettle and Kettle of Cochran.

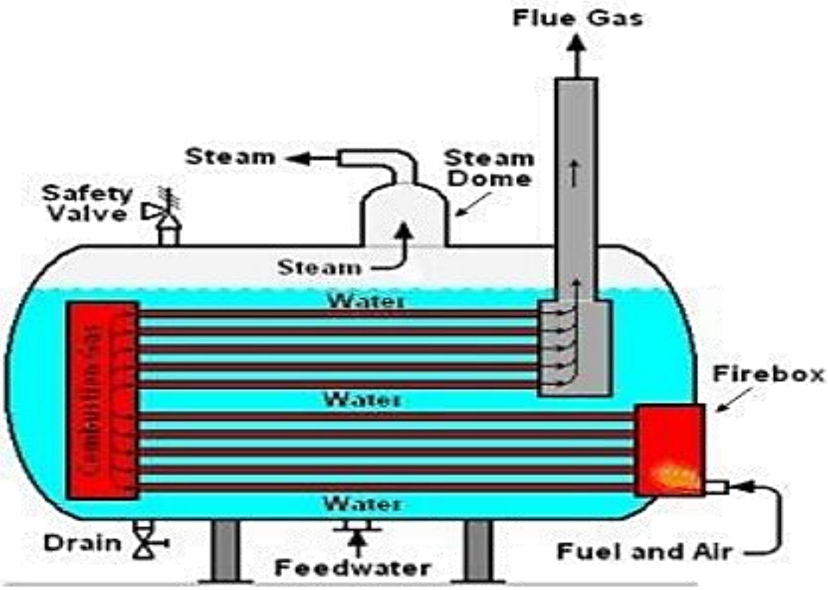


Figure 7. Fire-tube boiler.

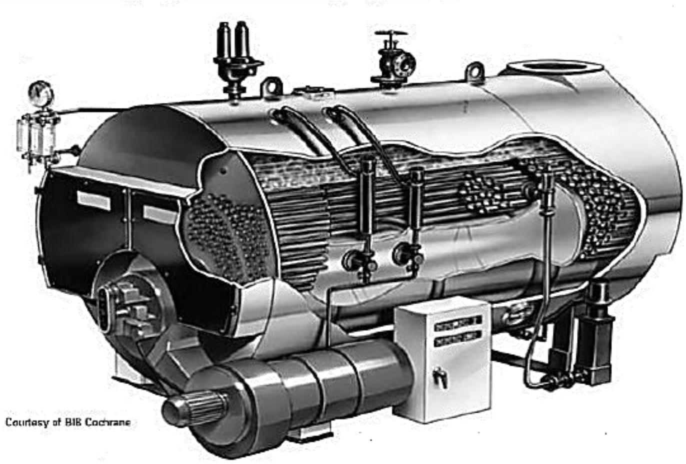


Figure 8. Schott Water Pipe Boiler.

c. Water-Tube Boiler.

It is like fire-tube boilers, water-tube boilers also consist of pipes and barrels. But the side of the pipe is filled with water while the side of the barrel is where the combustion process takes place. Which flows inside the pipe is boiler water, while the heating gases are outside the pipe. At present, water pipe boilers are developing more rapidly because they have a high speed in producing water steam, but does not have much water steam reserves in it.

Example of a water pipe boiler:

1) Babcock and Wilcox Boiler Section & Integral.
2) Foster Wheeler's Kettle.
3) Yarrow-kettle.
4) E S D boilers (ESD I, II, III and IV).

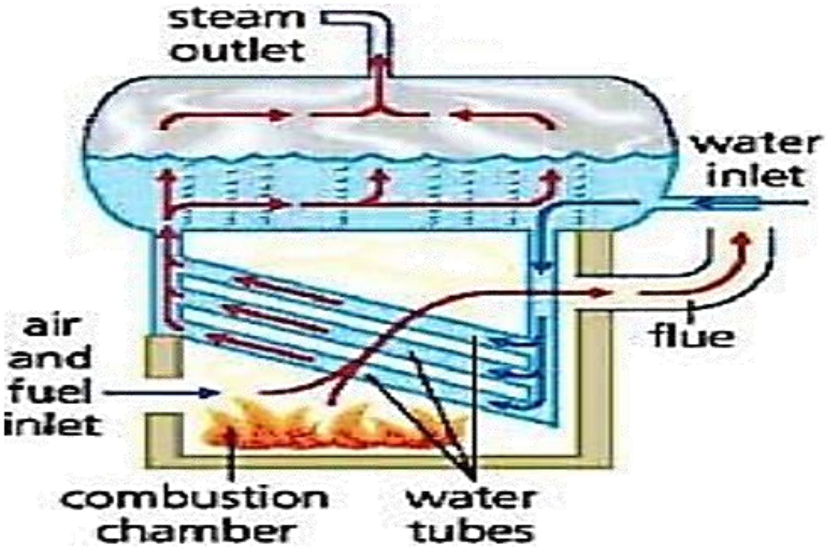


Figure 9. Babcock and Wilcox Kettle

d. Fire-tube and Water-tube Boiler Combination.

This type of boiler is a combination of fire-tube and water-tube boilers. A firebox in which there are pipes filled with water, the resulting water steam flows into the barrel with the fire pipes in it. This type of boiler is applied to several steam trains, but it is not very popular in industry, especially in shipping.

For example:

1) Werkspoor boiler.
2) Howden-Johnson boiler.

4. Steam boiler division according to its function on the ship.

On motor ships the use of steam is of course only for auxiliary aircraft. While on steamships, the main use of steam is to drive the main engine, while another use is for auxiliary aircraft. Therefore, according to its function on the ship, boilers are divided into two groups, namely:

a. Main boiler of the type Water Tubes Boiler.

It is a boiler that produces steam used to drive the main engine. At present the boilers used as main boilers are generally water pipe boilers.

Master boilers on board:

1) Foster Wheeler.
2) I S D (Internal Superheat D-type).
3) E S D (External Superheat D – type).
4) D S D (Double Superheat D-type).
5) E S R D (External Superheat Radiant D – type).
6) Babcock and Wilcok.
7) B&W Section.
8) B&W Integral.
9) Marine Radiant.
10) Combustion Engineering:
    a) CEV (Combustion Engineering V-series).
    b) CELTG (Combustion Engineering Law Temp Gas).
    c) CELTGR (Comb Eng Law Temp Gas Reheat).
    d) Kawasaki (Superheat Content, Full Cooled, Enclosed Membrant).

b. Auxiliary Boiler.

Namely a boiler produces steam, which is used for auxiliary equipment, such as pumps, heaters and others.

Types of boilers are usually used as an auxiliary boiler for example:

Boilers including auxiliary boiler:

1) La Mont Exh Gas Economicer.
2) Cochran Composite Boiler.

3) B&W M – type.

4) Foster Wheeler D – type.

3.4. Change of Energy in the Boiler

In the division of combustion engines, the steam installations are included as "External Combustion Engines" which is a machine where the energy is obtained from the combustion of fuel that occurs outside the engine (steam boiler). So, the function of the boiler in the external combustion engine installation is a place for burning fuel. In the boiler, the fuel is burned to produce heat. The heat of the fuel is then used to heat the water in the kettle so that it boils and creates steam. In the steam produced by this boiler contains an energy called "potential energy" which later in the steamer will be converted into "mechanical energy" either directly on the "piston steam engine" or by means of "kinetic energy" in the jet tube as shown in the figure below located in "Steam Turbine".

1. The term Steam.

   a. Steam Pressure.

      It is meant by steam pressure is the force of the steam pressing on the walls of the room occupied per certain unit area.

   b. Temperature/Steam Temperature.

      It is meant by steam temperature is the degree of heat possessed by steam according to the conditions and types of steam present. High and low temperature of the steam depends on the amount of heat received by the steam.

   c. Steam Heat.

      Heat is a form of work; the heat can only move from objects with a high temperature to an object with a low temperature. So, there is heat transfer, because of the temperature difference.

      To measure temperature, a thermometer is used, but this tool cannot measure the amount of heat. Because the amount of this heat depends on the temperature, it also depends on the weight and specific heat of the object.

2. Types of Steam.

   Seen by whether the steam still contains water or not, the steam is divided into 2 types, namely:

   a. Wet steam is steam with steam grains containing several percent of water.
   b. Dry steam is steam that does not contain water droplets.

      Dry steam can be divided into 2 more, namely:

      1) Saturated steam, is the steam with the highest pressure at a certain temperature.
      2) Superheated Steam, is steam with a maximum temperature where the pressure is not proportional to its temperature, or steam whose temperature is higher than the temperature of full steam at the same pressure.

      To quickly find out the type of steam produced from a steam boiler, you can use a table called the Mollier Diagram.

3. Steam Quality.

   To ensure equipment reliability and efficiency in the operation of steam aircraft, especially steam turbines, the quality of water and steam must be available at the point of use such as:

   a. An appropriate amount to ensure that adequate heat flow is available for heat transfer.
   b. At the correct temperature and pressure, or will affect performance.
   c. Clear from air and condensable gases that can impede heat transfer.
   d. Clean, as scale (e.g., rust or carbonate deposits) or dirt can increase the rate of erosion of pipe bends and small orifices of steam traps and valves.

e. Dry, the presence of water droplets in the steam will reduce the actual enthalpy, and will also result in the formation of scale on the pipe walls and heat transfer surfaces.
f. As a tool to determine the state level in a cycle, phase diagrams and steam tables can be used, both in manual form and in software form.

3.5. Enthalpy of Steam on HS Diagram

Enthalpy is a term in thermodynamics that expresses the amount of energy of a substance. Enthalpy consists of the internal energy of the system, including one of the five thermodynamic potentials and functions, as well as volume and pressure. The SI unit of enthalpy is the joule, but British thermal units and calories are also used. Since it is a thermodynamic potential, then to measure the enthalpy of a system, you must determine the reference point first, then you can measure the enthalpy change ΔH. The change in ΔH is positive for an endothermic reaction and negative for an exothermic reaction.

The properties as reviewed lead to conclusions about the various conditions that occur in the water-steam cycle. The results of these experiments are published in the form of thermodynamic tables regarding changes in the properties of water (Mollier Diagram / HS Diagram). The table is divided into two main sections, where the first section shows the properties of water and saturated steam and the other part shows the properties of superheated steam.

The symbols used in the table showing the various properties of water and steam and the descriptions associated with them. The meanings of these symbols are as follows:

P : absolute pressure (bar)

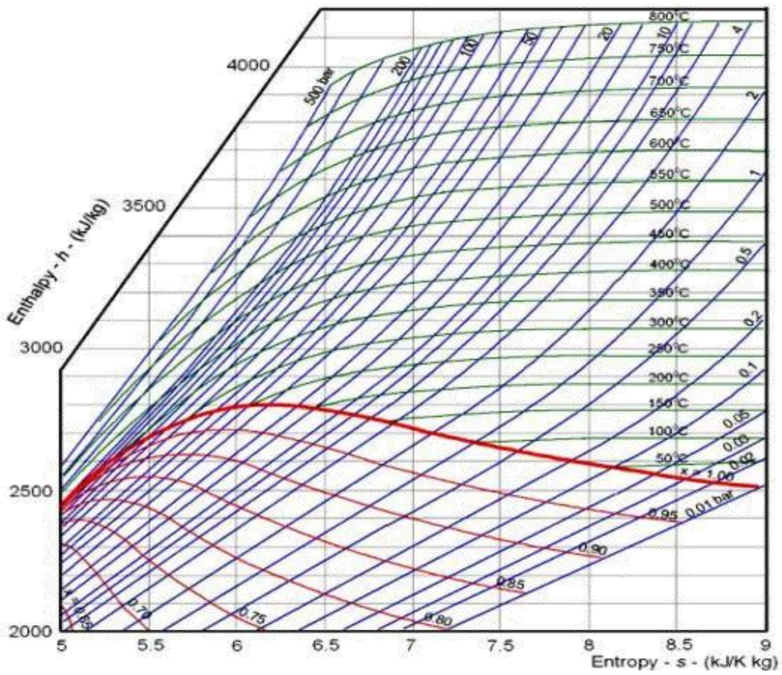
t : temperature (^{0}C)

h : enthalpy or total heat (kJ/kg)

v : specific volume (m^3/kg)

Dryness Fraction (within the saturated zone)

Entropy (kj/kg ^{0}C)



Source:http://fitbirmarket.ru/steam-table-and-mollier-diagram

Figure 10. Mollier Diagram

How to use HS Diagram.

1. Knowing only two definite values can be used to find all the other values.
2. In other words, to find out the value of Enthalpy and Entropy, it is preceded by knowing the Temperature and Pressure or Internal Energy of the steam.
3. The Mollier (or h-s) diagram Enthalpy is formed with a vertical line and Entropy is formed with a horizontal line and other values form a line/curve like the diagram below.
   a. The green line indicates the steam temperature.
   b. The blue line indicates the absolute pressure of the steam.
   c. The red line indicates the quality (dryness) of the steam.

Example 1: At a pressure of 30 bar (3 Mpa) and steam temperature of 400^0C, find:

1. Specific enthalpy of steam?
2. The specific entropy of steam?

Answer: These values can be searched directly from the steam table, which is at a pressure of 30 bar. (Table 3)

1. Specific enthalpy of steam (hs) = 2920 kj/kg
2. Specific steam entropy (ts) = 7.4 kJ/kg ^{0}C

3.6. Steam Saturation Table

Steam conditions as shown in pS can also be conveyed using the Steam Saturation Table. The properties as described above are based on experiments conducted over several years resulting in conclusions about the various conditions that occur in the water-steam cycle. The results of these experiments are published in the form of a thermodynamic table of changes in properties of water. The table is divided into two main sections, where the first section shows the properties of water and saturated steam while the other section shows the properties of superheated steam. The symbols used in the table showing the various properties of water and steam and the descriptions associated with them. The meanings of these symbols are as follows:

P : absolute pressure (bar)

t : temperature (^{0}C)

h : enthalpy or total heat (kJ/kg)

v : specific volume (m3/kg).

In addition, several subscripts are used, such as:

s : degree of saturation (ts is saturation temperature)

f : the saturation of water (h_f is the enthalpy of saturated water m when the water is at a saturated temperature) g : the nature of the gas/steam is saturated (h_g is the enthalpy of steam under saturated conditions).

fg : the degree of mixture, the change of water into steam or express latent heat (h_{fg} is the enthalpy required to change the water into a saturated steam).

Tabel 1. Steam Table.

Temp, T °C	Sat. Press., P_{sat} kPa	Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.00	2374.9	2374.9	0.00	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.02	2360.8	2381.8	21.02	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.228	0.001000	106.32	42.02	2346.6	2388.7	42.02	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.706	0.001001	77.885	62.98	2332.5	2395.5	62.98	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.339	0.001002	57.762	83.91	2318.4	2402.3	83.91	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.170	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.247	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.629	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.385	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.595	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.35	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.76	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.95	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.04	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	31.20	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	38.60	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
80	47.42	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
85	57.87	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
90	70.18	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
95	84.61	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
100	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470	7.3542
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
360	18666	0.001895	0.006950	1726.16	625.7	2351.9	1761.53	720.1	2481.6	3.9165	1.1373	5.0537
365	19822	0.002015	0.006009	1777.22	526.4	2303.6	1817.16	605.5	2422.7	4.0004	0.9489	4.9493
370	21044	0.002217	0.004953	1844.53	385.6	2230.1	1891.19	443.1	2334.3	4.1119	0.6890	4.8009

CHAPTER IV. STEAM TURBINE CONSTRUCTION

4.1. Introduction

Steam turbine is a force converting the potential energy of steam into kinetic energy and then converted into mechanical energy in the form of rotation of the turbine shaft. The turbine shaft directly or with the aid of a reduction gear, is connected with a mechanism that will be driven in the industrial sector, for example for electrical and for transportation. The process of converting potential energy into mechanical energy in the form of shaft rotation is carried out in various stages.

Basically, a steam turbine consists of two main parts, namely the stator and rotor which are the main components of the turbine and then added other components that support its work such as bearings, couplings, blind pistons and other auxiliary systems. A steam turbine utilizes the kinetic energy of the working fluid which is increased by the addition of thermal energy.

One of the uses of a steam turbine is to force a generator which is used to generate electricity. Steam power serves to convert heat energy from water steam into electrical energy. The process of heat energy indicated by a temperature gradient/ change is converted by a turbine jet into kinetic energy and the turbine blades convert this kinetic energy into mechanical energy in the shaft. In the end, the generator converts mechanical energy into electrical energy. The heat from the water steam, which is not converted into mechanical energy, is dissipated in the condenser by the cooling water. On other occasions, when used as a ship propulsion, the temperature change is also converted by a turbine jet into kinetic energy and the turbine blades convert this kinetic energy into mechanical energy on the shaft as a propulsion ship propeller.

Steam turbines used in the industrial world include the multistage type (pressure level), namely a steam turbine consisting of more than 1 turbine stage in the form of a High-Pressure Turbine/ HP (High Pressure Turbine/TT), Intermediate Pressure/IP (Pressure Turbine). Medium/ TM), and Low-Pressure LP (Low Pressure Turbine/TR)). The superheater steam (further heat) produced by the boiler enters the High Pressure (HP) turbine and exits the exhaust side to the boiler again for the reheater process to be reheated and then this is fed back to the Intermediate Pressure (IP) steam turbine. The steam coming out of the IP turbine goes directly to the Low Pressure (LP) Turbine. The steam coming out of the LP turbine enters the condenser to undergo a condensation process.

4.2. Steam Turbine Components

In general, a steam turbine consists of a turbine housing, road wheels, turbine blades, pipe/nozzles and so on. The description of each of these equipment is as follows:

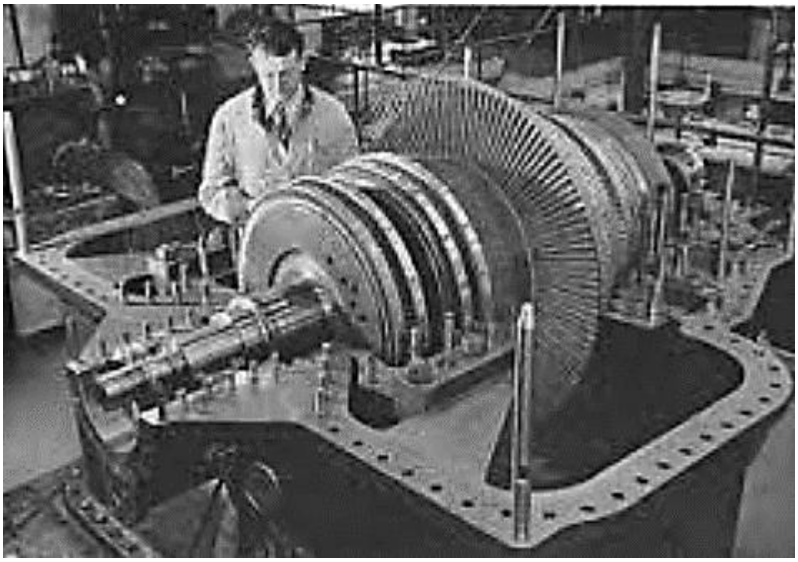


Figure 11. Steam turbine (Shin Nippon Machinery).

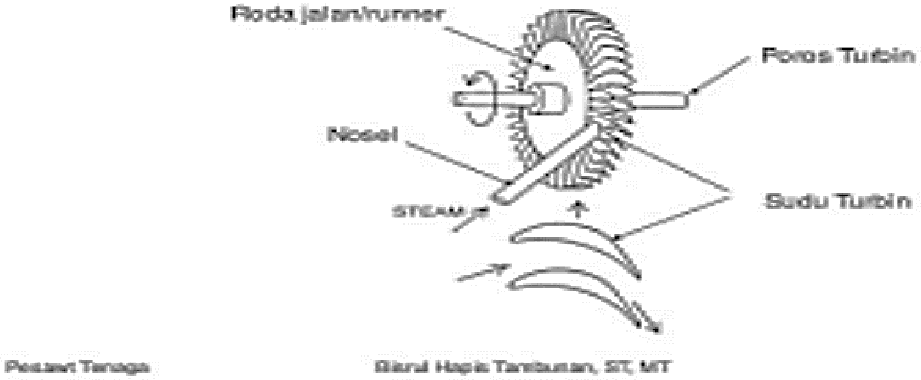


Figure 12. Part of Steam Turbine.

