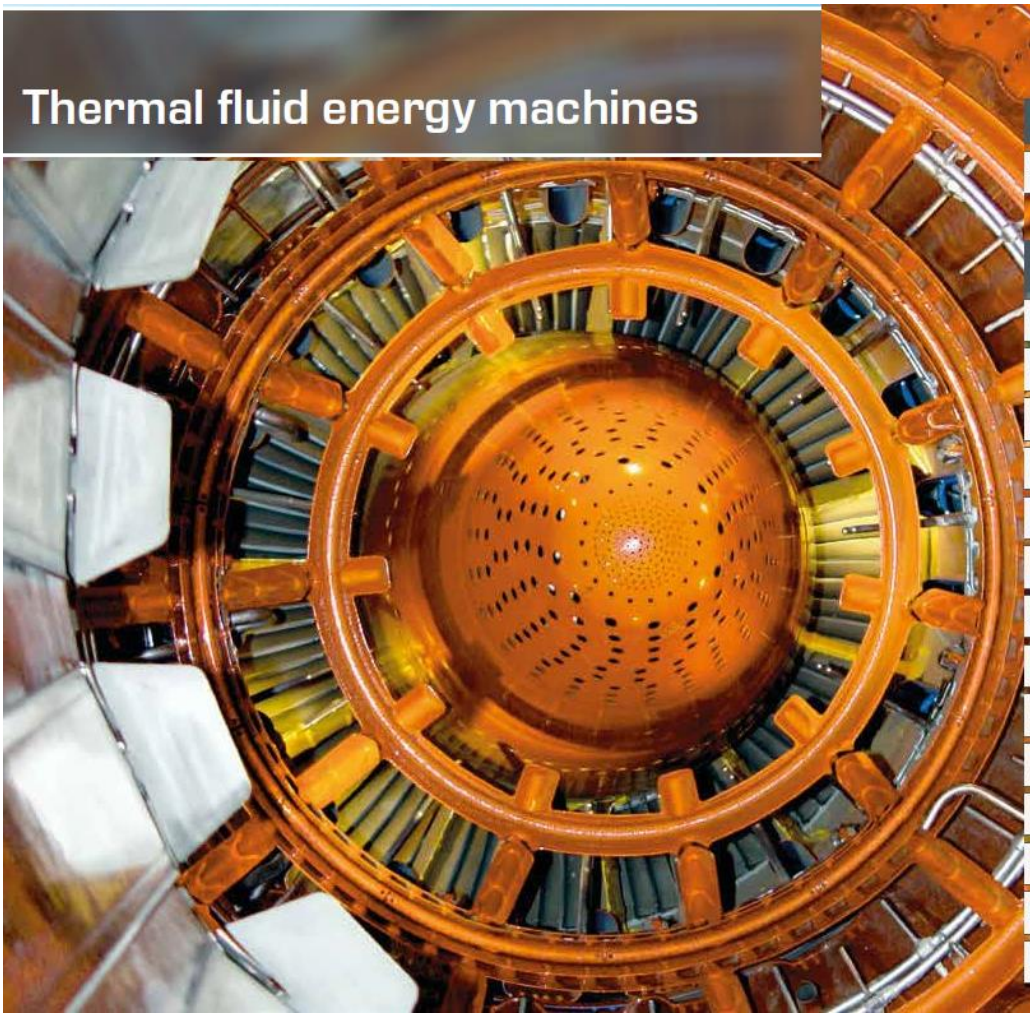
Thermal fluid energy machines



Introduction

Steam power plants

Thermal fluid energy machines

Classification of thermal fluid machinery

The characteristic feature used to differentiate between thermal and hydraulic fluid energy machines is the change in density.

- **thermal fluid energy machines:** variable density of the fluid
- **hydraulic fluid energy machines:** constant density

Thermal fluid energy machines: variable density of the fluid

Driven machines
Energy is added to the fluid

Turbomachines
Transfer of energy between the fluid and the machine by means of flow forces

- fan
- ventilator
- radial compressor

Positive displacement machines
Transfer of energy between the fluid and the machine by means of a variable volume, generated by a displacement device

- piston compressor
- screw compressor
- vane compressor

Driving machines
Energy is removed from the fluid

Turbomachines
Transfer of energy between the fluid and the machine by means of flow forces

- wind turbine
- steam turbine
- gas turbine
- jet engine

Positive displacement machines
Transfer of energy between the fluid and the machine by means of a variable volume, generated by a displacement device

- internal combustion engine
- steam engine
- Stirling engine
- gas expansion engine

The table below shows an extract from a typical curriculum of a technical university. The syllabus for the lecture on **thermal fluid energy machines** looks similar to this. Depending on focus, the syllabus can be modified in line with the classification of the fluid machinery. The GUNT devices cover most of these topics.

Thermal driving machines	GUNT products
Thermal engines	
Steam turbines	ET 805, ET 830, ET 833, ET 851
Action turbine	ET 851, HM 270 (catalogue 4a)
Reaction turbine	HM 272 (catalogue 4a)
Steam power plant	ET 805, ET 810, ET 813, ET 830, ET 833, ET 850/851
Gas turbines	ET 792 – ET 796
Setup with compressor/combustion chamber	ET 792
Gas turbine power plant	ET 795
Turbine as expansion machine	ET 792 – ET 796
Internal combustion engines	series CT 159, series CT 100, series CT 300, series CT 400
Petrol engine (four stroke)	CT 100.20, CT 150, CT 152, CT 300.04
Diesel engine (four stroke)	CT 100.22, CT 100.23, CT 151, CT 300.05, CT 400.02
Two-stroke principle	CT 100.21, CT 153
Thermal driven machines	**GUNT products**
Compressors	
Piston compressor	ET 432, ET 500, ET 508, ET 513, HM 299 (catalogue 4a)
Rotary compressor	HM 299 (catalogue 4a)
Radial compressor	HM 292 (catalogue 4a)

Basic knowledge

Steam power plants

Steam power plants play a key role in supplying electrical energy. In addition to electricity production, some steam power plants use part of the heat generated to supply district heating. This is why the Rankine steam cycle is still one of the most important industrially used cyclic processes today.

In a steam power plant, a steam turbine – driven by steam – generates mechanical energy. A generator then converts this mechanical energy into electrical energy. The steam required can be generated from nuclear energy, fossil fuels, solar energy or geothermal energy, for example.

Thanks to optimised processes, it has been possible to continuously improve the efficiency of electrical energy generation over the past years. Today, a total efficiency of almost 45% has been achieved.