4.2.1. Turbine Casing

The turbine housing is usually a conch or spiral shape which serves to direct the inflow of the guide blades. The turbine housing material is made of metal which is made impermeable to outside air. Steam from the boiler with a certain pressure and temperature, is distributed around the jet blade mounted on the turbine housing and serves as a guiding mechanism. The turbine housing is designed so that the steam enters the flue blade at a uniform speed. In general, there are two types of turbines according to the steam pressure that works in the turbine, namely the High-Pressure Turbine and the Low-Pressure Turbine. Between the two turbines there is no significant difference among the turbine housings of the turbines.

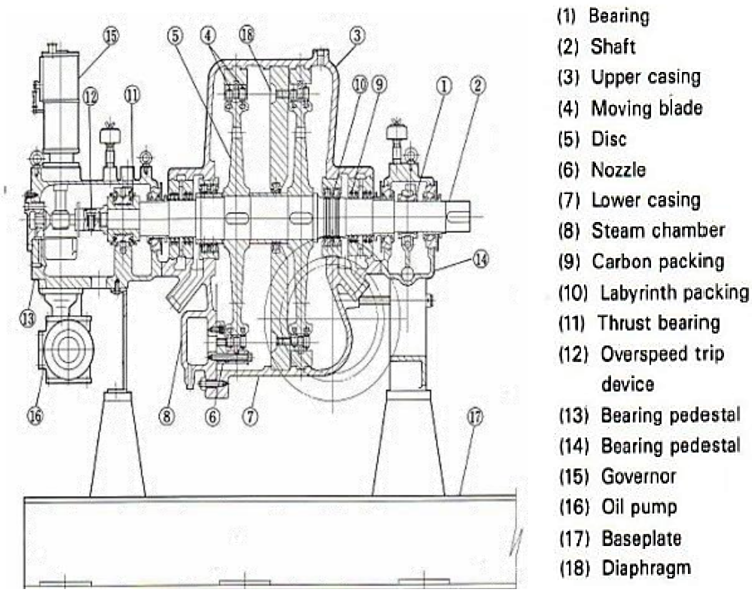


Figure 13. Steam Turbine Construction

4.2.2. Turbine Rotor

The turbine rotor is a solid round disc mounted on a shaft around which the road blades are attached. The wheels on action turbines have holes that serve as pressure leveling holes. In impulse/ reaction turbine, there are more than one wheel, and between the wheels there is a reversing blade attached to the turbine housing.

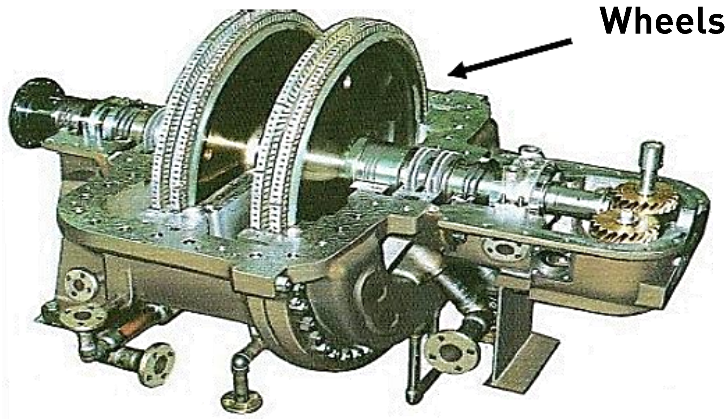


Figure 14. Impulse Turbine 2 rotors 4 stages (Shin Nippon).

Figure 15. Example of a reaction steam turbine rotor.

4.2.3. Rotor and Stator Blades (Road and Transmitter Blades)

The rotor blades or road blades are parts of the turbine attached to the road wheels. This blade functions to receive the speed power given by the steam converted into mechanical power at the turbine running wheel.

The Stator Blades/Emitting Blades are turbine parts attached to the turbine housing. The nozzle serves to convert the kinetic energy of the steam into steam velocity power.

In the reaction turbine, there is a jet blade located between the two road blades which also functions as a reversal of the direction of the steam. In some steam turbines, it is possible that the road and jet blades can be damaged and can be replaced with new blades.

Figure 16. Steam Turbine Rotor and Stator Blades (Stork,Holland).

4.3.4. Shaft Seals (Shaft Packing)

Shaft seals are part of the turbine between the shaft and the casing which functions to prevent water steam from leaving the turbine through the gaps between the shaft and the casing due to pressure differences and also to prevent air from entering the turbine (especially LP turbines because of water steam pressure more vacuum) while the steam turbine is operating.

The steam turbine uses a labyrinth seal system for shaft seals. This system is in the form of a winding part on the shaft and the casing whose two sides meet each other alternately. Between the shaft labyrinth and the casing labyrinth, there are a few cavities with a certain distance. This system aims to reduce the pressure of water steam in the turbine that enters the sidelines of the labyrinth so that the pressure between the water steam and the outside air will reach the same value at a certain point. In addition to the labyrinth seal system, there is an additional system called the seal & steam gland system. This system is in charge of maintaining the pressure in the labyrinth seal at a certain value, especially during the initial start up or shut down of the turbine where at that time there is no water steam entering the steam turbine.

Figure 17. Turbine Labyrinth

4.3.5. Turbine Bearings

Bearings on steam turbines have the following functions:

1. Hold Axial restraint of rotor components.
2. Hold the weight of the rotor.
3. Hold a variety of unstable forces from water steam to the turbine blades.
4. Hold to kinetic force due to residual imbalance or imbalance due to blade damage (anticipation).
5. Hold axial forces under varying electrical loads.

The types of bearings used in the design of steam turbines are thrust bearings, journal bearings, and a combination of them. In addition, a lubrication system using oil is needed, which is continuously circulated and cooled to lubricate the bearings that continue to experience friction during the steam turbine operation normally.

4.3.6. Balance Piston/Blind Piston

In a steam turbine, there is a 50% reaction force from the rotating blades producing an axial force against the rear side of the turbine's first cylinder, this force needs to be resisted by the balance piston system.

4.3.7. Turbine Stop Valves

Turbine Stop Valves is also called as Emergency Stop Valve because the function is to isolate the turbine from the steam supply in an emergency to avoid damage or also overspeed.

4.3.8. Turbine Control Valve

The function is to control the supply of water steam that enters the turbine in accordance with a control system depends on the amount of electrical load.

4.3.9. Turning Device

Turning device is a mechanism to spin the rotor of the turbine at the time of initial start or at the time after shut down to prevent distortion/ bending due to the heating or cooling process that is not match with the rotor.

4.4. Working Principle of Steam Turbine

The steam turbine consists of a disc surrounded by disc blades called the blades. These blades rotate due to the blowing of pressurized steam coming from the steam boiler, which has been preheated using solid fuel, liquid and gas. The steam is then divided using a control valve which will be used to rotate the turbine which is coupled directly to the pump and also coupled to a synchronous generator to produce electrical energy.

After passing through the steam turbine, the high-pressure and high-temperature steam appears to be low-pressure steam. The heat has been absorbed by the condenser causes the steam to turn into water then pumped back into the boiler. The remaining heat removed by the condenser reaches half the amount of the original heat entered. This results in the thermodynamic efficiency of the steam turbine being less than 50%. Modern steam turbines have a boiler temperature of about 500^0C to 600^0C and a condenser temperature of 20^0C to 30^0C.

In general, the working principle of a steam turbine is to receive kinetic energy from superheated steam (dry steam) released by the nozzle so that the turbine blades are pushed angularly or move around. The following explains the working principle:

1. Steam enters the turbine through the nozzle. In the nozzle, the heat energy from the steam is converted into kinetic energy and the steam expands.
2. The steam pressure when it comes out of the nozzle is smaller than when it enters the nozzle, but on the other hand the speed of steam leaving the nozzle is greater than when it enters the nozzle. The steam gushing out of the nozzle is directed to the turbine blades which are curved in shape and mounted on the turbine wheel. The steam flowing through the gaps between the turbine blades is deflected in the direction following the curvature of the turbine blades. This change in steam creates a force that pushes and then turns the turbine wheels and shaft.
3. If the steam still has speed when leaving the turbine blades, it means that only part of the kinetic energy of the steam is taken up by the turbine blades running. So that the remaining kinetic energy when leaving the turbine blades is utilized, more than one row of motion blades is installed in the turbine. Before entering the second row of moving blades. So, between the first row and the second row of moving blades, a row of guide blades is installed which is useful for changing the direction of the steam speed, so that the steam can enter the second row of moving blades in the right direction.
4. The speed of the steam when it leaves the last moving blade must be as small as possible so that the available kinetic energy can be utilized as much as possible. Thus, the turbine efficiency becomes higher because the energy loss is relatively small.

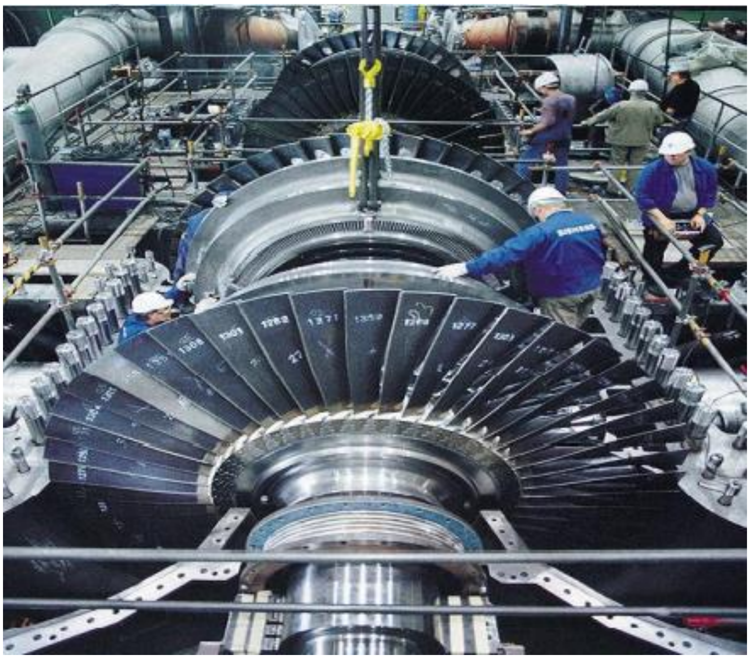


Figure 18. Steam turbine in construction.

4.5. Steam Turbine Classification

1. Turbine Classification based on Working Principle (steam expansion).
   a. Impulse Turbine.

   An impulse turbine or impulse stage turbine is a simple one or many (combined) rotors turbine which have blades in the rotor. The blades are usually symmetrical and have an inlet and an outlet angle. Because there is no expansion in the moving blades, the turbine blade shape is symmetrical.

   Dry steam (superheated steam) is expanded at the nozzle so that the maximum potential energy is converted into maximum kinetic energy. This energy conversion is shown by the equation. This energy conversion is shown by the equation: C2 is equal to the root of 2 times h1 minus h2.

   $$C2 = \sqrt{2 * (h_1 - h_2)}$$

Where C2 is the absolute speed leaving the nozzle, while h1 is the enthalpy entering and h2 is the enthalpy leaving the nozzle. The high-speed gas hits the blades where most of the kinetic energy is converted into rotation of the turbine shaft. To obtain maximum energy transfer, the turbine blades must rotate 1.5 times the speed of the dry steam jet.

Impulse turbines can be simple (single-stage) impulse turbines, multistage speed impulse turbines (curtis turbines), or multistage pressure impulse turbine (rateau turbine). The state of the steam flow in the turbine can be explained using a graph of absolute pressure and speed.

The steam velocity increases because the nozzle functions to increase the steam velocity, then the steam flows into the row of blades at constant pressure. But the absolute speed decreases because the kinetic energy of the steam is converted into work turning the turbine wheels. The steam leaving the turbine is still at high speed, so it still contains high energy or the energy loss is still too large.

To prevent too much energy loss, the steam is expanded gradually in a double-stage turbine. With a double-story turbine, it is hoped that the energy absorption process (the process of converting thermal energy into mechanical work) can take place efficiently.

The change in absolute pressure and velocity of the steam in a graded speed impulse turbine (curtis turbine). The steam is only expanded in the nozzle (first row of fixed blades) and then the pressure is constant. However, the turbine is still in the category of impulse turbines because in the row of motion blades there is no expansion (pressure drop). Even though, the steam pressure inside the moving blades is constant, the absolute speed drops because some of the steam energy is converted into work turning the turbine wheels. The steam velocity in the next fixed blade does not increase because the pressure is constant.

The characteristics of the impulse turbine include:

1) The steam expansion process/ pressure drop entirely occurs at the nozzle.
2) Has the same average pressure in the turbine so it is called Average Pressure.

Other impulse turbines are as follows:

1) Single stage turbine.
2) Combined impulse turbine.
3) Combined speed impulse turbine.

b. Reaction Turbine.

A reaction turbine is a turbine with an expansion (pressure drop) process that occurs both in the row of fixed and moving blades, the thermal energy of the steam is converted into kinetic energy in the conducting and traveling blades, and then the reaction force from the steam will drive the blades for rotating. The reaction turbine is also called the Parsons turbine in accordance with the name of the first turbine maker, Sir Charles Parsons (Suyanto: 2010)

Reaction turbine, a turbine in which the working fluid expansion process occurs both at the nozzle and in the moving blades, the thermal energy of the steam is converted into kinetic energy in the conveying blades and the traveling blades, and then the reaction force of the steam will push the blades to rotate.

The reaction turbine has three stages, each consisting of a row of fixed blades and two rows of moving blades. The moving blade of the reaction turbine can be easily distinguished from the impulse blade because it is not symmetrical, because it functions as a nozzle in the same shape as the fixed blade even though the arc is in the opposite direction. A reckless/ multistage reaction turbine. Each level consists of a fixed nozzle and a moving nozzle. A pressure drop occurs in both nozzles. The reaction turbine is a multistage turbine with a fixed nozzle and a moving nozzle alternately. The pair of fixed nozzle and movable nozzle is called one stage. Like impulse turbines, reckless reaction turbines can operate at low blade speeds to produce maximum power.

The characteristics of the reaction turbine are:

1) Partial decrease in steam pressure occurs in the nozzle and blades.
2) There is a pressure difference inside the turbine so it is called graded pressure.

An example of a reaction turbine (hero turbine).

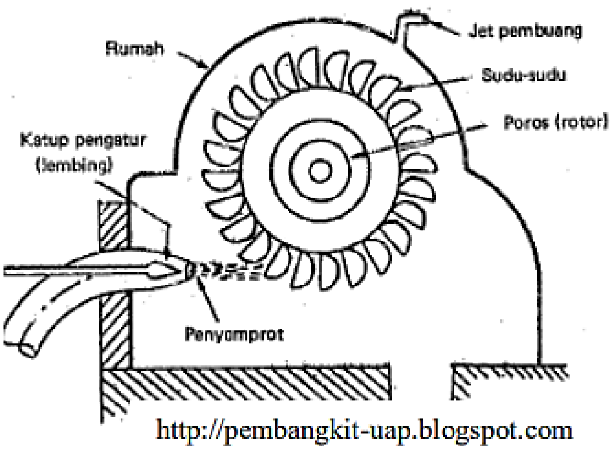


Figure 19. Reaction Turbine.

2. Classification of steam turbines based on the degree of drop pressure in the turbine.
   a. Single Stage

   Steam from the nozzle will push the blades continuously, causing the turbine wheel to rotate. The expansion of steam through the nozzle converts the enthalpy thermal energy into mechanical energy or high speed. The velocity of the steam is expanded to the blade.

The combination of a nozzle and a moving blade in the simplest turbine is a single-stage turbine. Single-stage turbines are used for special needs and can be identified by the steam escaping which still has a lot of energy. With a speed of one or more stages, this turbine is suitable for small power, e.g., compressor drive, blower, etc.

b. Multistage Turbine (Action and Reaction)

Here the turbine blades are made in stages, usually suitable for large power. In a multistage turbine, there are rows of 2 or more blades. So that the turbine speed/ pressure distribution occurs.

In a turbine with 3 stages, for example, it consists of 3 motion blades located on the shaft. Steam from the nozzle hits the blades will drive the rotating shaft. When the steam passes through the first nozzle, the steam velocity will increase, and the steam pressure will decrease. A decrease in pressure will be followed by an increase in the specific volume of steam. The steam expands some of the energy into the blade and leaves the first nozzle, and enters the second nozzle, where the steam expands some of the energy again. The energy is expanded at the 2nd and 3rd stages. After the steam passes through the 3rd stage, where the steam provides its energy to produce motion, the steam will leave the turbine as steam to the outside. The size of the blade of each stage will be larger than the previous stage as the specific volume of steam increases.

There is little loss/energy loss when the steam passes through the nozzle. The energy conversion process occurs in the nozzle, where the internal energy (pressure) of steam is converted into kinetic energy (velocity). The nozzle must be designed with a smooth narrowing of the steam flow area.

Then the steam will accelerate through the nozzle due to the narrowing of the flow area and will leave the nozzle with a high steam velocity. Then, the steam will hit the moving blade, where the blade is designed to take energy from the high steam velocity.

The moving blades will cause a change in the steam velocity when the steam passes through the blade, which results in the transfer of energy from the blade steam, namely in the form of a high steam velocity. When steam hits the blade, the steam exerts its force and energy on the blade, in the form of a change in momentum, which speed up the moving blade.

In the turbine process, thermal energy becomes mechanical energy, there are 2 transformations of main energy, namely;

1) The first energy transformation is a thermodynamic process, in which thermal energy is converted to kinetic energy, which results in high steam velocity and change in momentum.
2) The second energy transformation is a mechanical process, in which steam impinges on the moving blades, imparting momentum thereby turning the turbine shaft.

3. Classification of turbines based on the direction of steam flow.

As explained above, one of the characteristics of turbines can be distinguished based on the direction of steam flow, namely axial turbines, radial turbines, and helical turbines. In general, the direction of steam flow is determined by the relative positions of the nozzles, diaphragms, fixed blades and moving blades.

a. Axial turbine.

An axial turbine is a turbine in which the steam flows parallel to the turbine axis (shaft). In the expansion process, this turbine can be divided into impulse turbines and reaction turbines.

b. Radial turbine

A radial turbine is a turbine where the steam flows perpendicular to the turbine axis (shaft).

c. Helical turbine

A helical turbine is a turbine in which the steam flows tangentially to the rotor circle and collides with the moving blades. The blades are shaped in such a way that the direction of the steam flow reverses at each blade. Some of the helical turbines are used for steam recovery, where the steam coming out of the blades will be returned to hit the moving blades through the channels in the turbine, this will expand the steam energy more.

Besides the division of steam boilers based on steam flow whether single flow or double flow, there is a division of steam turbines based on steam flow, namely flow in one direction or two directions.

a. Single steam flow: Steam enters the turbine inlet and flows one way through the blades in an axial direction and exits the turbine.
b. Dual steam flow: Steam enters through the center of the turbine and flows through the blades towards each end of the shaft and exits through the exhaust chambers. The advantage of double steam flow is that the blades will be shorter compared to single steam flow at the same capacity and reduce axial thrust.

Meanwhile, based on the application in use, the steam turbines can be classified into three main types, namely:

a. Turbine generator, which is operated in industrial and thermal.
b. Mechanical turbine, which is operated to drive: compressor, pump, blower.
c. Marine turbine, which is operated to move the ship's propeller, and ship equipment.

The main differences between mechanical turbines and other turbines are:

a. Spins vary between (80% Sid 105%) of normal design rounds.
b. Differences in turbine output characteristics.
c. High rotation according to fire standards (American petroleum institute).

4. Classification of turbines based on Vapor Pressure Reduction Process.
   a. Condensing Turbine.

      Condensing turbines are used when all the steam energy is used to generate power. The steam coming out of the turbine is condensed in a condenser, to get a low enough counter pressure, resulting in high power. Then the condensed water can be recirculated back into the boiler. Condensing turbine also called direct condensing turbine. The turbine outlet pressure is less than 1 atm and is fed into the compressor.

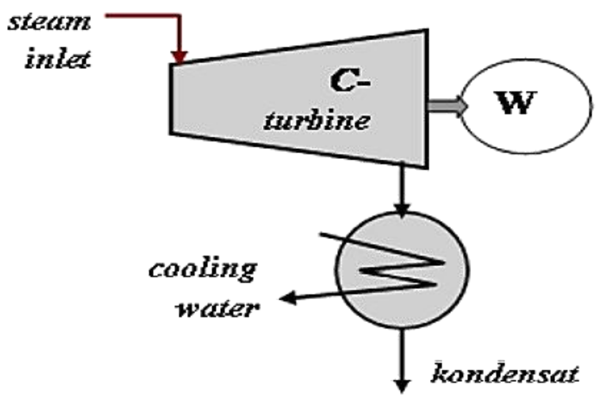
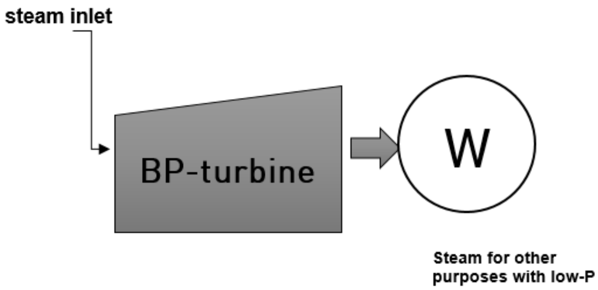


Figure 20. Illustrated Turbine Condensing (JP. Holman).

   b. Counter Pressure Turbine.

      Counter pressure turbines are used when an industry (factory) requires the use of multiple steam, namely as a potential energy source and at the same time as an energy source for processing purposes. The steam pressure leaving the turbine pressure (counter pressure) is adjusted according to the processing steam pressure.

Thus, the pressure and temperature of the steam from the boiler must be adjusted based on the pressure, the temperature of the processing steam and the power produced, the efficiency and consumption of steam for the turbine.



Source: http://pembangkit-uap.blogspot.com

Figure 21. Counter pressure turbine illustration.

Counterpressure turbine power is generated by the expansion of steam from the economic initial pressure down to the heating pressure. The layout of steam installation for counter pressure turbine. Steam comes out is still relatively high pressure. If the turbine exit pressure is still greater than 1 atm so that it can still be used to drive other turbines. This type of turbine is widely used in a chemical factory.

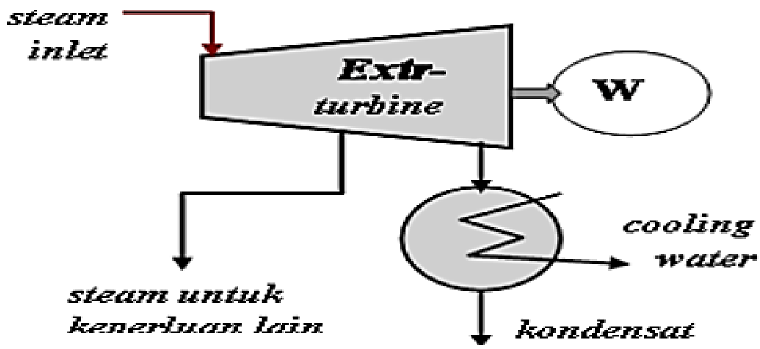
c. Extraction Turbine.

Extraction turbines are divided into two types, namely:

1) Condensation extraction turbine.
2) Counter pressure extraction turbine.

Condensation extraction turbine, operating with dual steam usage, i.e., for power generation (power supply), and also for supplying steam for extraction purposes. If there is no need for steam for extraction, then the turbine will work as a direct condensing turbine. Condensation extraction turbine.

In this turbine, some of the steam in the turbine is extracted for other heating processes, for example industrial processes.



source: http://pembangkit-uap.blogspot.com

Figure 22. Extraction Turbine, (JP. Holman).

Condensation extraction turbines are found in several industries, where low-pressure steam is used for various processing, and high-pressure steam as the primary mover for power generation. The turbine is also called a steam turbine with premature discharge as shown in figure 24 below.

A turbine with the pass out turbine consists of two parts, namely high-pressure turbine (TTT) and low-pressure turbine (TTR), with dual steam functions, namely: for processing and power generation purposes. Some of the steam from the high-pressure turbine (TTT) is removed for processing needs. The rest goes to TTR, expanding the turbine which will generate power to drive the load.

The steam from the processing and the steam from the TTR is introduced into the condenser, which then produces condensate water. Condensate water can be used as boiler feed water.

4.6. Losses In Turbine

1. Disadvantages in one stag turbine:
   a. Nozzle reheat is a loss when steam is expanded at the nozzle irreversibly adiabatically and results in an increase in steam

temperature (relative to temperature if steam is expanded isentropic).

b. Blade reheat is the frictional losses of the steam flow when it passes through the moving blades.

c. Windage losses are friction losses when steam leaves the blades.

d. Stage reheat is the sum of all losses in one expansion stage.

2. Disadvantages in multistage turbines.

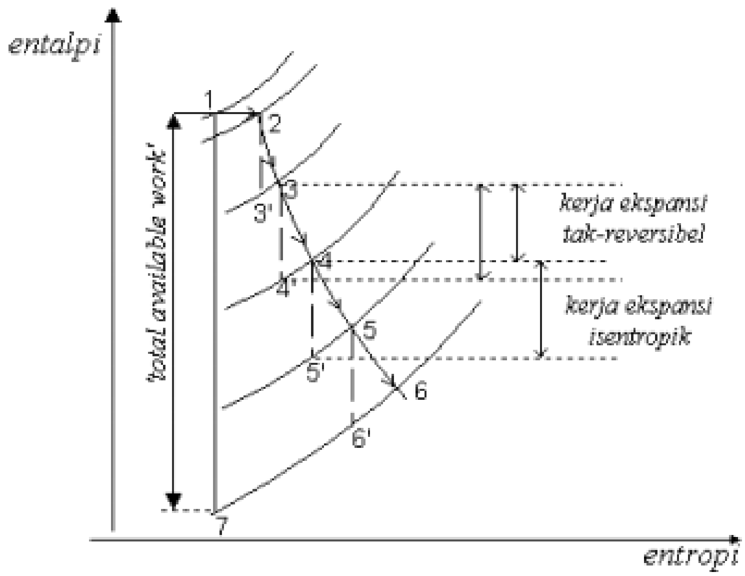


Figure 23. Diagram of Enthalpy and Entropy.

Reheat factor:

$$R = \frac{\sum(h_i - h_{i+s})}{(h_2 - h_7)} \geq 1$$

The isentropic efficiency of a multi-stage turbine is delivered in the following table.

Table 2. The isentropic efficiency.

Turbine Type	**HP Capacity**	**Efficiency %**	**Steam rate Kg/kWh**
1 Level	500	30	11.4
5 Levels	1000	55	6.30
7 Levels	4000	65	5.30
9 Levels	10000	75	4.54

$$\pi = \frac{\sum(h_i - h_{i+s})}{(h_2 - h_7)}$$

Explanation:

a. Steam power generation system is a steam generation system with superheated vapor potential energy.

b. One of the main components in the generation of steam power is a steam turbine.

c. The classification of steam turbines is based on steam flow, working principle, the process of reducing pressure in the turbine, reducing steam pressure.

d. The turbine functions in receiving shocks and suffering from force loads from the nozzle which kinetic dry steam before entering the nozzle, it has potential energy.

e. In the use of turbines, there are losses so that it reduces the isentropic efficiency.

CHAPTER V.
DE LAVAL TURBINE

In 1890, a Swedish engineer, **Gustav de Laval**, made a single stage turbine, with a capacity of 5 hp. The success of this turbine came from an early experiment in 1870. From seeing the reaction of the Hero machine, he saw the power created by the transmitter pipe. The first application of the invention is used not for steam turbines but for drying sand. The steam expansion device uses a nozzle connected to a centrifugal separator. The results of this invention produce a turbine that rotates at a speed of 40,000 revolutions per minute.

In industry, de Laval turbines are widely used to drive generators.

5.1. Characteristics of the de Laval Turbine:

1. It Is an action turbine:

   Action Turbine is a turbine in which the work generated is derived from the action forces performed by the blade paths.

2. Flat pressure turbine is the steam pressure before and after the blades is the same. The same steam pressure is because in the de Laval turbine road wheels there are pressure leveling holes that connecting the front and rear sides of the turbine.

3. Consists of 1 level of pressure where one unit of the nozzle is followed by a level/ series of blade paths. Pressure level is a pipe where there is a change in heat energy into velocity energy. Speed level is the blade path, where the velocity energy is converted into mechanical energy.

4. The shape of the jet blades and the traveling blades are symmetrical. The axis of the blade divides the blade shape into two equal parts.
5. Smoothing of the blade is less than 100%, it means the spraying of the blade by steam from the nozzle is not carried out at the same time.

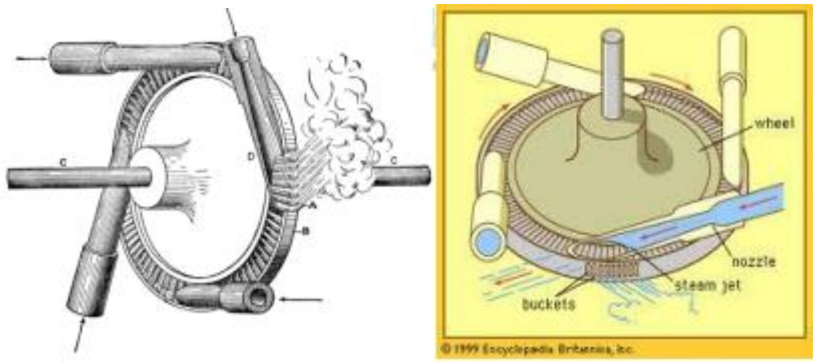


Figure 24. Construction of the de Laval Turbine.

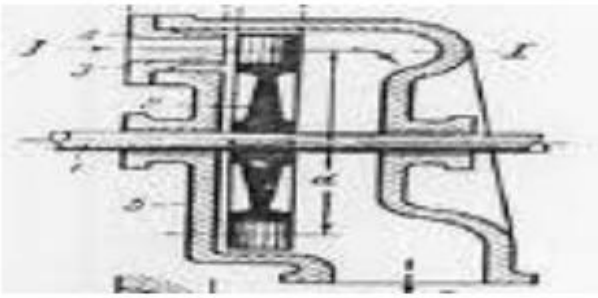


Figure 25. Cross Section.

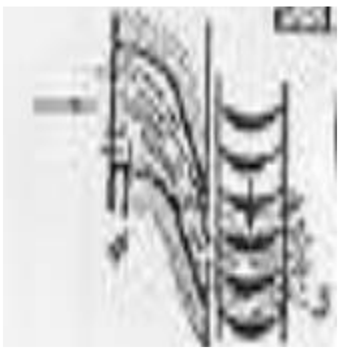


Figure 26. Emitting Blades & Traveling Blades.

Figure 27. Changes in Enthalpy and Vapor Pressure.

5.2. Speed Triangle

The speed triangle is a triangle with sides that describe the changes in the speeds occurred in a steam turbine, namely the change in steam velocity energy into mechanical power in the form of rotational speed on the turbine shaft. The speed triangle of the steam turbine consists of the absolute steam velocity of the traveling blades symbolized by "C", the relative steam velocity of the blades symbolized by "W" and the circumference of the blades symbolized by "U".

Speed Triangle:

1. Absolute steam velocity of the blade (C): m/s.
2. Relative steam velocity of the blade (W): m/s.
3. Speed around the blade (U): m/s.

The speed around the blade (U) is dependent on the diameter and RPM of the blade, with the following formula:

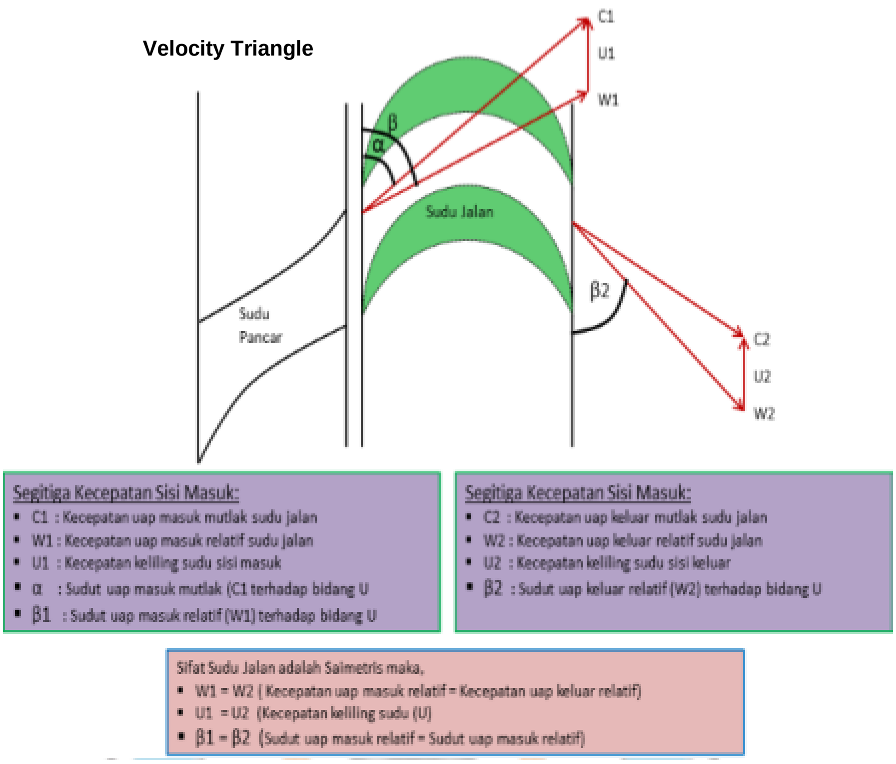
$$U = \frac{\Pi . D . n}{60} \quad m/dt$$

U = Speed around the blade (U)

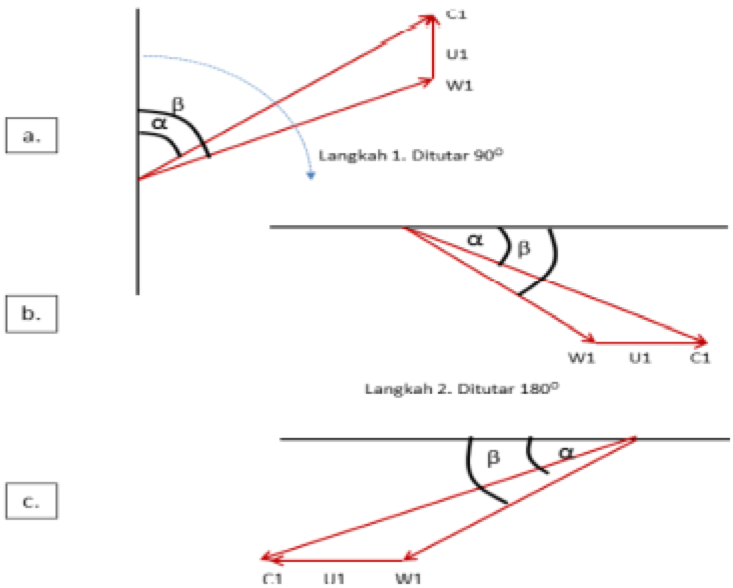
π = phi = 3.14

D = average diameter of the wheel/blade road (m)

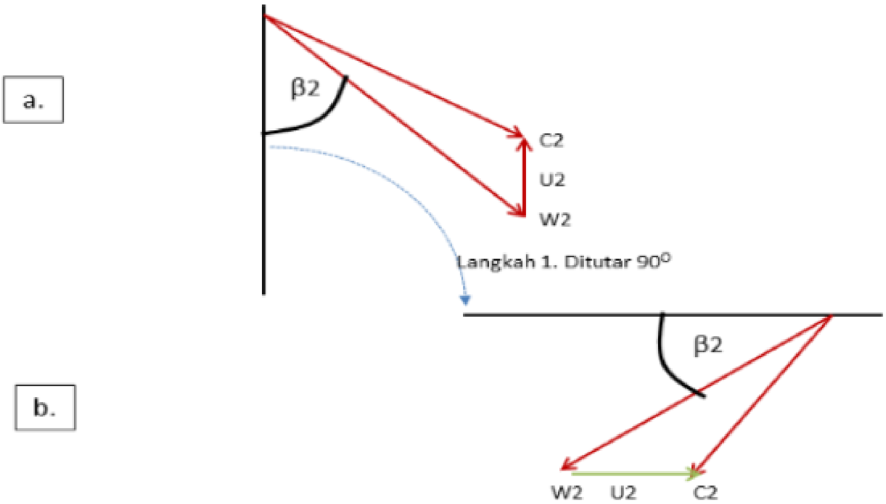
n = wheel rotation per minute (RPM)



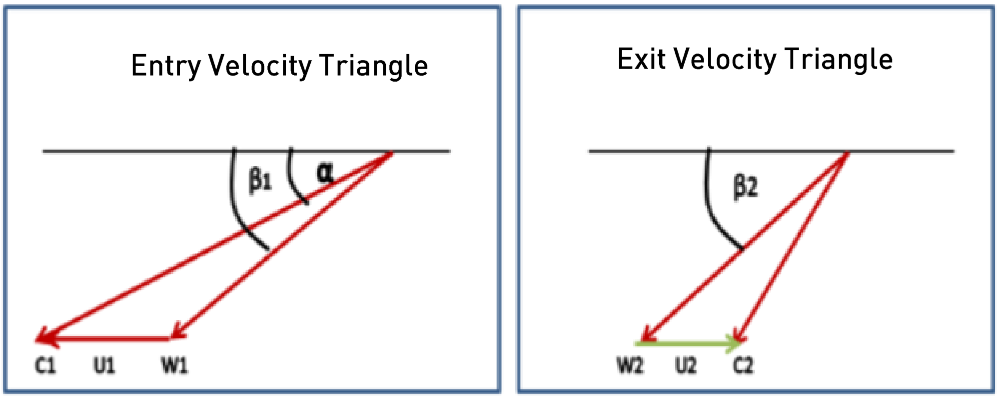
1. Illustration of the Entry Velocity Triangle:



2. Illustration of the Exit Velocity Triangle:

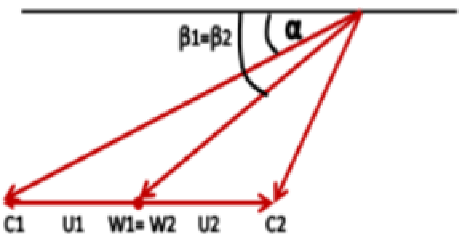


3. Combination of Entry and Exit Velocity Triangle.



From the two triangles obtained: W1 = W2 and $\beta 1 = \beta 2$ so both can be combined

Combination of Entry and Exit Velocity Triangle



5.3. Zeuner formula (Technical/International System)

As understood in the steam turbine, it is changing potential energy into kinetic energy (speed energy) and then kinetic energy is converted into mechanical energy. The change of potential into kinetic energy (velocity power) was conveyed by Zeuner with the following logic:

The heat contained in the steam (potential energy) is converted into kinetic energy (velocity energy) and velocity energy is half of the mass times the square of the velocity of a substance (steam).