Steam power plants essentially have the same design:

Heat source	Steam generator	Turbine with generator	Cooling

The following types of steam power plants are distinguished according to the heat source that provides the thermal energy:

Nuclear power plant

Coal-fired power plant

Oil-fired power plant

Rarely exclusive use of oil, mostly as an additive to coal.

Solar thermal power plant

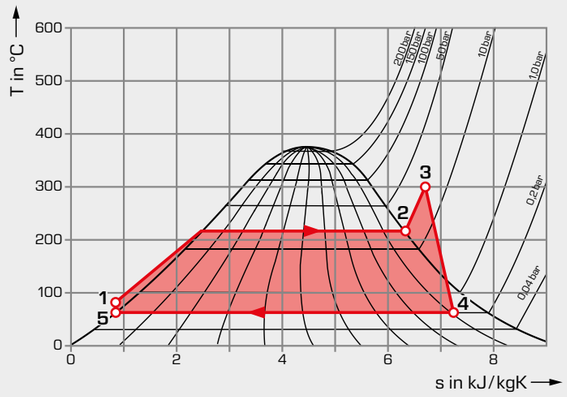
Gas and steam turbine power plant

Theoretical fundamentals of the cyclic process of a steam power plant

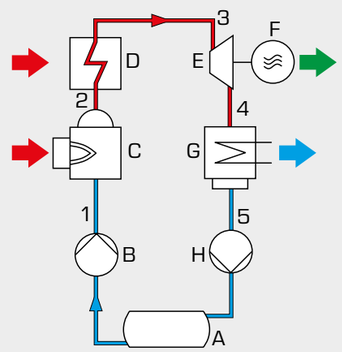
Rankine cycle

The Rankine cyclic process is used to assess, evaluate and compare steam power plants. This thermodynamic cyclic process describes the conversion of thermal energy into mechanical energy and vice versa. As with all thermodynamic cycles, it cannot exceed the efficiency of the corresponding Carnot process.

In steam power plants, first the thermal energy of a working medium (usually water but also ammonia, for example) is converted into mechanical energy. To this end, the working medium is alternately condensed at low pressure and evaporated at high pressure. The pressure is applied by the feed pump through expending work and reduced in the turbine while releasing work. The working medium is carried in a closed circuit.



T-s diagram of a steam power plant



Process schematic for a steam power plant

A feed water tank, **B** feed water pump, **C** steam boiler, **D** superheater, **E** steam turbine, **F** generator, **G** condenser, **H** condensate pump;

thermal energy, low temperature,
thermal energy, high temperature,
mechanical/electrical energy

The T-s diagram represents the Rankine cycle of a steam power plant. The working medium is water or water steam.

1 – 2
the water is **isobarically** heated and evaporated in a steam boiler at a pressure of 22 bar

2 – 3
isobaric superheating of the steam to 300°C

3 – 4
polytropic expansion of the steam in the steam turbine to a pressure of 0,2 bar; mechanical energy is released in the process

Point 4
wet steam area: the wet steam content is now only 90 %

4 – 5
condensation of the steam

5 – 1
increase of the pressure to boiler pressure via the condensate and feed water pump, the cyclic process is complete

ET 860
Safety devices on steam boilers

Description

- **steam boiler simulation with pressure and water level regulation**
- **safety chain with commercially available components**
- **transparent boiler, clear view of the water level**
- **GUNT software for data acquisition**

The pressure and temperature in a steam boiler are increased by constantly supplying energy so that the liquid medium (in most cases water) becomes gaseous. Steam boilers are monitored by safety devices which are electrically connected in series, the so-called “safety chain”. If one of the monitoring or control devices trips, an alarm is triggered and the entire system or the affected system component is switched off.

The ET 860 trainer enables a steam boiler simulation to demonstrate the operating principle and response behaviour of a safety chain according to legal regulations. The trainer has a closed water circuit which consists of a supply tank, a pump and a transparent steam boiler model with burner. The boiler is equipped with industrial components which monitor and/or regulate the water level and the pressure.

The components used have a high practical relevance. The safety chain for the burner is functional. Burner operation is simulated.

In addition to the safety devices, the system is equipped with 15 fault circuits. This enables the simulation of system component faults so that students can learn how to localise the faults.

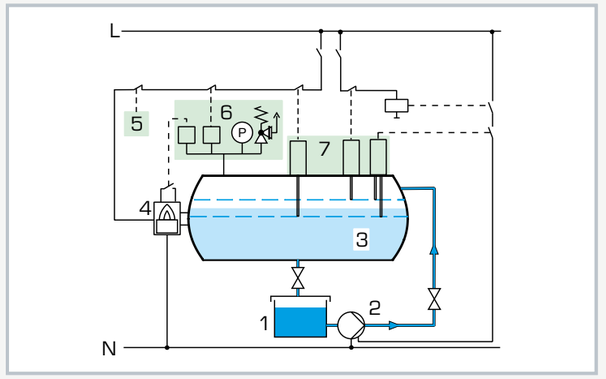
Sensors measure the water level and the pressure. The measured values are transmitted directly to a PC via USB. The data acquisition software is included. The process schematic with the safety components, the pressure curves and a representation of the water level can be observed in the software.

Learning objectives/experiments

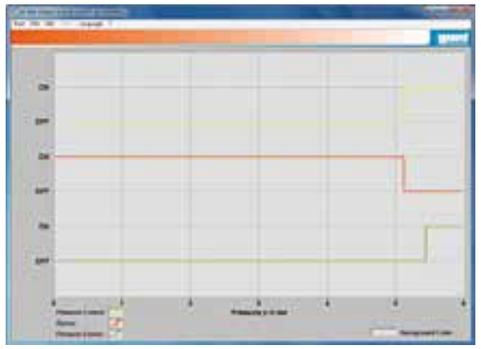
- model of an oil-fired steam boiler with operating and safety components
- characteristics of the monitoring elements
- fault circuits
  - burner with flame monitoring
  - pressure switch and limiter
  - feed water and level controller
  - high and low water limiter

ET 860
Safety devices on steam boilers

1 water level monitoring, 2 burner, 3 steam boiler model, 4 supply tank, 5 switch cabinet, 6 switch box for fault circuit, 7 pressure measurement equipment



Safety chain of a steam boiler
1 supply tank, 2 feed water pump, 3 boiler, 4 burner, 5 time control, 6 pressure monitoring, 7 water level monitoring;
green: safety chain according to legal regulations , blue: water



Software screenshot: behaviour of burner, pressure limiter and pressure controller if the pressure in the boiler rises