Potential Energy	∞	½ . Mass . Velocity^2
h1 – h2 (Kj)	∞	½ . m . C1^2 (Kgf . m)
Ho (Kj)	∞	½ . G/g . C1^2 (Kgf . m)
2 . Ho	∞	G/g . C1^2

Kgf .m^2 / dt^2 = Kgf . m

m/dt^2

Note: 1Kj = 1000/g Kgfm

2 . Ho 1000/g (Kgfm)	∞	G/g . C_1^2 (Kgf. m)
2 . Ho 1000	∞	G.C_1^2 **Note**: G = 1 kg of steam
C1^2	=	2000 Ho
C1	=	v 2000 Ho

C1 = 44.7 v Ho (m/sec)

5.4. Blades (ηs)

The efficiency of the blade (ηs) is the ratio between the work flow/ velocity of the useful steam in the blade with the work flow/ velocity given in the blade. The work flow/ velocity of the steam is proportional to ½ x mass of steam and the square of the velocity of the steam.

work flow/ steam velocity = ½ steam mass x square of the velocity of the steam.
= ½ x m x C^2

$$\eta s = \frac{\text{the work } flow \text{ velocity of the useful steam in the blade}}{\text{the work } flow \text{ velocity of the useful steam in the blade}} \; x\ 100\%$$

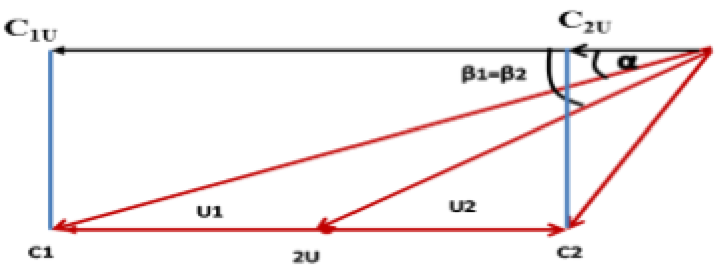
$$\eta s = \frac{\text{the work } flow \text{ velocity given in the blade} - \text{Wasted velocity effort on the blade}}{\text{the work } flow \text{ velocity given in the blade}} \text{ x } 100\%$$

$$\eta s = \frac{½ \text{ x m x } C_1^2 \text{ x m x } C_2^2}{½ \text{ x m x } C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{\cancel{½ \text{ x m}}\,(C_1^2 - C_2^2)}{½ \text{ x m x } C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{C_1^2 - C_2^2}{C_1^2} \text{ x } 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

5.5. Combined Side In and Out Velocity Triangle



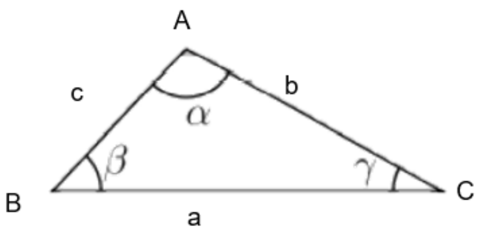
Note: U1 = U2

The Law of Cosines in Any Triangle

$$C_2^2 = C_1^2 + (2U)^2 - 2\,C1\,.\,2U * Cos\ \alpha$$

Notes:

1. Law of Cosine An arbitrary triangle is also called the Law of cosine, in trigonometry is a law that gives the relationship that applies in a triangle, namely between the lengths of the sides of the triangle and the cosine of one of the angles in the triangle.
2. Look at the triangle image below:



The law of cosine states that with is the angle formed by side a and side b, and c is the side opposite the angle.

The same law applies to sides a and b:

$$c^2 = a^2 + b^2 - 2ab\cos\gamma$$

$$a^2 = b^2 + c^2 - 2bc\cos\alpha$$

$$b^2 = a^2 + c^2 - 2ac\cos\beta$$

$$\eta s = \frac{C_1^2 - C_2^2}{C_1^2} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\eta s = \frac{C_1^2 - (C_1^2 + (2U)^2 - 2\,C1.\,2U.\,\mathrm{Cos}\ \alpha)}{C_1^2} \times 100\%$$

$$\eta s = \frac{C_1^2 - C_1^2 - 4U^2 + 2\,C1.\,2U.\,\mathrm{Cos}\ \alpha}{C_1^2} \times 100\%$$

$$\eta s = \frac{\cancel{C_1^2} - \cancel{C_1^2} - 4U^2 + 2\,C1.\,2U.\,\mathrm{Cos}\ \alpha}{C_1^2} \times 100\%$$

$$\eta s = \frac{4\,C_1.U.\,\mathrm{Cos}\ \alpha - 4U^2}{C_1^2} \times 100\%$$

$$\eta s = \frac{4\,\cancel{C_1}\,U.\,\mathrm{Cos}\ \alpha}{C_1^{\cancel{2}}} - \frac{4U^2}{C_1^2} \times 100\%$$

$$\eta s = \frac{4\ U.\,\mathrm{Cos}\ \alpha}{C_1} - \frac{4U^2}{C_1^2} \times 100\%$$

$$\eta s = 4\left[\frac{U}{C_1}\right]\cos\alpha - 4\left[\frac{U}{C_1}\right]^2 \text{ x } 100\%$$

Note: This formula applies to turbines that work "Ordinary"

Or:

$$\eta s = \frac{\cancel{C_1^2} - \cancel{C_1^2} - 4U^2 + 2\,C1.2U.\cos\alpha}{C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{2\,C1.2U.\cos\alpha - 4U^2}{C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{2U(2.C1.\cos\alpha - 2U)}{C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{2U(2.C_{1U} - (C_{1U} - C_{2U}))}{C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{2U(2.C_{1U} - C_{1U} + C_{2U})}{C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{2U(C_{1U} + C_{2U})}{C_1^2} \text{ x } 100\%$$

$$\eta s = \frac{2U.\Sigma C_U}{C_1^2} \text{ x } 100\%$$

Catatan: $\Sigma C_U = C_{1U} + C_{2U}$

5.6. de Laval Turbine in Maximum Working/Best

In a turbine that working in maximum/works as well as possible, it means that the heat loss coming out of the turbine is the smallest. In other words, this can happen if C2 is perpendicular to the plane U ($C2 \perp U$). The following is an image of the Maximum Working Turbine of de Laval Speed Triangle.

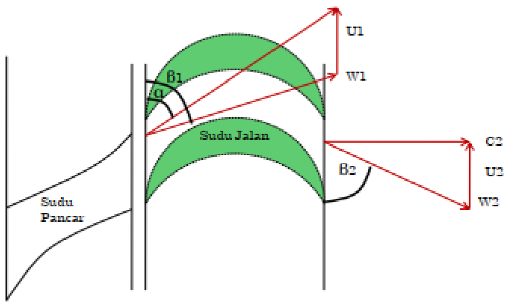
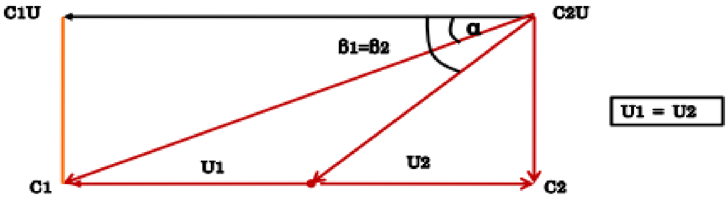


Figure 28. Maximum Working of de Laval Turbine in Velocity Triangle.



$$\cos\alpha = \frac{C_1U}{C_1} = \frac{2U}{C_1} \Rightarrow \frac{U}{C_1} = \frac{\cos\alpha}{2}$$

$$\eta s_{biasa} = 4\left[\frac{U}{C_1}\right]\cos\alpha - 4\left[\frac{U}{C_1}\right]^2 \times 100\%$$

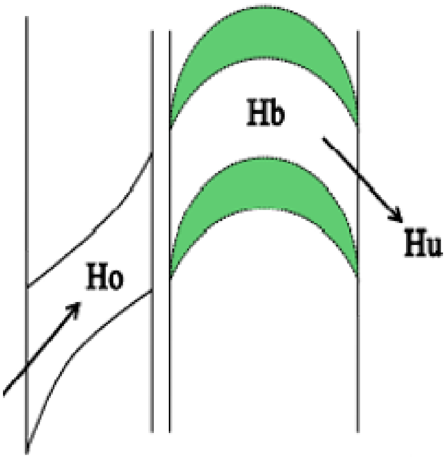
The formula for the turbine blade at maximum working is as follows:

$$\eta s_{max} = 4\left[\frac{\cos\alpha}{2}\right]\cos\alpha - 4\left[\frac{\cos\alpha}{2}\right]^2 \times 100\%$$

$$\eta s_{max} = 2\cos^2\alpha - \cos^2\alpha \times 100\%$$

$$\eta s_{max} = \cos^2\alpha \times 100\%$$

To get the turbine blade yield at maximum work, it can be done by calculating the useful heat with the heat given to the turbine as follows:



$$\eta s = \frac{\text{Useful heat}}{\text{given heat}} \times 100\%$$

$$\eta s = \frac{Hb}{Ho} \times 100\%$$

$$\eta s = \frac{Ho-Hu}{Ho} \times 100\%$$

$$\eta s = 1 - \frac{Ho-Hu}{Ho} \times 100\%$$

Figure 29. Maximum Working of de Laval Turbine Blade.

Note: This formula applies to running turbines and maximum working

5.7. Blade Shape (Symmetrical)

To give a good picture of the function of the blade, it can be done by describing the shape of the blade. The Action Turbine of blade are Symmetrical in shape. These blades have certain data that can be used as an aid to make a drawing of the shape of a blade.

Painting or making a symmetrical blade shape can be done by following these steps:

1. Knowing the specifications of the road blades, including:
   a. Width of blade = l (cm)
   b. Puncture distance = a (cm)
   c. Relative vapor angle = β^0
2. Taking the following steps for painting the blade:
   a. Make 2 parallel vertical lines that are "b" (width of the blade).
   b. Draw an axis between the parallel lines.
   c. Find the point A on the first parallel line & B on the second line where A & B are perpendicular to each other.
   d. Draw a line through points A&B that intersects the axis at point O at an angle of β^0 to the parallel line.
   e. From points A & B, draw a line perpendicular to the angle line β^0 that intersects the axis at point M.
   f. Draw arc AB with center M (arc AB is the blade chest)
   g. Make point C above A and point D above B with a distance of "a" (Stabilization distance).
   h. Draw a line through points C&D that intersects the axis at point P at an angle β^0 to the parallel line.
   i. From points C&D, draw a line perpendicular to the angle line β^0 which intersects the axis at point N.
   j. Draw an arc extending the lines AO & BO with the center point N (the drawn tangent is the blade ridge).

k. To draw the next blade can be started from point C & D in the same way as the previous step.

3. Figure of Symmetrical blade:

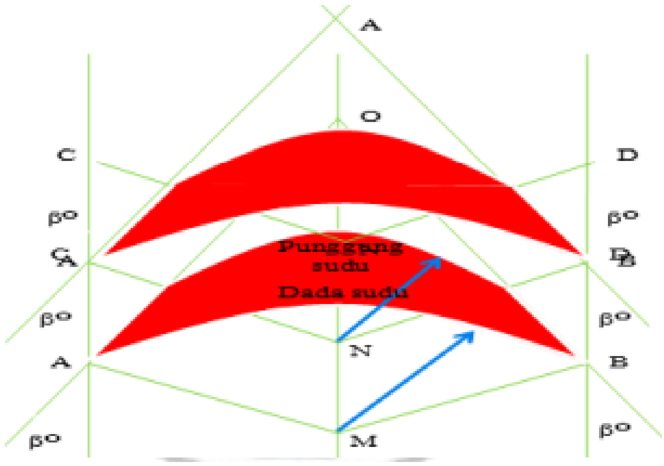


Figure 30. Symmetrical blade

5.8. Exercise

Example 1:

A steam turbine with a heat exhaustion that occurs in the blade is 760 KJ/kg. The turbine rotates 8600 RPM. If U:C_1 is 0.212 and the maximum blade is 78%. The Velocity Triangle of Steam Turbine is 35°. Calculate:

1. Velocity Triangle of Steam Turbine (m/s).
2. Blade at regular working turbine?
3. Circumference speed of wheels?

Known by: Steam Turbine

Ho	= 760 Kj/kg	
D	= 820 mm = 0.82 m	
n	= 860 rpm	
U/C1	= 0.212	
s max	= 78%	

Asked:

1. C1 = m/s
2. ηs ordinary = %
3. U1 = m/s
4. Figure of Triangle velocity (regular & max)

Answer:

1. C1 = 44.7√ Ho m/s

   = 44.7√ 760 m/s

   = 44.7 **x 27.57** m/s

   = 1232.3 m/s

2. ηs ordinary = %

   ηs ordinary $= 4 \left[\frac{U}{C_1}\right] \cos\alpha - 4 \left[\frac{U}{C_1}\right] x\ 100\%$

   η_{max} $= \cos^2 \alpha$ x 100%

   78% $= \cos^2 \alpha$ x 100%

   $\cos\alpha$ = 0.8832

   $= 4\ (0.212)\ 0.883 - 4\ (0.212)^2$ x 100%

   = 48%

3. Ho = h1 – h2 Kj/kg

   = 2950 – 2100 Kj/kg

   = 850 Kj/kg

4. U1 $= \frac{\pi\ x\ D\ x\ n}{60}$ m/s

   = (3.14 x 0.64 x 6400) / 60 m/s

   = 12861.44 / 60 m/s

   = 214.36 m/s.

Example 2:

A steam turbine with an average wheel/blade diameter of 640 mm. Because steam flows with a pressure of 35 bar and a temperature of 300^0C, it causes the turbine shaft to rotate at 6400 RPM. The Velocity Triangle of Steam Turbine is 35°. If the steam leaving the turbine has a pressure of 0.1 Bar, find:

1. Heat exhaustion in turbine?
2. Velocity Triangle of Steam Turbine (m/s).
3. Circumference speed of wheels?
4. Blade at regular working turbine?
5. The blade at the maximum working turbine?
6. Draw a regular and maximum working speed triangle (scale: 1 cm = 100 m/s)

Answer:

Known by: Steam turbine

P1	= 35 Bar		
T1	= 300^oC	h1	= 2950 kj/kg
D	= 640 mm = 0.64 m		
P2	= 0.1 Bar	h2	= 2100 kj/kg
α	= 35^0		
n	= 6400 rpm		

Asked:

1. Ho = ... Kj/kg.
2. C1 = ... m/s
3. U1 = ... m/s
4. ns regular = ... %
5. ns max = ... %

Figure of Velocity Triangle (regular & Max)

Answer:

1. Ho = h1 – h2 Kj/kg

   = 2950 – 2100 Kj/kg

   = 850 Kj/kg

2. C1 = 44.7√ Ho m/s

   = 44.7√ 850 m/s

   = 44.7 x 29.15 m/s

   = 1303.2 m/s

3. U1 = $\frac{\pi\ x\ D\ x\ n}{60}$ m/s

   = (3.14 x 0.64 x 6400) / 60 m/s

   = 12861.44 / 60 m/s

   = 214.36 m/s.

4. ns regular = 4 $\left[\frac{U}{C_1}\right]$ cos α – 4 $\left[\frac{U}{C_1}\right]^2$ x 100%

   = $\frac{U}{C_1}$ = $\frac{214.36}{1303.2}$= 0.1645

5. ns regular = 4 x 0.1645 x cos 350 – 4 (0.1645)2 x 100% $n$regular
   = C1 x 100% C1 U C1

   = 214.36 1303.2

   = 0.1645

   = 4 x 0.1645 x 0.904 – 4 x 0.027 x 100%

   = 0.595 - 0.108 100%

   = 0.487 x 100%

   = 48.7 %

6. ηs max $= \cos^2 \alpha \times 100\%$

$= \cos^2 35 \times 100\%$

$= (0.904)^2 \times 100\%$

$= 0.82 \times 100\%$

$= 82\%$

7. Figure of Velocity Triangle (regular, scale: 1 cm = 100 m/s)

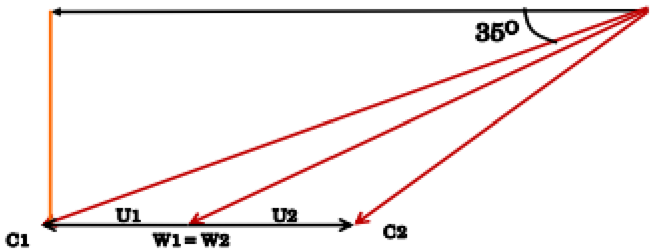
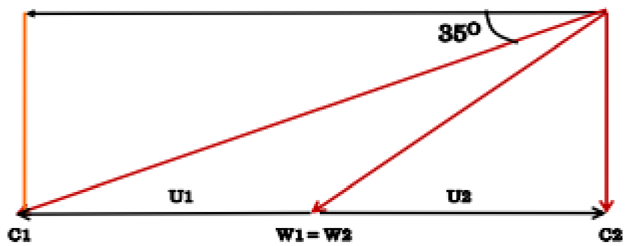


Figure of Velocity Triangle

(Max, scale: 1 cm = 100 m/s)



CHAPTER VI. ZOELLY TURBINE

Zoelly turbine is an action turbine (average pressure) consisting of several pressure levels, each pressure level consists of 1 stage. Zolley turbines are called pressure stage turbines, where the steam pressure decreases in each stage. The Zolley turbine is actually a de Laval turbine which is mounted in series on one turbine shaft.

In this turbine, a large heat exhaustion is applied and it is divided equally by several levels, this heat exhaustion is relatively small, resulting in a good blade. At each level with a fall in heat, it will be followed by an expansion and the expansion of each level is a continuation of the expansion in the previous level.

Between the first level and the next level, there is a difference in steam pressure and therefore each level must be packed, this pressure difference is not the same for all levels, at the initial level the pressure difference is large, while the last one is smaller.

6.1. Advantages and Disadvantages of Zolley Turbine

Advantages of Zoelly Turbine can be delivered as follows:

1. The yield of the flow is large, because the heat exhaustion for each level is small.
2. The inner yield is large.
3. Steam velocity and small friction.
4. The heat energy is small, because the heat energy that comes out in the first level is passed on to the next levels.

Beside of the advantages, there are some disadvantages of Zoelly turbine as follows:

1. Steam pressure/level is not the same.
2. Long turbine construction, due to many levels.
3. The purchase price is expensive.
4. More maintenance.

6.2. Usage

Zolley turbines are usually used to drive power plants (generators) and drive propellers in small units. The disadvantages of de Laval are a lot of heat energy wasted out of the turbine at mass times ½ the square of the steam velocity is calculated in kgm. By Zoelly, the steam speed is utilized again, as if combining more than one de Laval turbine into 1 turbine unit which is called a Zoelly turbine. Zoelly found a flaw in the operation of de Laval turbine, it is the amount of heat energy wasted out of the turbine.

6.3. Characteristics of Zoelly Turbine

1. Is an action turbine (flat pressure turbine).
2. Consists of several levels of pressure, each level of pressure followed by 1 level of speed.
3. The heat exhaustion is evenly distributed for each pressure level.
4. The shape of the blade is symmetrical.
5. Smoothing of the blade is smaller than 100%.

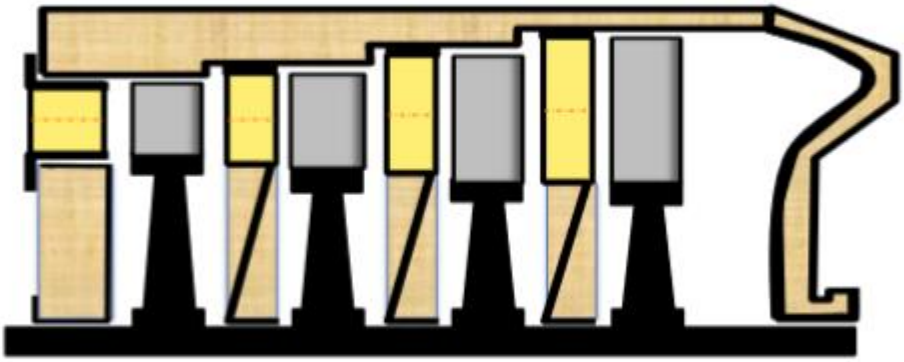


Figure 31. Cross Section of T. Zoelly 4 Pressure Levels.

6.4. Changes in Thermal Energy to Velocity Energy of T. Zoelly

To find out the change of thermal energy to velocity energy of T. Zoelly can be conduct like the concept delivered to the de Laval turbine. The conversion of thermal energy into velocity energy in Zoelly Turbine of 4 Pressure levels where each level consists of 4 speed levels can be described as follows:

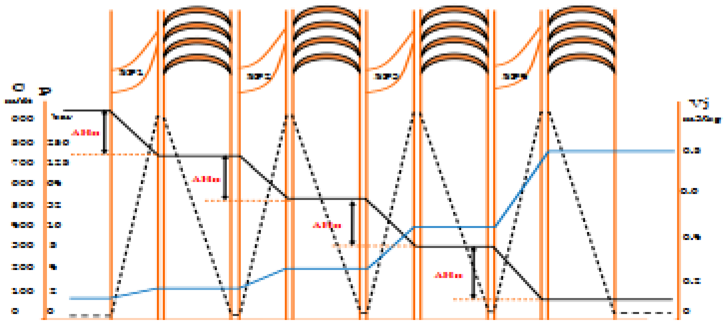


Figure 32. Converting heat energy to velocity energy

Explanation of Diagram.