Specification

[1] simulation of the operation of a steam boiler
[2] control of water level and pressure of the boiler and fault circuit
[3] 15 faults that trigger the safety chain
[4] safety chain according to legal regulations containing: level switches, pressure switch and pressure controller
[5] transparent boiler to observe the water level
[6] steam pressure simulated using compressed air
[7] operation of burner simulated
[8] front panel with process schematic, indicator lamps and lab jacks
[9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Boiler capacity: 110L
Supply tank capacity: 150L

Pump
- power consumption: 40...70W
- max. flow rate: 66L/min
- max. head: 4m

Pressure switch: 0,5...6bar
Pressure limiter: 0,5...6bar
Safety valve: 6bar

Measuring ranges
- pressure: 0...6bar
- level: 0...100%

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase
120V, 60Hz, 1 phase
LxWxH:: 1850x790x1800mm
Weight: approx. 220kg

Required for operation

Compressed air connection: 5bar
PC with Windows

Scope of delivery

1 trainer
1 GUNT software CD + USB cable
1 digital multimeter
1 set of laboratory cables
1 set of instructional material

ET 805.50
Determination of the vapour content

Learning objectives/experiments

- determining the vapour content using
  - a separating calorimeter with cyclone water separator
  - a throttling calorimeter with vapour depressurisation
- using an h-s diagram

Description

■ two different ways to determine the vapour content

The vapour content x is a dimensionless ratio between 0 and 1. It is defined by the ratio of mass of vapour and total mass. The total mass is calculated from the sum of fluid mass and vapour mass. If the vapour content is x=0, the evaporation medium is completely liquid, x=1 means dry saturated vapour, a value in between means wet vapour with a variable liquid content. Separating and throttling calorimeters are used to determine the vapour content. In practice, devices to determine the vapour content are used in steam power plants, downstream of steam turbines or at steam boilers upstream of the superheater.

ET 805.50 uses water as working medium. Water vapour is also known as steam.

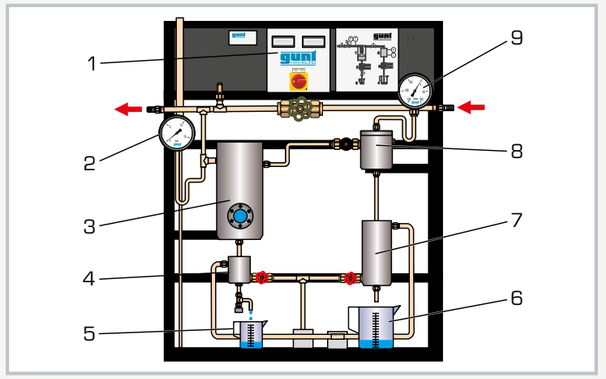
The ET 805.50 trainer uses a two-stage method to determine the vapour content. A separating calorimeter with cyclone water separator is used to determine vapour contents with a high liquid content (0,5<x<0,95). The liquid part is separated, cooled and collected in a measuring cup.

A downstream throttling calorimeter is used to determine vapour contents between x=0,95 and x=1. The wet vapour is depressurised in this process. The remaining vapour part is depressurised and then liquefied in a water-cooled condenser and also collected in a measuring cup. The two quantities can be used to determine vapour mass and total mass to calculate the vapour content.

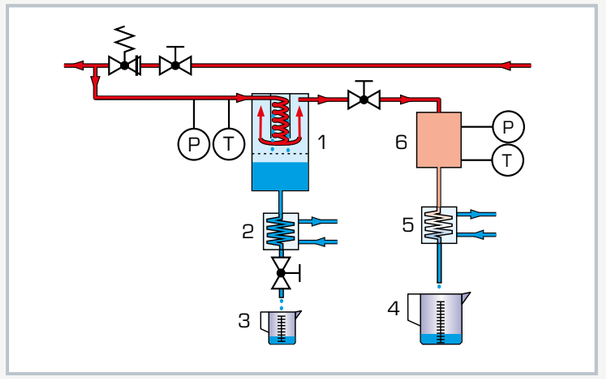
Sensors measure the pressure and temperature before and after depressurisation. The measuring results can be used to determine the vapour content with the h-s diagram.

The water vapour has to be generated externally, e.g. with the electrical steam generator WL 315.02. To determine the vapour content of the steam power plants ET 805, ET 830, ET 850 or ET 833, ET 805.50 is recommended.

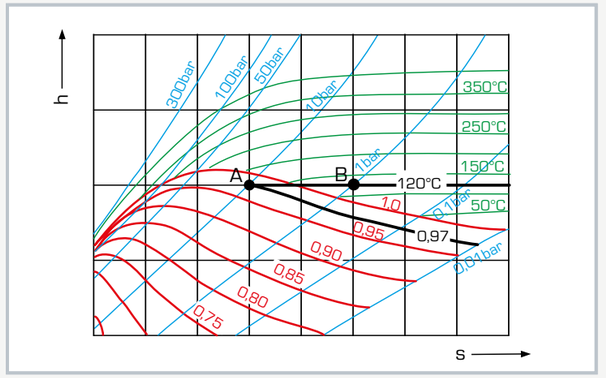
ET 805.50
Determination of the vapour content



1 displays for temperature, 2 vapour inlet manometer, 3 cyclone water separator, 4 cooler for separated water, 5 measuring cup for separated water, 6 measuring cup for liquefied vapour, 7 condenser, 8 tank for depressurising the vapour, 9 manometer for depressurisation process; red: vapour inlet and outlet



1 water separator with cyclone, 2 cooler, 3 measuring cup for separated water, 4 measuring beaker for liquefied vapour, 5 condenser, 6 tank for depressurising the vapour; red: wet vapour, orange: depressurised vapour, blue: water; P pressure, T temperature



h-s diagram; h enthalpy, s entropy; red: vapour content, green: temperature, blue: pressure; black: example of measuring result: A vapour at 10bar, B vapour after adiabatic depressurisation at 1bar, vapour content 0,97

Specification

[1] two different ways to determine the vapour content
[2] separating calorimeter for vapour content 0,5<x<0,95, with water-cooled aftercooler
[3] throttling calorimeter for vapour content x>0,95, with water-cooled condenser
[4] safety valve for safe operation
[5] water vapour has to be supplied by an external steam generator, e.g. electrical steam generator WL 315.02
[6] accessory for steam power plants ET 805, ET 830, ET 850 or ET 833

Technical data

Supplied vapour
- max. temperature: 240°C
- max. pressure: 10bar

Safety valve: 10bar

Measuring ranges
- temperature: 0...400°C
- pressure (inlet): 0...16bar
- pressure (outlet): -150...100mbar

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase
120V, 60Hz, 1 phase
UL/CSA optional
LxWxH:: 890x800x1890mm
Weight: approx. 90kg

Required for operation

steam: max. 10bar, 240°C
water connection, drain

Scope of delivery

1 trainer
2 measuring cups
1 set of weights
1 set of instructional material

ET 805 – ET 851
GUNT Steam power plants

GUNT steam power plants for laboratory and experimental applications offer a practical approach to teaching this important subject area in technical fields of study. They are particularly well suited for investigating and understanding the behaviour of steam power plants under different operating conditions. The plants are built with real, industrial components, and can also be used to teach aspects such as maintenance, repair, measurement technology, and control engineering.

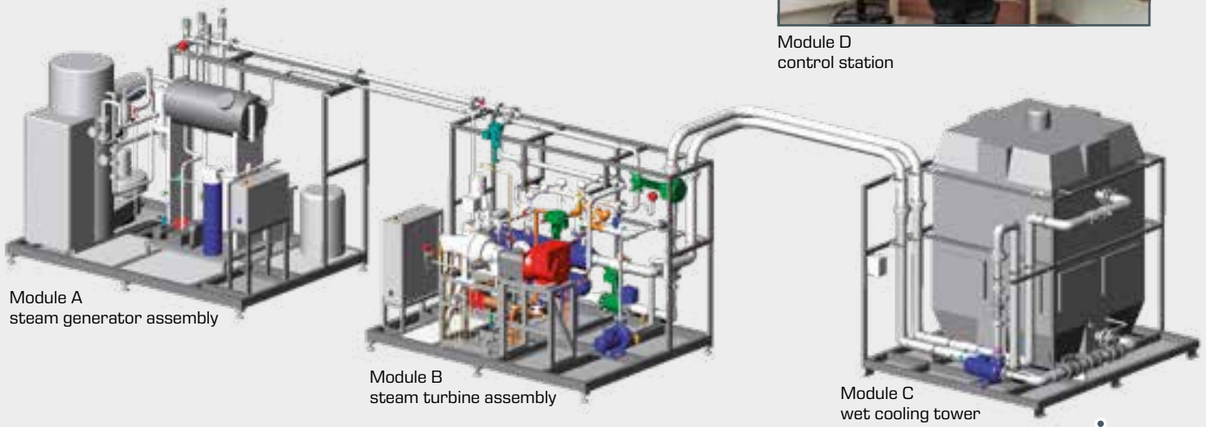
GUNT offers a wide range of steam power plants

The GUNT steam power plant product range encompasses everything from simple demonstration facilities with a power output of just a few watts, to modular systems in the medium power range, and a complex steam power plant with a process control system and an output power of 20 kW (ET 805).

Due to the size and complexity of ET 805, many aspects of its operating behaviour correspond to those of real large-scale plants, allowing for hands-on training. ET 805 consists of three separate modules and a control station.

ET 805 Steam power plant 20 kW
with process control system

Module D
control station



Module A
steam generator assembly

Module B
steam turbine assembly

Module C
wet cooling tower

ET 810
Steam power plant
with steam engine
(5 W)

ET 813 Two-cylinder steam engine (500W)
together with HM 365 Universal drive and brake unit and
ET 813.01 Electrical steam generator

ET 850 Steam
generator and
ET 851 Axial
steam turbine
(50W)

ET 830
Steam power plant, 1,5 kW

or

ET 833
Steam power plant 1,5 kW
with process control system

5 W | 50 W | 500 W | 1.500 W | 20.000 W

ET 810
Steam power plant with steam engine

Description

- **functional model of a steam power plant**
- **demonstrates the function of a steam engine**

In a steam engine, thermodynamic energy in the form of vapour pressure from steam generators is converted into mechanical energy. This can be used further downstream in the process to generate electricity or to power machinery and vehicles.

A steam power plant consists of a heat source for generating steam, a turbine or steam engine with a generator, and a cooling device for condensing the exhaust steam.

The ET 810 trainer contains the main components of a steam power plant: a gas-fired steam boiler, a single-cylinder piston steam engine with a generator, a condenser, a feed water tank, and a feed water pump.

The steam boiler generates water steam and supplies it to the piston steam engine. A piston and a crank mechanism convert the energy from the steam into mechanical energy.

A generator in the form of a DC motor generates electricity from the mechanical power. Four light bulbs are used as consumers of the resulting electrical energy. The exhaust steam is condensed in a water-cooled condenser.

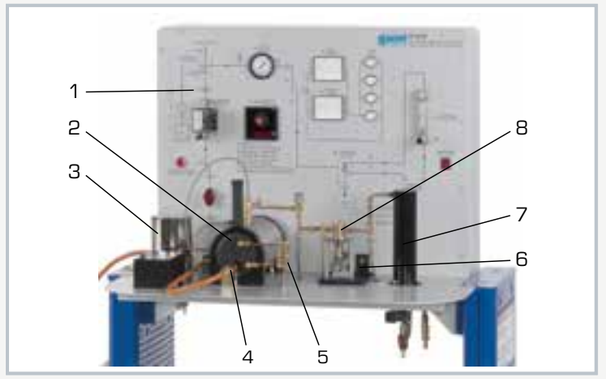
Safe operation is ensured by safety devices that monitor the boiler temperature and a safety valve.

Sensors record the temperature, pressure, and flow rate at all relevant points. The measured values can be read on displays. Current and voltage from the generator are measured and displayed in the experimental unit.

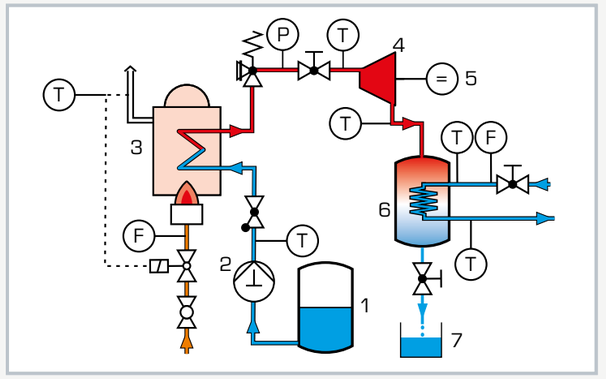
Learning objectives/experiments

- demonstration of the function of a steam engine
- familiarisation with the components of a steam power plant and how they interact
- recording the vapour pressure curve
- effect of re-evaporation and backfeed of cold water
- determining fuel consumption, the amount of steam generated, the boiler efficiency, and the capacity of the condenser