1. There is a heat exhaustion of ΔHo per pressure level.
2. Absolute steam inlet velocity per stage:

   $C1 = 44.7\sqrt{\Delta Ho}$

3. The total heat exhaustion (Ho) is:
    a. $Ho = \Delta Ho + \Delta Ho + \Delta Ho + \Delta Ho$
    b. $Ho = 4\,\Delta Ho$
    c. $\Delta Ho = Ho / 4$,
4. Absolute steam inlet velocity per stage

    $C1 = 44.7\sqrt{Ho / 4}$
5. So: In a Zoelly turbine consisting of "m" pressure levels, then:
    a. $\Delta Ho = Ho / m$
    b. $C1 = 44.7\sqrt{Ho / m}$

6.5. Speed Triangle of Zoelly Turbine

The Zoelly turbine speed triangle is the same as the de Laval turbine. The following is an example of a Zoelly 2 Pressure Level Turbine speed triangle as follows:

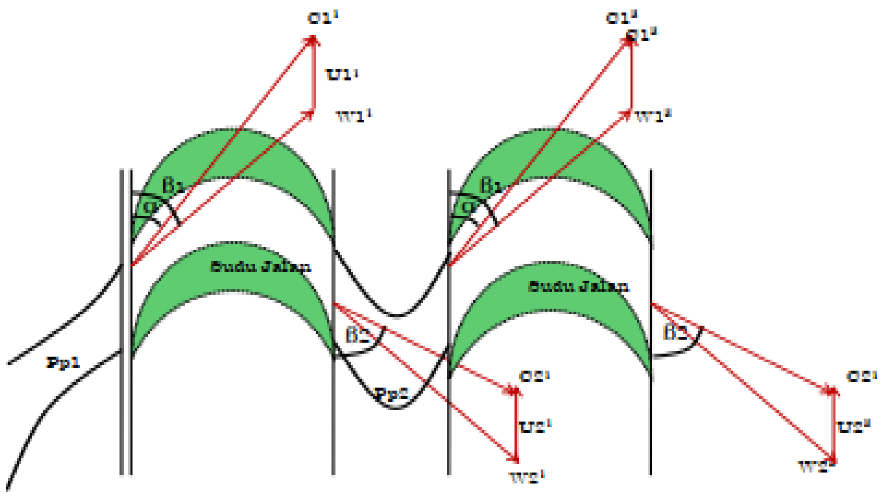
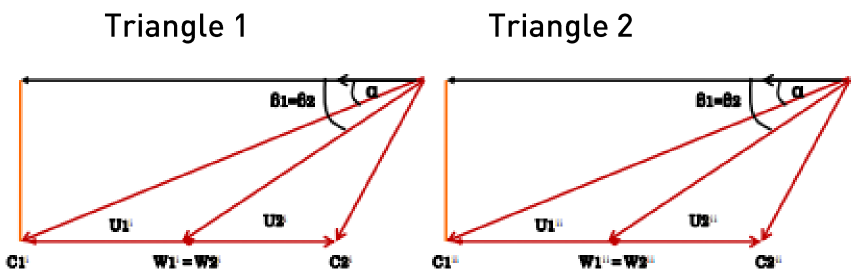


Figure 33. Speed Triangle of Zoelly Turbine 2 Pressure Levels.

The Heat exhaustion is evenly distributed at each pressure level and the angular segment of the nozzle is the same size, i.e., and the diameter of the wheel is measured at the same size, two speed triangles are obtained which are equal and congruent between levels I and II, as follows:



$$\left.\begin{array}{l} C1^{i} = C1^{ii} \\ C2^{i} = C2^{ii} \\ U1^{i} = U1^{ii} \end{array}\right\} \text{ Triangle 1 = Triangle 2}$$

Figure 34. Level I and II speed triangle.

With the data submitted to describe the Zoelly Turbine of Speed Triangle in 2 Pressure Level, it is enough to describe only one speed triangle. This also applies to Zoelly turbines with a Pressure Level of more than 2 (m Pressure Level).

6.6. Zoelly Turbine Blade Yield

The blade yield on the Zoelly Turbine with m Pressure levels can be conveyed as follows:

$$\eta s = 4\left[\frac{U}{C_1}\right]\cos\alpha - 4\left[\frac{U}{C_1}\right]^2 \times 100\% \qquad \text{.............................(1)}$$

or

$$\eta s = \frac{\Delta Ho - \Delta Hu}{\Delta Ho} \times 100\% \qquad \text{.............................(2)}$$

If the Zoelly turbine consists of "m" pressure levels, then the blade yield for each pressure level is:

$$\eta s = \frac{Ho/m - Hu/m}{Ho/m} \times 100\%$$

6.7. Zoelly Turbine of Maximum Work

Like the de Laval Turbine of Zoelly turbine can work optimally/ as well as possible. The Zoelly Turbine of Speed Triangle is the same as the de Laval turbine. The following is an example of a Zoelly Turbine of 2 Pressure as follows:

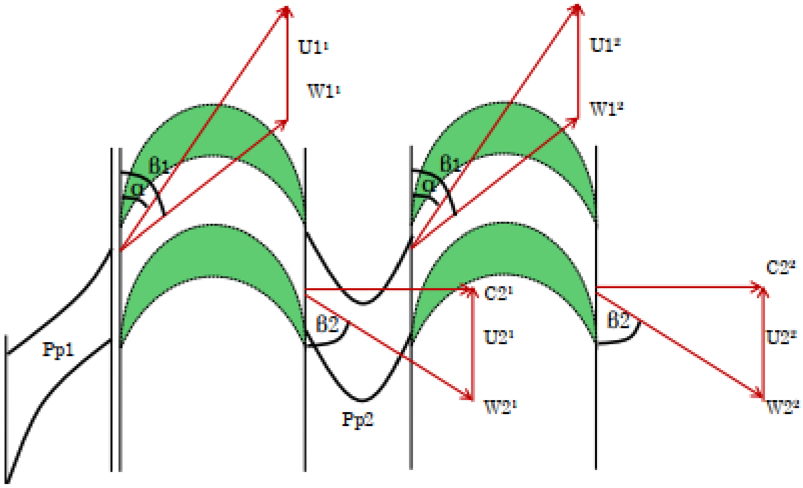
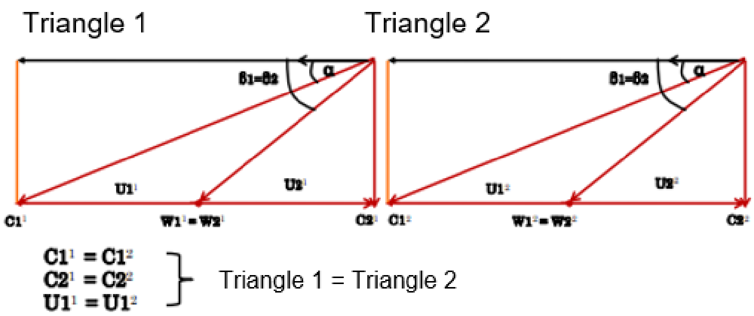
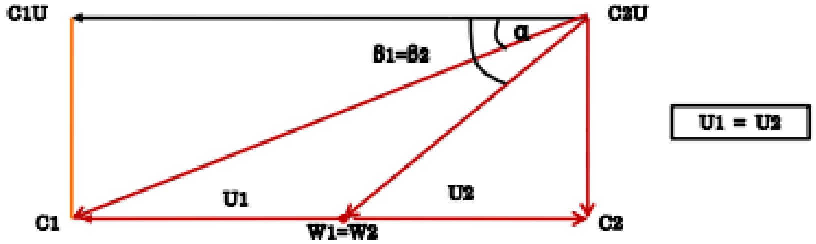


Figure 35. Zoelly Turbine Speed Triangle 2 Pressure Levels.

With the Heat exhaustion is evenly distributed at each pressure level and the angular segment of the nozzle is the same size, i.e., and the diameter of the wheel is measured at the same size, two velocity triangles are obtained which are equal and congruent between levels I and II, as follows:



With the data submitted, to describe the maximum work of Zoelly turbine Speed Triangle, it is enough to only describe one speed triangle, as follows:



$$\text{Cos } \alpha = \frac{C_1U}{C_1} = \frac{2U}{C_1} \Rightarrow \frac{U}{C_1} = \frac{\text{Cos } \alpha}{2}$$

$$\eta S_{biasa} = 4\left[\frac{U}{C_1}\right]\text{Cos } \alpha - 4\left[\frac{U}{C_1}\right]^2 \text{ x } 100\%$$

$$\eta S_{max} = 4\left[\frac{\text{Cos } \alpha}{2}\right]\text{Cos } \alpha - 4\left[\frac{\text{Cos } \alpha}{2}\right]^2 \text{ x } 100\%$$

$$\eta S_{max} = 2\text{ Cos}^2\alpha - \text{Cos}^2\alpha \text{ x } 100\%$$

$$\eta S_{max} = \text{Cos}^2\alpha \text{ x } 100\%$$

Chapter VII. Power Turbine (Steam Turbine Power)

7.1. Theoretical Power (Po) Turbine

Theoretically, the power generated by the turbine depends on the heat exhaustion (Ho) and the amount of steam (G) used. Heat exhaustion (Ho) = h1 – h2, where h1 & h2 are the heat contained in the steam at a certain pressure per 1 kg of steam. Amount of Steam (G) is the amount of steam used every 1 second (kg/s). The amount of heat is converted into Power/ Theoretical Power (Po) is: Ho (Kj/kg) x G (kg/s).

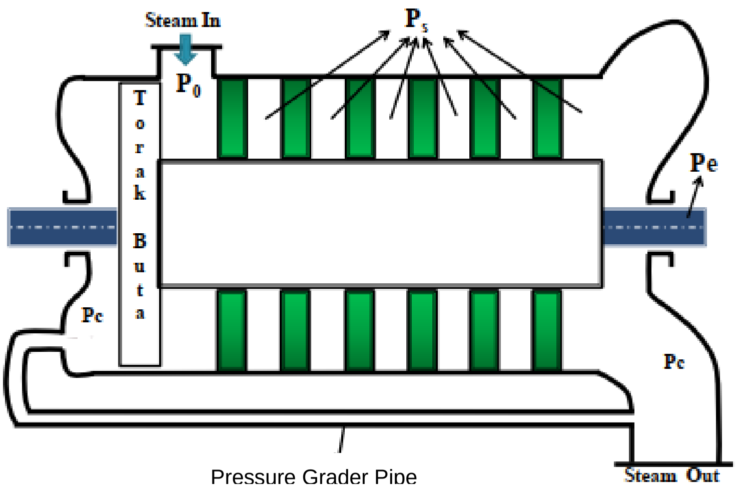


Figure 36. Steam Turbine Power and Usability.

Po = Ho (Kj/kg) x G (kg/dtk)

Po = Ho x G (Kj/dtk) → 1Kj/dtk = 1 Kw

Po = Ho x G (Kw)

7.2. Yield/Turbine Use

Yield/Turbine power is the ratio of useful heat to the heat supplied to a steam turbine. The yield/utility associated with the operation of the steam turbine is as follows:

1. Blade Yield (ηs).

   The blade yield is the yield related to the work of the traveling blades (SJ) and the transmission blades (SP) as turbines. The usability of this blade is closely related to the blade power (Ps) of the turbine

2. Yield of Indicator/In (ηi).

   Yield Indicator/In is the yield associated with losses in the turbine. Usability Indicator/In this is closely related to Turbine Power Indicator (Pi)

3. Mechanical Yield (ηm).

   Mechanical yield is the yield associated with the mechanical motion of the turbine, and this is related to Turbine Effective Power (Peff).

7.3. Blade Energy (Ps) of Turbine

Not all the steam that enters to the turbine is used to drive the blades, there is some flowing steam and wasted out of the turbine without moving the blades. Flowing steam drives the blade used to calculate Blade energy (Ps) Turbine. Blade energy (Ps) is Theoretical energy (Po) which is influenced by Blade Yield (ηs).

$Ps = Po \times \eta s$ .... (Kw)

$Ps = G \times Ho \times \eta s$ .... (Kw)

7.4. Power Indicator (Pi)

Indicator losses inside the turbine such as steam friction, steam eddies, steam vents and steam leaks carry the wasted heat out of the turbine. Indicator Power (Pi) or Turbine Internal Power is Theoretical Power (Po) taking into account the Turbine Internal Yield (ηi).

$Pi = Po \times \eta i$ .... (Kw)

$Pi = G \times Ho \times \eta i$ .... (Kw)

7.5. Effective Power (Peff)

Effective Power (Peff) is the power acting on the turbine shaft after considering the Indicator Yield (ηi) and Mechanical Yield (ηm) of the turbine. Mechanical yield (ηm) is the loss due to mechanical motion in the turbine. A straight comparison between Indicator Yield (ηi) and Mechanical Yield (ηm) can be expressed as Thermodynamic Yield (ηthd).

$\eta thd = \eta i \times m$

$Peff = Po \times \eta thd$ ....(Kw)

$Peff = G \times Ho \times \eta i \times m$ ....(Kw)

7.6. Regulating Turbine Power

Steam Turbine Governing (STG) is a mechanism/procedure to control steam flow rate to the steam turbine so as to maintain a constant rotational speed. Load variations during operation have a significant impact on the performance of the steam turbine. In practical situations, the load often varies from the designed one. Thus, there is a considerable deviation from the desired performance which causes the turbine to be uneconomical.

The main objective of STG in steam turbine operation is to regulate the steam flow in order to maintain a constant speed of rotation regardless of the varying load achieved by the steam turbine. The steam flow rate is monitored and controlled by an interposing valve located between the boiler and turbine. Steam Turbine of Flowing Steam Settings → Turbine Power.

For a purpose, the power acting on a steam turbine must be regulated. To adjust the amount of power as needed on the installation of steam turbine propulsion ship is required particularly when the ship is maneuvering.

Theoretical Power Concept (Po) of Turbine: Power depends on Heat exhaustion (Ho) and Steam Consumption (Gap), so the turbine power regulation is influenced by these two things.

Based on this description, there are two ways to set of turbine power, i.e.:

1. Quantitative Setting.

   This setting is to regulate the amount of steam that enters to the nozzle. The tool used for this purpose is "Nozzle Control/Nozzle Governing".

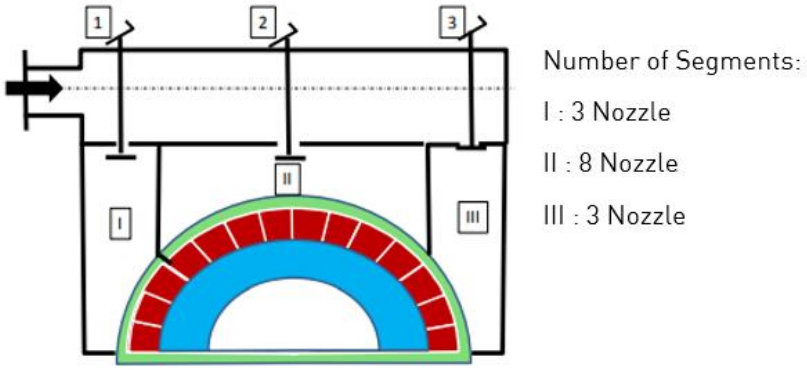


Figure 37. Nozzle Control/Nozzle Governing.

Illustration of Operation:

a. Valve 2 is opened: Turbine works 50% of maximum power (Number of steams is 50% ⟶ Turbine power 50%).
b. Valves 1 & 2 are opened: Turbine is running at 75% power. (Number of steams is 75% ⟶ Turbine power 75%).
c. Valves 1, 2 & 3 are opened: Turbine runs at 100% power. (Number of steams is 100% ⟶ Turbine power is 100%).

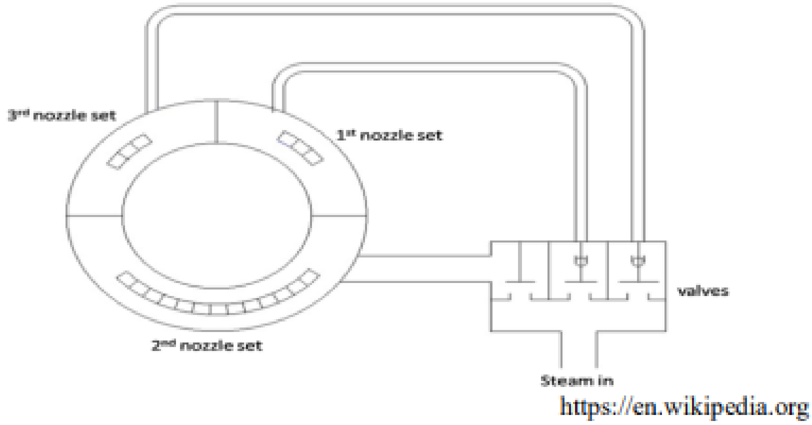


Figure 38. Schematic of nozzle governor.

Setting of Quantitative power is related to *Steam Consumption Rate* (G) (Willan‟s Line). The variation of steam consumption G (kg/hour) with turbine load during operation is given by the following formula:

$$G = aL + C$$

Where: G = Total of steam consumption (kg/h)

a = Total of steam per Kwh (kg/kWh)

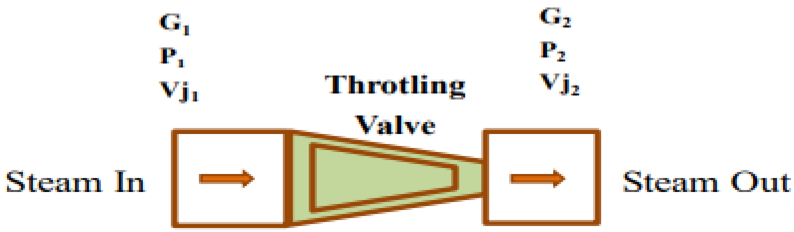
L = Turbine Power (KW)

C = Total of steam without load (kg/h)

2. Qualitative Arrangement

Qualitative arrangement is conducted by reducing the steam pressure at the turbine in, thereby reducing energy availability. The steam is passed through a device with a constriction method so that it reduces the pressure. The flow rate is controlled using a partially open steam control valve. The decrease in pressure due to throttling is followed by an increase in the Specific Volume of Steam. A change in pressure and an increase in the specific volume of a steam causes the enthalpy of the steam to remain constant. The interposing valve with this method is known as the "**Throttle Valve**". The note that needs to be conveyed is that the quality of steam depends on the pressure and temperature of the steam.

The Use of Throttling Valve:



G1 = G2

P1 → P2

Vj1 ← Vj

The use of Throttle Valve has an impact on changes from the enthalpy of steam which can be seen in the following HS diagram

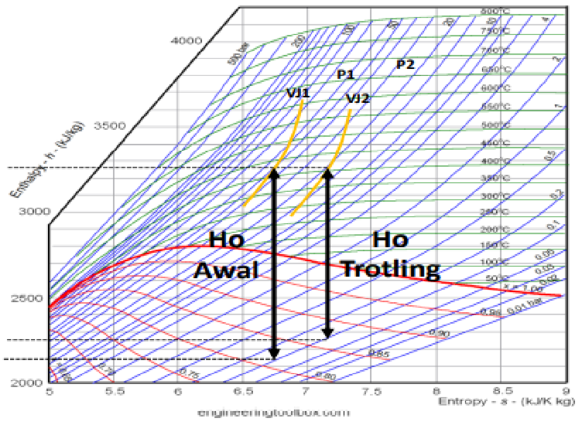


Figure 39. Changes in the enthalpy of vaporization

Changes in the enthalpy of vaporization will change the power working on the turbine, as follows:

$$Po = Steam * Hi$$

$$Ho \text{ (before Throttling)} = h1 - h2$$

$$Ho'' \text{ (after Throttling)} = h1 - h2''$$

$$Ho'' \text{ (after Throttling)} \leftarrow Ho \text{ (before Throttling)}$$

$$\Downarrow$$

$$Po'' \text{ (after Throttling)} \leftarrow Po \text{ (before Throttling)}$$

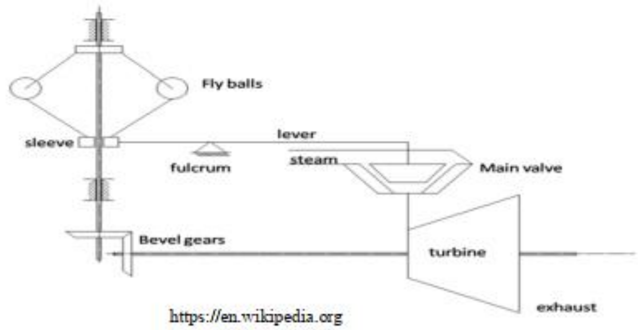


Figure 40. Schematic of throttle governor.