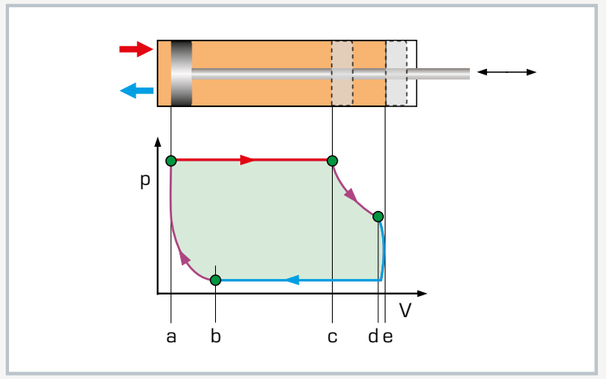
ET 810
Steam power plant with steam engine



1 process schematic with displays and controls, 2 steam boiler, 3 feedwater tank, 4 burner, 5 boiler water level indicator, 6 generator, 7 condenser, 8 steam engine



1 feedwater tank, 2 feedwater pump, 3 steam boiler, 4 steam engine, 5 generator, 6 condenser, 7 condensate tank; T temperature, P pressure, F flow rate; orange: gas, red: steam, blue: water



p,V diagram: p pressure, V volume; a top dead centre and inlet opens, c inlet closes, d outlet opens, b outlet closes; red: inlet, blue: outlet, green: work done, purple: compression and expansion

Specification

[1] demonstration of a steam power plant with single-cylinder piston steam engine
[2] gas-fired boiler for steam generation
[3] water-cooled condenser
[4] DC generator
[5] light bulbs as consumers
[6] sensor and display for temperature, pressure, flow rate, voltage and current
[7] safety valve and temperature monitoring for safe operation

Technical data

Steam engine
- power: max. 5W
- speed: max. 1200min^{-1}
- cylinder: Ø 20mm

Generator
- DC motor: max. 3,18W at 6000min^{-1}

Gas-fired boiler
- safety valve: 4bar
- gas connection 3/8"L (propane or butane)

Measuring ranges
- temperature: 8x -20...200°C
- pressure: 0...6bar
- flow rate:
  - 0...110L/h (gas)
  - 15...105L/h (water)
- voltage: 0...10VDC
- current: 0...250mA

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase
120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 1700x810x1440mm
Weight: approx. 110kg

Required for operation

water connection, drain, gas supply 3/8"L (propane gas or butane gas)

Scope of delivery

1 trainer
1 set of hoses
1 oil (100mL)
1 set of accessories
1 set of instructional material

ET 813 + ET 813.01 + HM 365
Steam power plant with two-cylinder steam engine

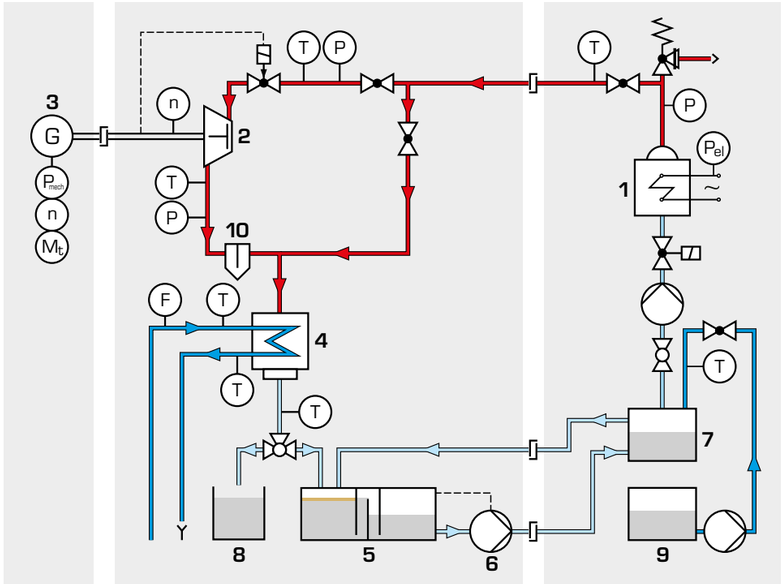
The experimental plant, consisting of a two-cylinder steam engine ET 813, the electrical steam generator ET 813.01 and the universal drive and brake unit HM 365, illustrates the typical cyclic process of a steam power plant. The clear layout and comprehensive instrumentation allow you to observe and understand all functions.

- part of the GUNT-FEMLine
- operating principle of a piston steam engine
- cyclic process of a steam power plant
- power measurement
- energy balances
- determination of efficiency
- electrical steam generator: quick start-up, fully automatic, reliable, no exhaust gases, no fuel necessary
- no special authorisation needed (in EC countries)

HM 365 Universal drive and brake unit

ET 813 Two-cylinder steam engine

ET 813.01 Electrical steam generator



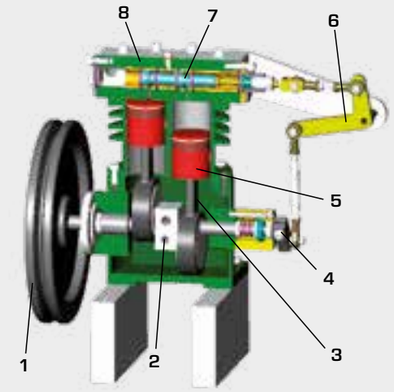
HM 365 | ET 813 | ET 813.01

Steam is generated in the electric steam generator **1** and fed to turbine **2** via pipes. The turbine is loaded via the brake unit **3**. The exhaust steam from the steam engine then enters the water-cooled condenser **4**. The condensate is carried to the cascade tank **5**, where lubricating oil is separated from the steam engine. From here, pump **6** pumps the condensate into the feedwater tank **7** and the circuit is closed.

1 steam generator, **2** turbine,
3 brake unit, **4** condenser,
5 cascade tank, **6** pump,
7 feedwater tank,
8 condensate measuring tank,
9 fresh water tank,
10 oil separator;
steam,
cold water / fresh water,
feedwater

A single action two-cylinder steam engine with enclosed crank drive is the core element. Because of its enclosed design this kind of steam engine is called a steam motor.

A piston slide valve inside the cylinder cover controls the flow of steam. The crankshaft moves the piston slide valve via a small crank and a bell crank lever.



Steam engine

1 flywheel, **2** crankshaft, **3** connecting rod,
4 drive crank to operate the slide valve, **5** piston with piston rings,
6 bell crank lever, **7** piston slide valve, **8** cylinder cover

Software for data acquisition

The software enables display of measured values on a PC. Recording and saving of data history is possible.

With the help of spreadsheet programmes (e.g. MS Excel) saved data can be evaluated. The measured values are directly transmitted to the PC via USB.

ET 813
Two-cylinder steam engine

The illustration shows a similar unit.

Learning objectives/experiments

- together with HM 365 and ET 813.01
  - determining the amount of steam generated, the mechanical power and the power consumption
  - calculating the overall efficiency
  - determining the heat dissipated in the condenser
  - recording the vapour pressure curve
  - effective output
  - specific steam consumption by the steam engine
  - thermal capacity of the boiler

Description

- **functioning of a two-cylinder piston steam engine**
- **energy balance of the steam power plant**
- **design of a complete steam power plant together with steam generator ET 813.01 and universal drive and brake unit HM 365**
- **part of the GUNT-FEMLine**

In a steam power plant, thermal energy is converted into mechanical energy, and ultimately into electrical energy. A steam power plant consists of a heat source for generating steam, a turbine or steam engine with generator, and a cooling device for condensing. The steam engine is used to convert thermal energy into mechanical energy.

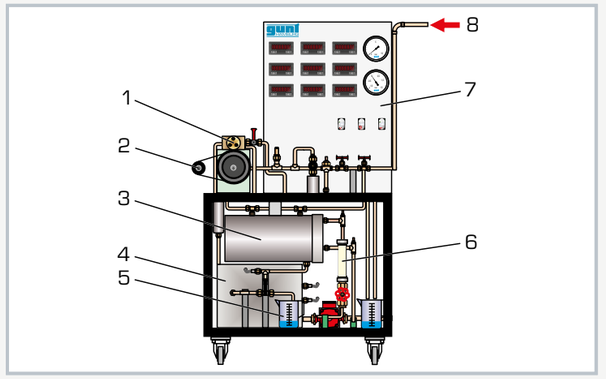
The ET 813 steam engine, together with the brake unit HM 365 as a consumer of the electrical energy and the steam generator ET 813.01, forms a complete steam power plant.

The trainer includes a steam engine, a condenser and a condensate tank, and comprehensive instrumentation.

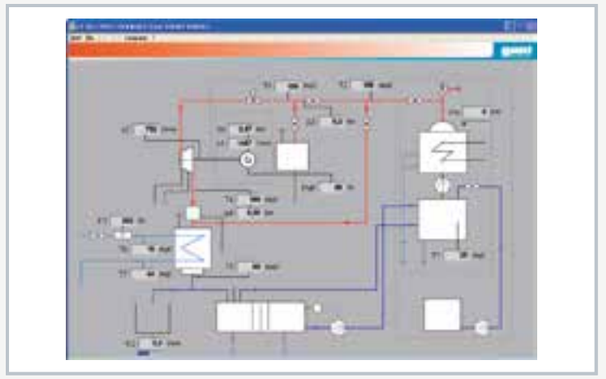
The steam engine is a sealed two-cylinder steam engine with 180° crank offset and single-acting plunger. It can be used to show the operating properties and functioning of a piston steam engine. Since the exhaust steam in piston steam engines contains entrained lubricating oil, an oil separator and a cascade tank ensure the condensate is cleaned as necessary, so that clean water can be fed back into the feedwater tank of the steam generator ET 813.01.

Sensors record the temperature, pressure, speed, and flow rate at all relevant points. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included.

ET 813
Two-cylinder steam engine



1 steam engine, 2 belt drive to HM 365, 3 condenser, 4 condensate tank, 5 condensate measuring tank, 6 sensor for cooling water flow rate, 7 displays and controls, 8 live steam supply from ET 813.01



Software screenshot: process schematic

Experimental setup ready for operation: left: brake unit HM 365, centre: two-cylinder steam engine ET 813, right: steam generator ET 813.01

Specification

[1] two-cylinder piston steam engine
[2] atmospheric capacitor
[3] condensate tank as cascade tank with condensate pump
[4] steam engine loaded via brake unit HM 365
[5] sensor and display for temperature, pressure, flow rate, and speed
[6] determination of amount of steam via condensate
[7] steam supplied by steam generator ET 813.01
[8] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Two-cylinder piston steam engine
- speed: max. 1000min^{-1}
- max. continuous power: 500W
- 2 cylinders

bore: 50mm
stroke: 40mm

Condensate pump
- power consumption: max. 60W
- max. flow rate: 2,9m^3/h
- max. head: 4m

Condenser
- transfer surface: 3800cm^2

Measuring ranges
- temperature: 7x 0...400°C
- pressure: 0...10bar / 0...1,6bar
- speed: 0...1200min^{-1}
- flow rate: 100...1000L/h (cooling water)

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 950x800x1750mm
Weight: approx. 200kg

Required for operation

water connection, drain, steam (8kg/h, 7bar)
PC with Windows recommended

Scope of delivery

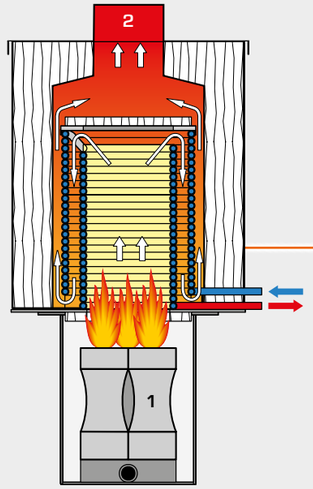
1 trainer
3 measuring cups
1 stopwatch
1 set of accessories
1 GUNT software CD + USB cable
1 set of instructional material

ET 850 + ET 851
Laboratory scale steam power plant

When combined, the ET 850 Steam generator and the ET 851 Axial steam turbine from GUNT represent a real laboratory-sized steam power plant.

This plant has all the important components of a real large-scale plant: A once-through water-tube boiler with superheater, a condenser with water jet pump for vacuum operation, a feed water tank, pumps for condensate and feed water, a steam turbine with dynamometer, shaft sealing with labyrinth and sealing steam.