7.7. Practice

Problem 1:

A ship is driven by an action/Impulse turbine of one working pressure level. The mass of flowing steam is 20 kg/s with an absolute inlet angle of 20^0. The absolute inlet steam velocity is 600 m/s and the Circumferential Velocity is 250 m/s. Ignoring the losses, calculate:

1. Turbine Work?
2. Axial thrust on Turbine Bearing?

Answer

Known by: Action Turbine

α = 20^0C

C1 = 600 m/s

U1 = 250 m/s

G steam = 20 kg/s

Asked:

1. Po = ... (KW)
2. Fak Poros = ...

Answer:

1. Po= G x Ho

   = 20 kg/dtk x 179.56 Kj/kg

   = 3591.2 Kj/dtk

   = 3591.2 Kw
2. F Aks Prs = ...?

Question 2:

A Zoelley Turbine of 8 pressure level works normally. The turbine inlet steam pressure is 45 bar with a temperature of 400^{O}C. 90% vacuum condenser. The heat exhaustion is evenly distributed at each level. The diameter of the blade is measured in the center of the 510 mm blade. The turbine rotates at 100 RPS. Steam Inlet Pressure is 18^{o}C.

Asked:

1. Heat exhaustion?
2. Steam speed?
3. Disadvantages of steam exiting the turbine?
4. If other losses excluding steam losses = 75 kJ/kg, and mechanical yield of 94%, determine the thermodynamic yield?
5. If the effective power is 2944 EKW, calculate the steam consumption specifically? (kg/EKW-hour)

CHAPTER VIII. CURTIS TURBINE

8.1. Characteristics of Curtis Turbine

Basically, T Curtis is a combination of 2 Zoelly turbines. Briefly, the characteristics of the Curtis Turbine can be conveyed as follows:

1. It is a flat pressure/action turbine.
2. Consists of one or two pressure levels, which each pressure level is followed by two or more speed levels.
3. Between two successive speed levels, there is a series of blades used to reverse the direction of steam movement (blades back/SB and attached to the turbine housing).
4. Between two successive pressure levels, there is a series of jets which in addition to being used to reverse the direction of steam movement (pipeline/PP attached to the turbine housing) also serves to increase the steam velocity again.
5. The shape of the blade is symmetrical.
6. Blade polishing ← 100%.

8.2. Curtis Turbine Variation

1. Two pressure levels wherein the first and second pressure levels are followed by two speed levels respectively.
2. Two pressure levels where the first pressure level is followed by three speed levels and the second pressure level is followed by two speed levels.

3. Two pressure levels where the first pressure level is followed by two speed levels and the second pressure level is followed by three speed levels.

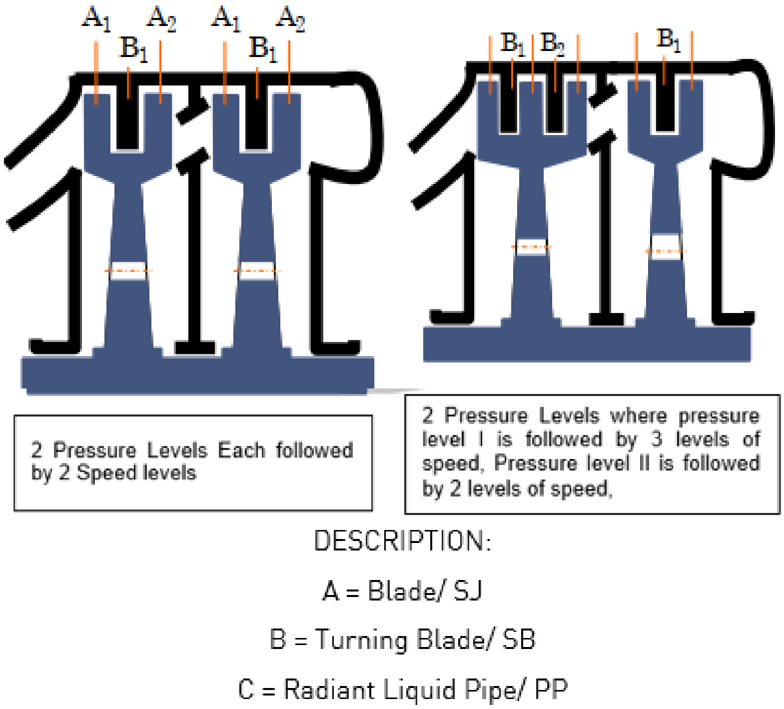


Figure 41. Cross Sections of Curtis Turbine Construction Variations.

8.3. Curtis Turbine of 2 Pressure Level Where First Pressure Level Followed by 3 Speed Levels & Second Pressure Level Followed by 2 Speed Levels

The change in heat energy into potential energy can be explained as follows:

1. Tk. First pressure with 3 tk. Speed.

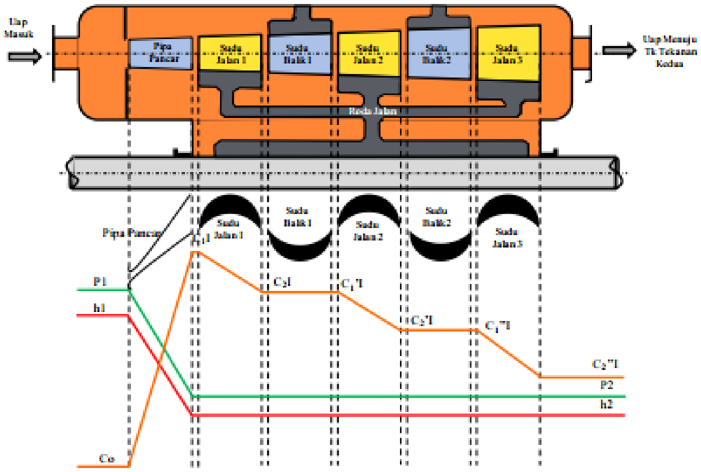


Figure 42. Process at Pressure level I.

Description:

a. Pressure & enthalpy decreased in the pipe (Pp).

b. The speed at Pp increases from Co to C_1 and enters the blade (Sj)1 which is partially converted into mechanical power (U1I).

c. $C_1I = 44.7\sqrt{Ho}/ mcI$.

d. $U1I = \pi D\ n / 60$.

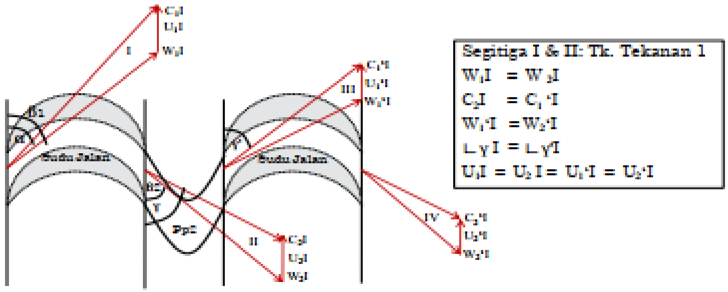
e. Steam exits Sj_1 with a speed of C_2I into the blade (Sb)1.

f. In Sb1, the steam does not change in velocity, but only changes in "direction", and enters Sj_2 at a speed of C_1'I which is partially converted into mechanical energy.

g. Steam exits Sj_2 at the speed of C2'I then enter Sb_2 to change its direction again.

h. Steam enters Sj_3 with a speed of C1'I some of it is converted back into mechanical power. The speed of steam coming out of Sj3 or leaving the turbine is just C2''''I.

2. Speed Triangle of Pressure Level 1 with 2 Speed Levels.



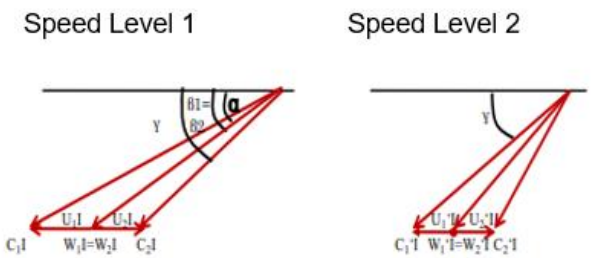


Figure 43. Velocity Triangle Pressure level I with 2 Speed levels.

8.4. Practice

Question 1:

Turbine Curtis of First Pressure level followed by 2 Speed level. The useful heat at velocity level I is 275 Kj/kg and at velocity level II is 200 Kj/kg. Useless heat left this pressure level is 42% of the available heat. Second Pressure level followed by 2 Speed level. The useful heat at velocity level I is 240 Kj/kg and at velocity level II is 150 Kj/kg. Useless heat left this pressure level is 12% of the available heat. The absolute vapor inlet angle is 16^0.

Asked:

1. Working turbine blade yield?
2. Absolute steam inlet velocity?

3. The RPM of the turbine shaft if the circumference of the wheel and the diameter of the shaft are 170 m/s and 520mm, respectively.
4. If the turbine is operated at its maximum what is the circumferential speed of the wheels and the current axle RPM?

Known by: TC Tk. Tek I ◊ 2 tk.kec.

mc_I	= 2
Hb_I	= 250 Kj/kg
Hb_II	= 180 Kj/kg
Hu	= 15% Ho
α	= 18^0

Asked:

1.	ηs_{mc}	= ....%?	
2.	$C_1 I$	= .... m/dt	
	$C_1 II$	= ....m/dt	
3.	RPM	= ....m/dt	(U=150 m/dtk; D=540mm.
4.	U_{Imak}	= .... m/dt	
	nmak	= ....?	

Answer:

a) $\eta sI = \frac{Hb}{Ho} \times 100\%$

$\eta sI = \frac{430}{781.8} \times 100\%$

$\eta sI = $ **55 %**

HbI = Hb1 +Hb2 = 250 +180 Kj/kg
= 430 Kj//kg
HoI = HbI +HuI
HoI = 430 + 45 % Ho
55 % HoI = 430
HoI = 430 / 0.55 = 781.8 Kj/kg

$\eta sII = \frac{Hb}{Ho} \times 100\%$

$\eta sII = \frac{380}{431.8} \times 100\%$

$\eta sII = $ **88 %**

HbII = Hb1 +Hb2 = 230 +150 Kj/kg
= 380 Kj//kg
HoII = HbII +HuII
HoII = 380 + 12 % HoII
88 % HoII = 380
HoII = 380 / 0.88 = 431.8 Kj/kg

$\eta sTC = \eta sI + \eta sII = $ **55 % + 88 % = 143 %**

Chapter IX. Parson Turbine

The Parson turbine is the first modern steam turbine developed by Sir Charles Parson in 1884. In its development in the industrial world, the Parson turbine is able to replace the function of the piston (Steam Engine), this is due to the advantages of the Parson turbine because it has heat efficiency and greater power compared to the weight ratio. In the process, the Parson Turbine does the work of producing good rotation to drive rotating mechanical equipment, mainly driving electric generators (over 80% of the world's power plants are driven by Steam Turbines) and other purposes. For further development the Parson Turbine is used as a Ship Primer Mover.

Figure 44. Sir Charles Parson and his Dedication.

The Parson turbine is a reaction turbine where the work generated by the action and reaction forces acts on the turbine blades. The Parson turbine is also known as the Multiple Pressure Turbine or Overpressure Turbine because it consists of several pressure levels and each pressure level consists of one speed level. At each speed level, the turbine consists of a series of transmission and the blades.

The work generated in the turbine is obtained from the actions and reaction forces on the blades. The action force formed later is changed in the absolute velocity process on the nozzle while the reaction force is from the relative velocity process, so that each unit of the blade gets an axial force with a smaller pressure direction. The axial force of the blade is transmitted to the turbine housing while the axial force of the blade is transmitted to the rotor.

9.1. Characteristics of Parson Turbine

1. It is a reaction turbine (over pressure), which works on the action and reaction forces.
2. Consists of several levels and each level consists of 1 full set of delivery blades and 1 full set of blades.
3. The steam pressure before is greater than after the transmission and the blades.
4. At each level, there are 2 heat exhaustions, namely in the transmission and blades which are the same in each level.
5. The shape of the blade is the same as the shape of the blade, which is an asymmetrical shape, where the absolute inlet angle of steam inlet ($\alpha 1$) is not the same as the absolute steam outlet angle ($\alpha 2$) at each level.
6. Turbine power regulation is carried out qualitatively (quality regulation) and quantitatively (quantity setting).
7. Blade polishing is 100% (sanding = a lot of steam flowing blade).

9.2. Parson Turbine Operation

In operation the Parson Turbine has a large efficiency and power advantage and has a large flow yield as well. In addition, there are several disadvantages that must also be considered in its operation. The disadvantages are the need for an area/ room due to the large number of levels, the occurrence of large steam leaks and the occurrence of axial forces due to the vapor pressure in front of the blades bigger than behind the blade and additional equipment is required to overcome the the force.

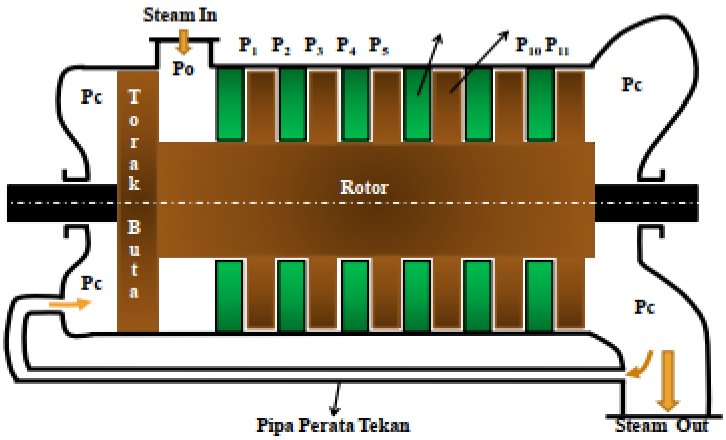


Figure 45. Cross Section of Parson Turbine.

From the picture above, several things can be conveyed as follows:

1. The arrangement of the transmit blade is attached to the fiber turbine housing. The blade is attached to the rotor.
2. The front of the rotor is attached to a device called a demmy piston, which functions to compensate for the difference in force before and after SJ.
3. There is also a pressure leveling pipe that connects the used steam room with the blind piston chamber.
4. There is a decrease in vapor pressure at each pressure level, where: Po → P1 → P2 → P3→.............→ Pc.
5. The pressure difference will cause a working forces on the turbine house and shaft.
6. The absolute steam inlet velocity (C1) is the same as the relative steam outlet velocity (W2).
7. The absolute steam inlet angle (α) is the same as the relative steam outlet angle (β2).

9.3. Speed Triangle of Parson Turbine

The change in potential energy into kinetic energy and so on into mechanical energy in the Parson Turbine at one pressure level can be explained by the Speed Triangle as follows:

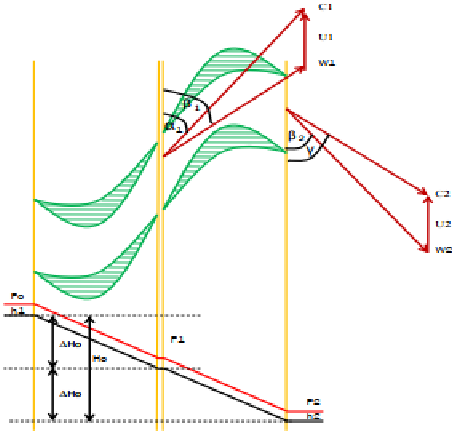


Figure 46. Change of Parson Turbine Power.

In the figure 46, it can be explained that there are two speed triangles, namely the incoming side velocity triangle and the outgoing side velocity triangle.

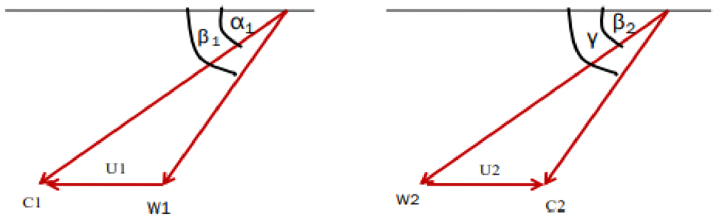


Figure 47. In and Out Side Speed Triangle.

From the picture it can be conveyed the speeds occurred in the turbine, as follows:

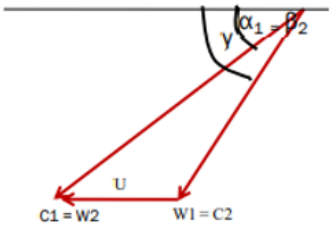
$C1 = 44.7\sqrt{}\ Ho$ Sudu pancar $= 44.7\sqrt{}\ \Delta Ho$ m/s

$W2 = 44.7\sqrt{}\ Ho$ Sudu jalan $= 44.7\sqrt{}\ \Delta Ho$ m/s

$U1 = U2 = \pi.\ D.\ n\ /60$

$C1 = W2 = 44.7\sqrt{}\ \Delta Ho$ m/s

Since the angle is the same magnitude as the angle $\beta 2$, the Speed Triangle (Δ) of Parson Turbine in one pressure level can be described as follows:



Δ Ho + Δ Ho = Ho

2 Δ Ho = Ho

ΔHo = Ho/2

$$C1 = W2 = 44.7\sqrt{\Delta Ho}$$

C1&W2 TP 1 pressure level 2 speed level

The Absolute Steam Inlet Velocity (C_1) & Relative Vapor Outflow Velocity (W_2) are applicable to Parson Turbine 1 pressure level followed or having 2 speed levels. For the Parson Turbine with a number of pressure levels more than 2 where each pressure level there are 2 speed levels, the value of the Absolute Intake Steam Velocity (C_1) & the Relative Vapor Outflow Velocity (W2) can be conveyed as follows:

$$C1 = W2 = 44.7\sqrt{\frac{Ho}{2.mp}}$$

C1 & W2, T. Parson consists of mp levels, where there are 2 levels of speed for each pressure level.

9.4. Degree of Reaction

The degree of reaction is the ratio of the useful flow work on the blade to the total flow work at each pressure. The useful workflow at each pressure is the flow steam in the transmission and the blades.

$$DR = \frac{\cancel{½ m}\ W2u - \cancel{½ m}\ W1u}{\cancel{½ m}\ C1u - \cancel{½ m}\ C2u + \cancel{½ m}\ W2u - \cancel{½ m}\ W1u}$$

$$DR = \frac{W2u - W1u}{C1u - C2u + W2u - W1u}$$ → Karena : C1u = W2u & W1u = C2u

$$DR = \frac{C1u - C2u}{C1u - C2u + C1u - C2u}$$

$$DR = \frac{1\ \cancel{(C1u - C2u)}}{2\ \cancel{(C1u - C2u)}} = ½ \quad \text{atau} \quad 50\ \%$$

Reaction Degree of 50% can occur with a heat exhaustion condition in SJ = Heat Exhaustion in SP and SP form is the same as in SJ form.

CHAPTER X.
STEAM TURBINE RENDEMENT

10.1. Thermic Yield of Steam Turbine Installation

Thermic yield of a steam turbine installation or heat efficiency is the ratio between the useful heat and the heat supplied to the steam turbine installation.

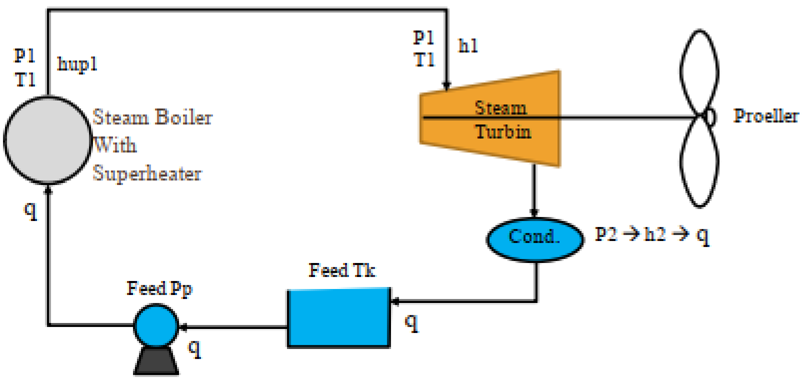


Figure 48. Main Steam Installation.

From the figure, it can be conveyed as follows:

1. P1 = Boiler Exit Steam Pressure = The inlet steam pressure of the turbine
2. T1 = Boiler Exit Steam Temperature = The inlet steam temperature of the turbine
3. h1 = Enthalpy of steam entering turbine.
4. h2 = Enthalpy of steam exiting the turbine.
5. q = Enthalpy of the water entering the boiler.

From the data contained from the figure, it can be conveyed the Thermal yield of the Steam Turbine Installation (ηth) as follows:

1. Useful heat at installation = h1- h2 Kj/kg
2. Heat supplied to the installation = Heat delivered by Fuel = Useful heat to convert the filling water into steam = h1- q Kj/kg.
3. So: $\eta th = \frac{h_1 - h_2}{h_1 - q} \times 100\%$

Note: The value of q is found in the steam table by taking into account the enthalpy of water when its pressure is equal to the pressure of the steam exiting the steam turbine.