- once-through water-tube steam boiler design assures highest safety
- quick steam generation due to small water capacity
- electrical superheater enables adjustable superheating of steam
- clean and odourless combustion due to heating with propane or natural gas
- water-cooled condenser evacuated by water jet pump enables operation without steam turbine ET 851 as well



Sectional view of the ET 850 Steam generator

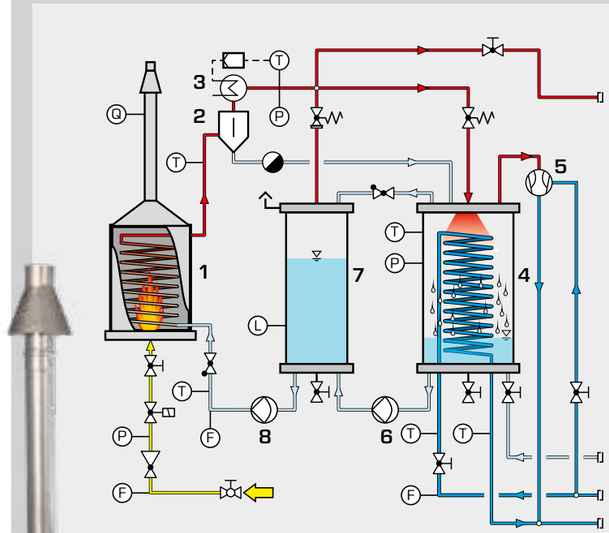
1 burner, **2** exhaust gas, ⬆ direction of flow of the heated air along the heat exchanger

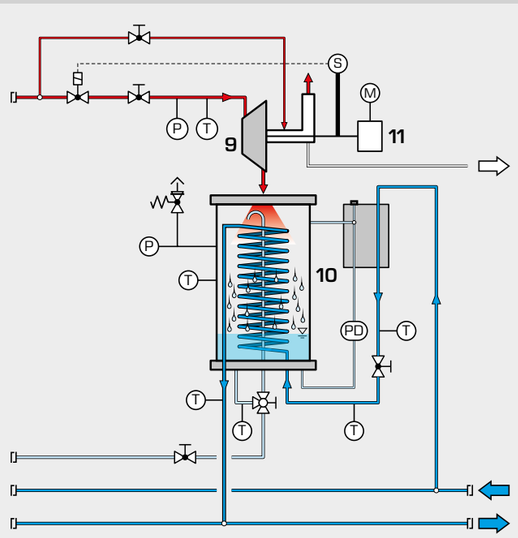
ET 850 Steam generator

1 steam boiler,
2 water separator,
3 superheater,
4,10 condenser,
5 water jet pump,
6 condensate pump,
7 feed water tank,
8 feed water pump,
9 turbine,

ET 851 Axial steam turbine

11 brake;
F flow,
P pressure,
PD differential pressure,
Q exhaust gas analysis,
S speed,
T temperature,
M torque



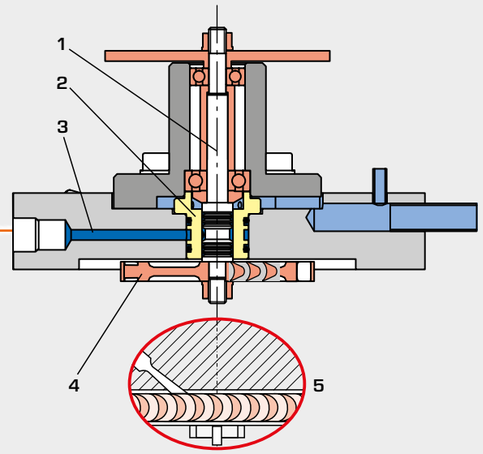


ET 850 Steam generator

ET 851 Axial steam turbine

The operating behaviour is very similar to that of a real plant. Students can observe and practice the careful adjustment of the steam generator, turbine, condenser and superheater. The data acquisition software evaluates the results efficiently and accurately, and provides a quick overview.

- single-stage axial flow impulse turbine
- vertical shaft mounted on ball bearings
- contactless labyrinth gland with sealing steam enables vacuum operation
- transparent, water-cooled condenser
- wearless eddy current brake with permanent magnet
- safety cut-off in case of overspeed via trip valve
- steam flow rate determined via condensate level



1 shaft, **2** labyrinth unit, **3** steam inlet, **4** rotor,
5 sectional view of nozzle and blades

ET 850
Steam generator

2E

Learning objectives/experiments

- specific characteristic values of a steam boiler
- efficiency of a steam generator
- analysis of the exhaust gases
- influence of different burner settings
- saturation temperature and pressure of the steam
- steam enthalpy
- determination of the heat flux density and the overall heat transfer coefficient

Description

- **laboratory-scale steam generator for wet or overheated steam**
- **characteristic values of a steam boiler**
- **various safety and monitoring devices**
- **setting up a complete steam power plant in conjunction with the ET 851 steam turbine**

A steam generator generates steam which will later be used in drives for steam turbines or for heating. Steam generators and steam consumers together form a steam power plant. Steam power plants work according to the Rankine cycle which is still one of the most important industrially used cyclic processes. Steam power plants are mainly used for electrical power generation.

The ET 850 steam generator and the ET 851 axial steam turbine together form a complete laboratory-scale steam power plant.

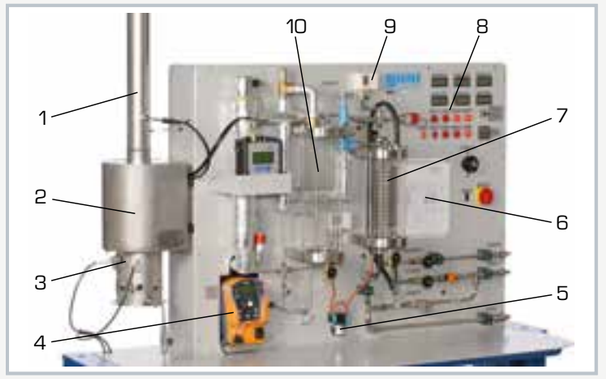
The ET 850 trainer serves to familiarise students with the components and principle of operation of a steam generator and enables them to examine the characteristic values of the system.

If the steam generator is operated without the steam turbine, the generated steam is directly liquefied in a condenser and fed back into the evaporation circuit via condensate and feed water pump. A water jet pump evacuates air from the condenser and generates negative pressure. The steam boiler is a once-through boiler with small water content and a short warm-up time.

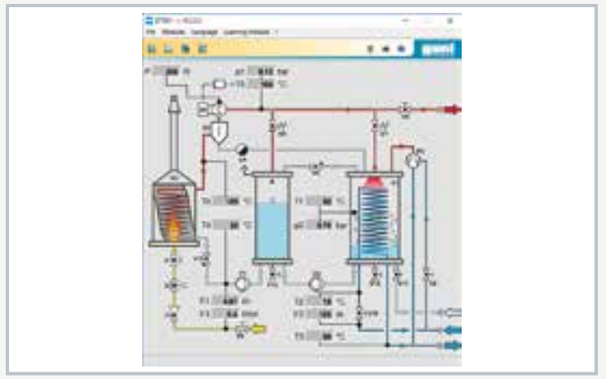
As all components are clearly arranged on the front panel, the cyclic process can be easily monitored and understood. Sensors record the temperature, pressure and flow rate at all relevant points. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included.