10.2. Internal Yield (Hi) of Steam Turbine

Not all of the potential heat carried by the steam is entirely useful and is used to generate kinetic energy (velocity power). Some of this heat is lost in the turbine due to the characteristics and construction of the steam turbine. The heat loss occurred in the turbine is called Internal Loss (Indicator Loss). These internal losses can then be used to calculate the Internal Yield/ Indicator (ηi) and Turbine Indicator Power (Pi).

The Internal Yield /Indicator (ηi) is the comparison between the Practical Heat Exhaustion (Hi) and Theoretical Heat Exhaustion (Ho), as follows:

$$\eta i = \frac{Hi}{Ho} 100\%$$

The practical heat exhaustion (Hi) is the theoretical heat exhaustion (Ho) minus the losses in the turbine.

$$\eta i = \frac{Ho - \text{the losses in the turbine}}{Ho} 100\%$$

Disadvantages in the Turbine, including:

1. Friction Loss.

   When flowing through the nozzles, the steam meets the obstacles in the form of friction with the surface of the jet and blade (only the friction between the steam and the rolling blade). Friction Losses are expressed in Kj/Kg.

Example: Friction Loss = p Kj/Kg.

2. Loss of Ventilation.

Due to the gap between the construction of the nozzle and the blade, some of the high-velocity steam flows between them into the space of the wheel (ventilation leak). Mathematically, this loss cannot be calculated. Loss of Ventilation are expressed in Kj/Kg.

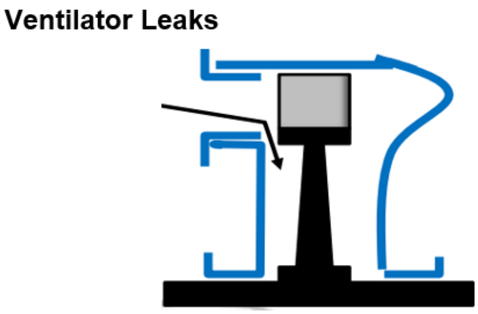


Figure 49. Ventilator Leaks

Example: Loss of Ventilation = q Kj/Kg

3. Vortex Losses.

This is due to not all of the steam that enters then exits from the blades perfectly. The steam left on the sidelines of the blades rotates along with the movement of the wheels. This rotating steam is an additional burden on the turbine. Systematically, this loss also cannot be calculated. Vortex loss is expressed in Kj/Kg.

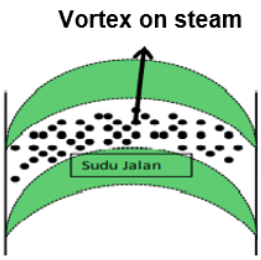


Figure 50. Vortex Losses

Example: Vortex Losses = r Kj/Kg

4. Outflow Loss.

It is a loss because the steam entering the blade which has a speed of C_1 is not completely converted into power. The steam leaving the blade has a velocity of C_2. So, it can be said that the outflow loss is proportional to $1/2m\ C2^2$. Outflow losses can be expressed by "Hu".

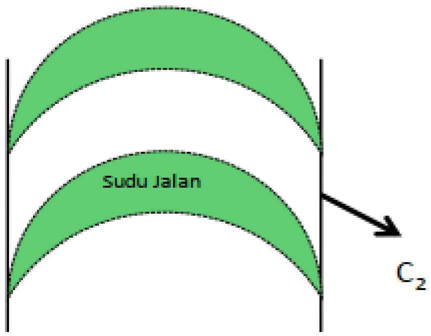


Figure 51. Outflow Loss.

From these various losses, it can be collected as follows:

Friction Loss	= p
Loss of Ventilation	= q
Vortex loss	= r
Outflow Loss	= $1/2m\ C2^2$

So that the Internal Yield/ Indicator (ηi) can be formulated as follows:

$$\eta i = \frac{Ho - (p + q + r + ½\, m\, C_2^{\,2})}{Ho} \times 100\%$$

$$\eta i = \frac{Ho - (p + q + r + Hu)}{Ho} \times 100\%$$

With a reason stated that other losses outside of the outflow loss are ignored, it can be made an equation that: p + q + r = 0, then:

$$\eta i = \frac{Ho - (0 + Hu)}{Ho} \times 100\%$$

$$\eta i = \frac{Ho - Hu}{Ho} \times 100\%$$

At the time of other losses excluding outflow losses ignored, then:

$$\eta i = \eta s$$

10.3. Practical & Theoretical Process

Theoretical Process (Ho) of Steam Turbine is the difference between the enthalpy of steam entering and exiting the turbine. While the Practical Process (Hi) of Steam Turbine: The difference between the Heat exhaustion with the Total Loss in the turbine. Theoretical and Practical Process (Hi) of Steam Turbine can be conveyed with the following formula:

$$\eta i = \frac{h_1 - h_2{}^i}{h_1 - h_2} = \frac{Ho - x}{Ho} = \frac{Hi}{Ho} \times 100\%$$

HS Diagram describes Theoretical and Practical Process of (Hi) Steam Turbine as follows:

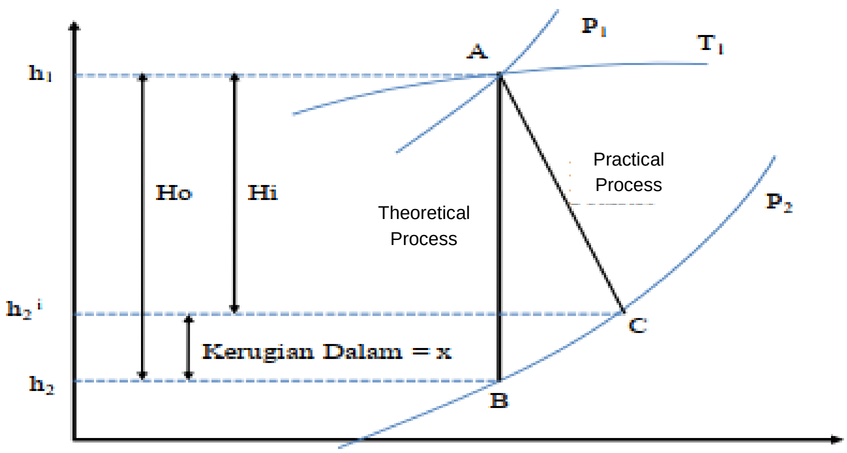


Figure 52. HS Diagram of Theoretical and Practical Process

10.4. Exercise

Question 1:

A 5-pressure level of parson turbine, works best with a 50% reaction rate. The heat exhaustion for each level is 10% less than the previous level.

Steam consumption is 5.5 kg/sec. Thermodynamic yield is 57% and Heat Exhaustion available in 343 kJ/kg vapor. 18^o vapor angle.

Asked:

1. Heat exhaustion of each level?
2. Theoretical data and effective power?
3. The velocity triangle and the magnitude of their respective velocities?
4. Specific steam usage?

Known: - Parson Turbine

mp	= 5
DR	= 50%
G steam	= 5.5 kg/sec
ηthd	= 57%
Ho	= 343 kJ/kg.
α	= 180

Asked:

1. Ho each level =.................. kj/kg
2. Po = ... Kw

   Peff = ... Kw
3. Figure Triangle velocity
4. G steam sp = ... Kg/EKWhour

Answer:

1. Ho each level =....................kj/kg.

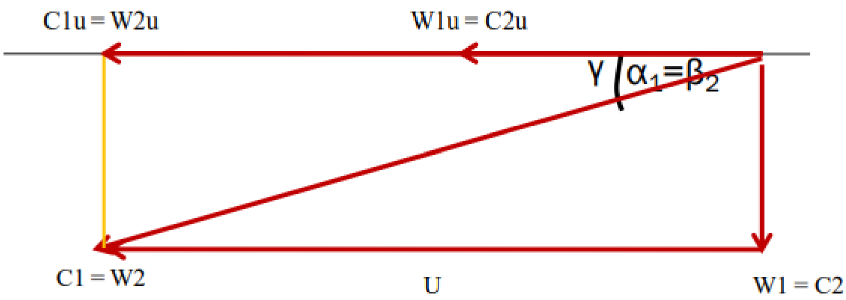
   Ho each level = HO / 2 x mp = 343 /2 x 5

   = 34.3 kJ/kg.

2. Po = G x HO = 5.5 kg/sec X 343 kj/kg = 1886.5 Kw

   Peff = PO x thd = 1886.5 Kw x 57% = 1075 Ekw.

3. Triangle velocity.



C1 = W2 = 44.7√Ho each level

= 44.7√34.3 = 261.79 m/dt

C2 = W1 = C1 x sin α

= 261.79 X sin 18^0

= 261.79 x 0.309 = 80.9 m/dt

U1 = U2 = C1 x cos α

= 261.79 X cos 18^0

= 261.79 x 0.951 = 248.2 m/dt

4. G_{steam} sp = ...Kg/EKWjam

   G_{steam} sp = G_{steam} / EKW

   = 5.5 kg/dt / 1075 EKW

   = 0.00511 kg/EKWdtk

   = 18.4 kg/EKWjam

CHAPTER XI.
BLIND PISTON AND MITCHAEL BLOCK

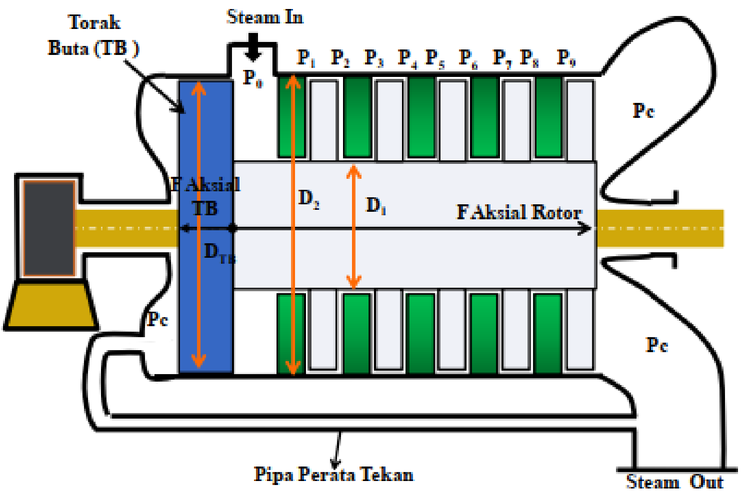


Figure 53. Cross-section of a Parson turbine with Blind Piston

According to the general characteristics, the turbine reaction consists of several pressure levels (TT) where each stage consists of a series of blades (SP) and a series of rolling blades (SJ). In each TT occurs the difference in vapor pressure before and after SP and SJ, causing an axial force (F Axial) which leads to areas with lower pressures.

The working force on an object is dependent on the working pressure and cross-sectional area of the object.

Force (F) = Pressure (P) x Cross-sectional area

Force (F) $= \frac{Kgf}{Cm^2} \times Cm^2 = Kgf$

In the Reaction Steam Turbine, the Axial Force works on the transmitting and traveling blades.

11.1. The axial force at the blade

Axial Force on each Blade in transmits at each level can be delivered as follows:

$$F_{AksSP1} = \frac{\pi}{4}(D_2{}^2 - D_1{}^2)(P_0 + P_1) \;.....Kgf$$
$$F_{AksSP2} = \frac{\pi}{4}(D_2{}^2 - D_1{}^2)(P_2 + P_3) \;.....Kgf$$
$$F_{AksSP3} = \frac{\pi}{4}(D_2{}^2 - D_1{}^2)(P_4 + P_5) \;.....Kgf \quad \text{dst}$$

$$F_{AksSP} = F_{AksSP1} + F_{AksSP2} + F_{AksSP3} + F_{AksSP4} + F_{AksSP5} \;.....Kg$$

$$F_{aksSP} = \Pi/4\,(D_2{}^2 - D_1{}^2)\,((P_0 - P_1) + (P_2 - P_3) + (P_4 - P_5) + (P_6 - P_7) + (P_8 - P_9)\ Kgf$$

The axial force at the blade is accepted by the turbine house (stator). Because the nozzle is part of the turbine house. The force is then passed on to turbine base and then forwarded to the hull as a driving force.

11.2. Axial Force of Working Blade

The axial force working on each blade at each level can be conveyed as follows:

$$F_{aksSJ1} = \Pi/4\,(D_2{}^2 - D_1{}^2)\,(P_1 - P_2)\ Kgf$$
$$F_{aksSJ2} = \Pi/4\,(D_2{}^2 - D_1{}^2)\,(P_3 - P_4)\ Kgf$$
$$F_{aksSJ3} = \Pi/4\,(D_2{}^2 - D_1{}^2)\,(P_5 - P_6)\ Kgf\ ,\ ......\ \text{dst}$$

$$F_{aksSJ} = F_{aksSJ1} + F_{aksSJ2} + F_{aksSJ3} + F_{aksSJ4} + + F_{aksSJ5}\ Kgf$$
$$F_{aksSP} = \Pi/4\,(D_2{}^2 - D_1{}^2)\,((P_1 - P_2) + (P_3 - P_4) + (P_5 - P_6) + (P_7 - P_8) + (P_9 - Pc)\ Kgf$$

Because the blade is attached to the turbine shaft, the force is received by the turbine shaft (rotor) and towards the rear (less pressure) and forwarded to the propeller shaft. This force is not only useful as a ship's thrust but also causes losses because the position of the shaft can move backwards so that it can cause friction between the SJ1 with SP2, between SJ2 and SP3 etc. The friction between SJ and SP can cause fatal damage to SJ and SP, respectively.

11.3. Rotor Axial Force

Because the heat exhaustion is the same at each pressure level, the pressure difference (ΔP) at each pressure level is the same so that the axial force working on the Shaft/Rotor (Fask Rotor) is the average of SP Fax plus SJ Fax is:

$$F_{AksRotor} = \frac{\pi}{4}(D_2^2 - D_1^2)\left(\frac{P_0 - P_1 + P_1 - P_2}{2}\right) + \left(\frac{P_2 - P_3 + P_3 - P_4}{2}\right) + \left(\frac{P_4 - P_5 + P_5 - P_6}{2}\right) + \left(\frac{P_6 - P_7 + P_7 - P_8}{2}\right) + \left(\frac{P_8 - P_9 + P_9 - P_c}{2}\right) Kgf$$

$$F_{AksRotor} = \frac{\pi}{4}(D_2^2 - D_1^2)\left(\frac{P_0 - \cancel{P_1} + \cancel{P_1} - P_2}{2}\right) + \left(\frac{P_2 - \cancel{P_3} + \cancel{P_3} - P_4}{2}\right) + \left(\frac{P_4 - \cancel{P_5} + \cancel{P_5} - P_6}{2}\right) + \left(\frac{P_6 - \cancel{P_7} + \cancel{P_7} - P_8}{2}\right) + \left(\frac{P_8 - \cancel{P_9} + \cancel{P_9} - P_c}{2}\right) Kgf$$

$$F_{AksRotor} = \frac{\pi}{4}(D_2^2 - D_1^2)\left(\frac{P_0 - \cancel{P_2}}{2}\right) + \left(\frac{\cancel{P_2} - \cancel{P_4}}{2}\right) + \left(\frac{\cancel{P_4} - \cancel{P_6}}{2}\right) + \left(\frac{\cancel{P_6} - \cancel{P_8}}{2}\right) + \left(\frac{\cancel{P_8} - P_c}{2}\right) Kgf$$

$$F_{AksRotor} = \frac{\pi}{4}(D_2^2 - D_1^2)\left(\frac{P_0 - P_c}{2}\right) Kgf$$

The rotor axial force is the accumulation of SP axial force and SJ axial force which cannot be avoided. The axial force of the rotor to additional push to the ship's hull also causes the movement of the blades to move towards the rear and it is possible that they rub against the beam blades nearby. To prevent backward movement, a "New Force" is created which is equal in magnitude to but in the opposite direction to the Axial Force of the Rotor.

The new force is due to the operation of a "Blind Piston" which is a solid piston placed in front of a series of steam turbine blades.

The force that arises is called the blind piston force (F_{TB}), as follows:

$$F_{AksTB} = \frac{\pi}{4}(D_{TB}^2 - D_1^2)(Po - Pc)\, Kgf$$

11.4. Diameter of the blind piston

The blind piston installed on the reaction turbine is expected to be of the appropriate diameter. This is intended to produce the Axial Force TB (F_{AKSTB}) which is the same as the Axial Force of the Rotor ($F_{AksRotor}$). The diameter of the blind piston in each turbine can be calculated by the following:

$$F_{AksRotor} = F_{AksTB}$$

$$\frac{\pi}{4}(D_2{}^2 - D_1{}^2)\left(\frac{P_0 - P_c}{2}\right) = \frac{\pi}{4}(D_{TB}{}^2 - D_1{}^2)(Po - Pc)$$

$$(D_2{}^2 - D_1{}^2)(P_0 - P_c) = 2\,(D_{TB}{}^2 - D_1{}^2)(Po - Pc)$$

$$D_2{}^2 - D_1{}^2 = 2\,D_{TB}{}^2 - 2\,D_1{}^2$$

$$D_2{}^2 - D_1{}^2 + 2\,D_1{}^2 = 2\,D_{TB}{}^2$$

$$2\,D_{TB}{}^2 = D_2{}^2 + D_1{}^2$$

$$D_{TB}{}^2 = \frac{D_2{}^2 + D_1{}^2}{2}$$

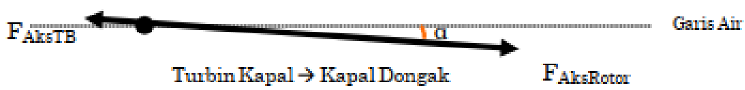
$$D_{TB} = \sqrt{\frac{D_2{}^2 + D_1{}^2}{2}} \; \ldots.\,cm$$

11.5. Ideal blind piston

Ideally $F_{AksRotor} = F_{AksTB}$, but this is only recommended for turbines used on land due to the fact that the turbine base surface is always flat. For ship turbines, because generally the condition of the ship is trim by astern more than even keel (flat), then $F_{AksRotor} \rightarrow F_{AKSTB}$ is made. The explanation can be given as follows:

Ideal force ➡ Flat turbines

Because the ship is jacked up more often (Uneven/Even keel), an angle (α^0) is formed between the keel and the waterline, so the $F_{AksRotor}$ & F_{AksTB} will look like the following picture:



The force only works vertically or horizontally, so the projection of $F_{AksRotor}$ & F_{AksTB} to the waterline (horizontally) is $F_{AksRotor}$ cos α & F_{AksTB} cos α.

Due to the relative construction factor where the short distance from the blind piston is installed, the force works on TB, F_{AksTB} cos α is relatively the same as F_{AksTB}. Meanwhile, due to the long construction factor and proportional to the force works on the rotor, then the $F_{AksRotor}$ cos α is relatively smaller than the $F_{AksRotor}$, so:

$$F_{AksTB} \cos \alpha = F_{AksTB}. \; // \; F_{AksRotor} \cos \alpha \leftarrow F_{AksRotor}$$

In this jackhammer condition, F_{AksTB} cos α → $F_{AksRotor}$ cos α. As a result of these conditions at this time there will be friction between SJ2 and SP1, SJ3 and SP2, SJ4 and SP3 etc.

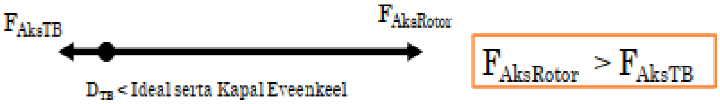
To avoid this problem, theoretically the installation of a blind piston is with a diameter smaller than ideal conditions and larger than the turbine rotor diameter calculation, as follows:

$$D1 \quad < \quad D_{TB} \quad > \quad \sqrt{\frac{D_2 2_+ D_1 2}{2}}$$

By installing a blind piston with this design, in the case of a jack-up ship, F_{AksTB} cos α = $F_{AksRotor}$ cos α, there will be no friction between SP and SJ.

11.6. Mitchael Block

By conducting this, it is hoped that there will be no problems when the steam turbine is used. But the problem will reappear when the ship returns to the Even keel position. Usually, the officers will make the position of the ship is even keel when the ship is maneuvering to leave the port or come to the side of the port. Even though the maneuvering time is short, it can also damage the ship's turbine construction. The ships with a design diameter of TB which are smaller than ideal conditions, when the $F_{AksRotor}$ of even keel ship, it will be larger than F_{AksTB}, as a result, SP will rub against SJ.



To anticipate problems during these conditions, the ship's steam turbine is installed a retaining block called the "Mitchael Block". Mitchael Block will accommodate the excess force that occurs due to the operation of the $F_{AksRotor}$ which is larger than the F_{AksTB} (during the even keel ship). As for the advantages of the force accommodated by Mitchael Block is the amount of $F_{AksRotor}$ - F_{AksTB}.

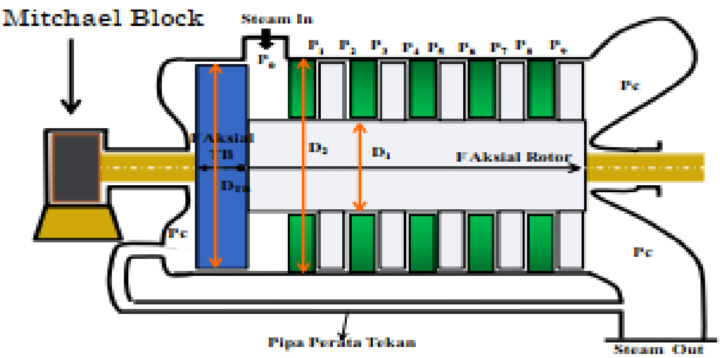


Figure 54. Cross-section of a Parson Turbine with Blind Piston and Mitchell Block

11.7. Exercise

A reaction steam turbine is used as the main propulsion of the ship. The turbine is equipped with a Blind Piston and Michell Block. The diameter of the turbine shaft is 240 mm and the diameter of the blade is 420 m on average. The turbine inlet steam pressure is 45 bar and the condenser vacuum is 90%. Asked:

1. What is the diameter of the blind piston installed on the turbine so that the turbine can work at its best?
2. If a blind piston with a diameter of 350 mm is installed, what is the force by Michell Block during the even keel?
3. Draw the turbine construction complete with the Blind Piston and Michell Block.

CHAPTER XII. STEAM TURBINE OPERATION

To operate the Steam Turbine, especially the Main Propulsion Turbine, it is necessary to maintain the turbine condition in an even condition (even keel vessel). The base and bolts must be ensured that they are locked to the bottom of the turbine so that the entire turbine is completely strong and flat.

12.1. Steam Turbine Support System

In addition to paying attention to the equipment contained in the steam turbine, it is also necessary to check the function of the supporting equipment for the work of the steam turbine. As for support, several auxiliary equipments are used to help the steam turbine cycle process so that it can run properly are as follows:

1. Lube oil system.
2. Steam boiler fuel system.
3. Steam boiler work.
4. Cooling system.
5. Control system (air control or electric system).
6. Hydraulic system.

12.2. Blowing Out of The Steam Pipe

Turbine operators must guarantee the turbine performance with the assumption that the available steam is really clean. Tools provided steam (steam boiler) must be properly before producing good steam as needed and recommended. In order to avoid any damage to the turbine blades, it is necessary to clean any impurities in the form of water, bran and other foreign matter remaining in the steam generating apparatus (boiler) from the initial pipe, and this action must be carried out before the turbine is started to the first time. The presence of water in the system can be seen by the occurrence of a water hammer when steam flows into the steam distribution pipe. To remove this water, it is necessary to blow out the existing pipe using the available drain valves.

12.3. Steam Turbine Commissioning

Steam Turbine Commissioning is running of the turbine for the first time. For the implementation is to check for the first time include:

1. Steam pipes and valves leading to the turbine.
2. Coupling alignment (if necessary, align in hot conditions).
3. All equipment such as: gauge, overspeed trip mechanism, low oil pressure tripping and emergency tripping.

In order to keep the turbine in good condition, carrying out the operating procedures and preventive maintenance correctly, and always under the supervision of experts.

12.4. Turning on the Main Steam Turbine

The steps to turn on the steam turbine are as follows:

1. Check the surface level and the condition of the lubricating oil.
2. Turn on the primary oil pump (electric pump or turbo pump). Turbines use an electric oil pump when the electricity is cut off, it can use a hand oil pump. Set it to automatic condition.
3. Turn on the auxiliary condenser pump for the condenser pending media.
4. Turn on the vacuum pump to produce a vacuum in the condenser.
5. Turn on the condensate pump.

6. Positioning the low oil pressure on switch in the ON position and the emergency switch in the OFF position.
7. Open successively the drain valve, used steam faucet, steam intake faucet and cooling water faucet.
8. Check the position of the load limit pointer (black triangle sign) must be in positions 0 to 2.
9. Position of the connecting excitation cutch to the propeller shaft position the connecting mechanism switch in the OFF position.
10. Turn off the pilot valve, wait until the quick action stop valve opens, help the governor by hand and turn on the turbine at low speed for about 15 minutes (600 – 800 rpm) then turn the load limit knob to the right until the position is number 10.
11. Increase the knob speed setting slowly up to 1500 rpm (turn right to increase and left to decrease rpm).
12. Check the lubricating oil pressure, it must be between 3 – 6 bar at a temperature of 40 – 75°C.
13. Make sure the primary oil pump (electric oil pump or turbo oil pump) stops when the LO pressure is appropriate.
14. Close all drain valves, the steam trap faucet must remain open.
15. Close the direct steam injection faucet that enters the BPV.
16. Reposition the connecting excitation clutch to the propeller shaft and position the connecting mechanism switch in the ON position.
17. The turbine is operated, to be used for propelling the ship.

12.5. Stopping the Main Steam Turbine

The steam turbine is stopped from operating when the ship reaches the port of destination. Steps to stop the ship's main propulsion turbine must be carried out prior to ship maneuvering activities. This step is with first reduce the load acting on the steam turbine. The steps to stop the steam turbine after the maneuver is completed are as follows:

1. If there is a notification that the ship's movement is complete, then the position of the clutch excitation linking to the propeller shaft position the connecting mechanism switch in the OFF position.
2. Pull out the pilot valve.
3. Turn the load limit knob to the left, so that the load limit pointer points to numbers 0 – 2.
4. Turn the speed setting knob to the left until it runs out.
5. Open the primary oil switch (the electric Oil Pump turns on automatically).
6. Close the used steam faucet, enter the steam faucet and open the drain valve.
7. Open the direct steam injection faucet that goes to BPV.
8. When the turbine has completely stopped, close the turbo oil pump faucet or turn it OFF. switch electric oil pump, low oil pressure switch and emergency switch remain in the OFF position.
9. Stop the auxiliary condenser pump for condenser pending media.
10. Stop the vacuum pump to produce a vacuum in the condenser.
11. Turn on the condensate pump.
12. Close the cooling water faucet and the drain valve.

12.6. Steam Turbine Maintenance

To ensure that the turbine remains in good performance for the operation of the ship, the turbine must be carried out in special care.

1. Routine Care/Special Routine.

Table 3. Table of routine/special treatment.

No.	Components	Treatment Type
1	Governor System	Check, clean replace LO
2	Quick Action Stop Valve	Check the function and leak
3	Clutch:	Check, measure

No.	Components	Treatment Type
4	Gear Box	Check wear, LO Pressure
5	Lubricating Oil Pump	Check for wear, LO Pressure
6	Washing Oil	Filtering, replace if necessary
7	Vacuum Pump and System	Check for leaks
8	Condensate system	Check and check for leaks
9	Aux Condenser system	Check for leaks
10	Element Spin on Type	Changed
11	Oil Cooler	Filtering, check for leaks, replace O Ring
12	Wind Power Generator filter	Check filter, clean
13	Instrument Turbine Cable	Check the function
14	Lubricating oil	Check, replace

2. Daily Checking.

   Daily checks are carried out by the steam turbine operator as long as the turbine operates alternately during each watch period. The types of checks carried out are:

   a. The level and condition of the lubricating oil in the tank.
   b. The condition and pressure of the condenser cooling water.
   c. Visual form of the turbine.
   d. The sound produced by the turbine.
   e. Function and work of measuring tools.

3. Repair and Overhaul.

   The activities carried out for repairs and overhauls are when the turbine has been operating (running hour) in accordance with the operating instructions. These overhaul activities include.

Table 4. Overhaul activities.

No.	Components	Treatment Type
1	Turbine Wheel	Check blade condition & surface
2	Pinion Shaft	Check conditions and tolerances.
3	Bearing	Check clearance, shim / replace
4	Governor system	Overhaul and check

4. Trial.

Tests are needed to carry out periodically on the work of a steam turbine. Generally, this test is also based on recommendations from the operating manual. The tests carried out are as follows:

a. Oil Low Pressure Trip Mechanism.
b. Overspeed trip mechanism.
c. Low oil pressure alarm.
d. Emergency trip push button.

REFERENCES

Jackson, L and Morton, T.D. *General Engineering Knowledge for Marine Engineers*. 5th ed. London, Thomas Reed Publications Ltd 1990. (lSBN 09-47- 63776-1) T2.

Joel, R. *Basic Engineering Thermodynamics in S.I. Units*. 5th ed. Harlow, Longmann, 1996 (ISBN 05-82- 25629-1) T3.

Morton, TD *Motor Engineering Knowledge for Marine Engineers*. London. Thomas Reed Publications Ltd, 1994 (ISBN 09-01-2856-5) T4.

Taylor, D.A.*Introduction to Marine Engineering. 2nd ed*. London, Butterworth. 1990 (ISBN 07-50-6253-9) T5.

Saputra, Fajar Rizki. *Proses Kerja pada Sistem Pembangkit Listrik Tenaga Uap (PLTU) Bahan Bakar Batubara* Sumber: http://ptmproduction.blogspot. Diakses 23 Januari 2107.

Taufan, Muhammad, (2011). *Sejarah Turbin Uap*. http://www.rider-system/sejarah-turbin-uap Diakses 2 Februari 2106

Onny. Siklus Rankine (2). *Efisiensi Termal* https://artikel-teknologi.com/siklus-rankine-2-efisiensitermal/. Diakses 12 Desember 2016.

Undang-Undang Uap Tahun 1930- JDIH Kemnaker jdih.kemnaker.go.id/data_puu/UU_Uap_1930.pdf

Supardi, Nurul Iman, (2011).*Tabel Properti Termodinamika Untuk Uap (Steam Table)*. https://nurulimantmunib.wordpress.com/tabel-uapjenuh. Diakses. 1 Januari 2017.

Fitbirmarket http://fitbirmarket.ru/steam-table-andmollier-diagram. Diakses 12 Januari 217.

Rauf, S. Bobby P.E. *Thermodynamics Basics – Enthalpy, Entropy, Molliers Diagram and Steam Tables*.

Wirabima. *Sejarah Turbin Uap*. http://www. com/sejarah-turbin-uap/. Diakses 12 Desember 2016.

Suyanto:2010. Klasifikasi Turbin

Yunus, Asyari D.*Mesin Konversi Energi.Teknik Mesin*, Universitas Darma Persada – Jakarta.

ATTACHMENT

IMO MODEL COURSE: 7.04

OFFICER IN CHARGE OF AN ENGINEERING WATCH

FUNCTION 1. MARINE ENGINEERING AT THE OPERATIONAL LEVEL

PART B1. COURSE OUTLINE

Knowledge, Understanding, and Proficiency

COMPETENCE:

1.4 OPERATE MAIN AND AUXILIARY MACHINERY AND ASSOCIATED CONTROL SYSTEM

Training Outcome:

Demonstrates a Knowledge and Understanding of:

1.4.1 BASIC CONSTRUCTION AND OPERATION

PRINCIPLES OF MACHINERY SYSTEM

1.4.1.2 MARINE STEAM TURBIN

TOTAL HOUR: 50

1.4 OPERATE MAIN AND AUXILIARY MACHINERY

AND ASSOCIATED CONTROL SYSTEM

1.4.1 BASIC CONSTRUCTION AND OPERATION PRINCIPLES OF MACHINERY SYSTEM

1.4.1.2 MARINE STEAM TURBINE

TEXTBOOKS:

1. T2. Jackson, L, and Morton, T.D. General Engineering Knowledge for Marine Engineers. 5th ed. London, Thomas Reed Publications Ltd 1990. (lSBN 09-47- 63776-1)
2. T3. Joel, R. Basic Engineering Thermodynamics in S.I. Units. 5th ed. Harlow, Longman, 1996 (ISBN 05-82- 25629-1)
3. T4. Morton, TD Motor Engineering Knowledge for Marine Engineers. London. Thomas Reed Publications Ltd, 1994 (ISBN 09-01-2856-5)
4. T5. Taylor, D.A.Introduction to Marine Engineering. 2nd ed. London, Butterworth. 1990 (ISBN 07-50-6253-9)

TEACHING AIDS:

1. A1. Instruction Manual (Part D of this course)
2. A2. Manufacturers' Manuals. Manufacturers 'instruction manuals and handbooks are the main sources of information instructing the correct procedures in dismantling, inspection and assembly of the specific items of machinery listed.
3. A3. Video cassette player / DVD player, personal computer
4. A4. Marlins English language Study Pack 1 and Study Pack 2 with audio cassette and teacher's notes (www.marlins.co.uk)
5. V4. Handling and treatment of heavy fuels (Code No. 143)
6. V5. Fuel oil burner theory and diagnostics (Code No. 604)
7. V6. Internal care of marine boilers (Code No. 150)

9. V7. Centrifugal pumps -theory and operation (Code No. 9)

REQUIRED PERFORMANCE:

1.2 Marine Steam Turbine (50 Hour)

1.2.1. Rankine Cycle (20 Hour)

1. States that the Rankine cycle is the ideal cycle where the working fluid is used in both liquid and vapour phases, such as:
   a. steam power plant
   b. refrigeration plant
2. Describes the four main components of steam plant as:
   a. the steam boiler, which produces superheated steam from feed water, the required energy being supplied from the combustion of a fuel in air.
   b. the turbine(s), which adiabatically expand the high pressure superheated steam to obtain useful output work (W).
   c. the condenser, which receives the low-pressure exhaust steam from the turbine to cool it and condense it to water.
   d. the feed pump, which raises the pressure of the condensate to the boiler pressure and pumps it back into the boiler
3. States the Rankine cycle efficiency as the ratio:

$$\text{Rankine Cycle Efficiency} = \frac{\text{Energi derived from the cycle as useful wor}}{\text{Energy supplied to the cycle}}$$

4. States that the output energy of the cycle is the turbine work (W)
5. States that the turbine work (W) is defined as the difference in energy contained in the superheated steam entering the turbine and the energy contained in the exhaust steam leaving the turbine
6. States that the energy input of the cycle is the energy transferred from the fuel during combustion in the boiler
7. States that because the working fluid is in both the liquid and steam phases during the cycle, energy
8. levels and other properties for the working fluid must be obtained from tables of thermodynamic properties
9. Draws and labels a simple line diagram of a steam plant, using "blocks" for the four main components and arrows to indicate flow

of the working fluid and indicating energy values at important points in the cycle

10. Solves simple numerical problems related to the above objectives

1.2.2. Basic Construction (10 Hour)

1. Names the materials used in the manufacture of the listed items, then describe, with the aid of sketches, the assembled construction of these items:
    a. high pressure turbine casing
    b. low pressure turbine casing
    c. astern turbine casing
    d. low pressure turbine exhaust casing
    e. high pressure turbine rotor
    f. low pressure turbine rotor
    g. receiver pipe
    h. reduction gear
    i. wheels
    j. pinions
    k. main condenser
    l. gland condenser
    m. gland packing steam leakoff reservoir
    n. gland packing steam reservoir
    o. gland packing steam leak-off reservoir
    p. gland packings
    q. gland steam makeup valve, gland steam spill valve
    r. maneuvering valve
    s. astern guardian valve
    t. flexible coupling
    u. thrust bearing
    v. labyrinth packings

x. nozzles

y. blades (moving blade, stationary blade)

z. shroud

2. States the feature of impulse turbine

3. States the feature of reaction turbine

4. Sketches types of turbine plant arrangement

   a. bleeder turbine (extraction turbine)

   b. regenerative turbine

   c. reheat turbine

1.2.3. Operation principles (20 hours)

1. Explains why main condenser is kept in vacuum

2. Explains how to keep main condenser in vacuum

3. Describes the importance of draining inside turbine casing

4. Describes, with the aids of a sketch/computer aided drawing, function of gland packing steam

5. Explains the function of maneuvering valve

6. Explains the role of extraction steam

7. Describes that gland steam pressure is controlled by make-up valve and spill valve

8. Describes how to keep the hot well level of condenser

9. Explains spinning operation

10. Explains the meaning of throttle governing and nozzle governing, which is the way of control of turbine output

11. Explains meaning of auto-spinning system

12. States that the main turbines are provided with a satisfactory emergency supply of lubricating oil, which will come into use automatically in case of failure of lubricating oil system.

AUTHOR'S PROFILE

Abdi Seno

Abdi Seno, M.Si, was born on April 21, 1971 in Padang. His marine education began when he took his Diploma degree at BPLP Semarang, graduated in 1994 majoring in engineering. Then the Strata B level was taken at STIP Jakarta, graduated in 1998. Specialist education (ATT-1/Master marine Engineer) was successfully completed in 2014 at BP3IP Jakarta. The author studied postgraduate at UNISBANK Semarang majoring in Human Recruitment Management, graduated in 2011. Currently, the author is active as a lecturer in the engineering study program and serves as Head of the Quality Assurance of Politeknik Ilmu Pelayaran Semarang.

TRANSLATOR'S PROFILE

Pratama Irwin Talenta

Pratama Irwin Talenta, S.Pd., M.Pd. was born in Rembang on May 1, 1990. His first degree was taken in IKIP PGRI Semarang in English Education, graduated in 2012. His Master's degree was achieved in 2014 in Universitas Negeri Semarang with the same major. He has experience in translating several articles for accredited international journals as well as International Accreditation documents for the Faculty of Law, Universitas Diponegoro in 2021.

Teaching Experiences, the translator has worked as a teaching staff in Unissula and the Language unit of Politeknik Ilmu Pelayaran Semarang. Currently, he is a lecturer in the English Education study program, at Universitas National Karangturi.

Latifa Ika Sari

Latifa Ika Sari is an English lecturer at Politeknik Ilmu Pelayaran (PIP) Semarang. Born in Semarang, on July 31, 1985, she has a great passion for the field of English Education and Psychology. In 2006, Latifa completed her Diploma III majoring in English for Office Management at Universitas Dian Nuswantoro Semarang. In 2008, She completed her Bachelor's Degree in Psychology at Universitas Diponegoro (UNDIP) Semarang. In 2014, he obtained a Bachelor's degree in English Education from Universitas Terbuka, Jakarta. Her Master's degree in English Education was achieved in 2017 from Universitas Negeri Semarang (UNNES). Her best achievement was in 2021 when she completed her doctoral degree in English education from the same university.

Latifa joined the Ministry of Transportation in 2008. Starting her career as a counselor for cadets at Balai Pendidikan dan Pelatihan Ilmu Pelayaran Tangerang (now Politeknik Pelayaran Banten), she was then assigned to teach Maritime English in 2009. In 2015, Latifa moved to Politeknik Ilmu Pelayaran (PIP) Semarang and was appointed to become a lecturer in 2019.

Latifa actively participates in various scientific meetings (seminars, conferences) related to English language teaching and learning. She has written several research articles published in various proceedings and journals. Her research interests include English for Specific Purposes (ESP), Maritime English, evaluation, and social semiotics.

Steam Turbine (Main Engine)

The material of this textbook covers the development of turbines steam, the Rankine Cycle, and in the form of the Steam Turbine Ideal Cycle, This section also mentions the steam boiler as a steam generator, The turbine construction section is covers its Components, Working Principles, and Classification of Steam Turbines, and Losses in Steam Turbines,

Another section covers the Characteristics, Velocity Triangle, Zeuner's Equation (SI), Triangle Speed, Blade Performance, Shapes of Turbine Moving Blade - Turbine de-Laval, Zoellly, Curtis, and Parson, Turbine Power discusses Theoretical Power, Blade Power, Indicator Power, and Turbine Effective Power and their technical settings, At the end of this textbook covers the axial forces that occur in turbines and operating procedures and maintaining steam turbines,

Penerbit Politeknik Ilmu Pelayaran Semarang
Jl. Singosari 2 A Semarang
Telp. 024-8311527
Email: penerbit@pip-semarang.ac.id