The steam generator has been constructed according to the Pressure Equipment Directive, it has been pressure-tested and is equipped with all legally required safety devices.

ET 850
Steam generator



1 chimney for exhaust gas, 2 steam boiler, 3 burner, 4 feed water pump, 5 condensate pump, 6 process schematic, 7 condenser, 8 displays and controls, 9 pressure switch, 10 feed water tank



Software screenshot: process schematic

Left: ET 850 steam generator; right: ET 851 axial steam turbine; set up ready for operation, together they form a steam power plant

Specification

[1] steam generator with gas-powered heater
[2] ET 851 steam turbine can be connected to operate a steam power plant
[3] condenser as a thick-walled glass cylinder with water-cooled tube coil and water jet pump for air extraction
[4] closed-circuit feed water supply
[5] sensor for temperature, pressure, flow rate
[6] safety facilities in accordance with the Pressure Equipment Directive for safe operation
[7] exhaust gas analysis with exhaust gas analyser
[8] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Burner
- heating power: 6kW

Steam generator
- once-through boiler
- operating pressure: 8bar, max. pressure: 10bar
- max. steam temperature: 250°C
- max. steam output: 8kg/h
- power of superheater: 750W

Measuring ranges
- temperature: 0...400°C
- pressure:
  - 0...1,6bar abs. (condenser)
  - 0...16bar (live steam)
- flow rate:
  - 0...14L/min (propane gas)
  - 0...720L/h (cooling water)
  - 0...15L/h (feed water)

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase, 120V, 60Hz, 1 phase
LxWxH: 1830x790x1770mm (without chimney)
Weight: approx. 280kg

Required for operation

gas supply (propane gas): 700g/h, 50mbar
water connection: 720L/h, 2bar, drain
ventilation, exhaust gas routing
PC with Windows recommended

Scope of delivery

1 trainer
1 GUNT software CD + USB cable
1 exhaust gas analyser
1 packing unit of distilled water (20L)
1 set of tools
1 set of instructional material

ET 851
Axial steam turbine

2E

Description

- **laboratory-scale axial single-stage steam turbine**
- **variety of safety and monitoring equipment**
- **design of a complete steam power plant together with the ET 850 steam generator**

Steam turbines are turbomachines. In practice, steam turbines are mainly used in power plants to generate electricity. A distinction is made between turbines depending on the flow direction and state of the steam, the working process, and steam supply and discharge.

The ET 851 experimental unit is a single-stage axial impulse turbine with a vertical axis. The steam required is generated by the steam generator ET 850. The turbine can be operated with saturated steam or superheated steam. The steam is expanded in the turbine and condensed via the water-cooled condenser. Load is applied to the turbine via an eddy current brake. The turbine has a non-contact labyrinth seal on the shaft with a sealing steam circuit. The turbine is fitted with various safety devices in order to prevent damage such as by excessively high speed or pressure in the system.

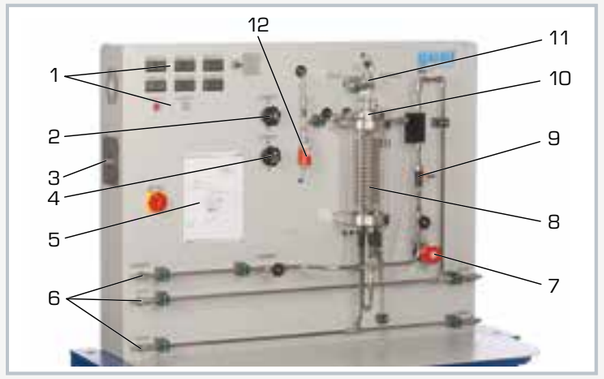
Sensors record the temperature, pressure, and flow rate at all relevant points. Turbine speed and torque are measured electronically at the eddy current brake. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included.

The ET 851 axial steam turbine, together with the ET 850 steam generator, forms a complete laboratory-scale steam power plant.

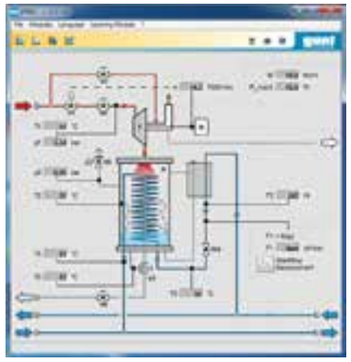
Learning objectives/experiments

- principle of operation of a steam turbine:
  - steam consumption of the turbine
  - turbine output at different settings
  - investigation of the losses occurring in different turbine components
  - power and torque curve
  - overall efficiency compared to the theoretical efficiency

ET 851
Axial steam turbine



1 displays and controls, 2 valve for sealing steam, 3 steam connection, 4 valve for steam inlet, 5 process schematic, 6 water connections, 7 pressure sensor for condensate measurement, 8 condenser with coil, 9 cooling water flow rate sensor, 10 turbine, 11 eddy current brake, 12 pressure sensor



Software screenshot: process schematic

Left: ET 850 steam generator and right: ET 851 axial steam turbine; assembled ready for operation, together both units form a complete steam power plant

Specification

[1] single-stage axial impulse turbine, mounted in corrosion-resistant, sealed ball bearings
[2] load on the turbine by eddy current brake
[3] condenser with water-cooled coiled tube
[4] steam supply from ET 850 steam generator
[5] various safety devices for safe operation
[6] sensors and digital indicator for speed, temperature, pressure and flow rate
[7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Single-stage axial impulse turbine
- impeller inner diameter: 54mm
- max. speed: 40000min^{-1}
- max. inlet pressure: 9bar abs.
- max. outlet pressure: 1bar abs.
- nominal power output: 50W

Measuring ranges
- pressure
  - steam inlet: 0...16bar
  - condenser: 0...1,6bar
  - differential pressure: 0...50mbar
- cooling water flow rate: 0...720L/h
- speed: 0...50000min^{-1}
- torque: 0...70Nmm
- temperature: 0...400°C

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase
120V, 60Hz, 1 phase
LxWxH: 1530x790x1770mm
Weight: approx. 180kg

Required for operation

water connection: 350L/h, drain
PC with Windows recommended

Scope of delivery

1 trainer
1 GUNT software CD + USB cable
1 set of instructional material

ET 830
Steam power plant, 1,5kW

Description

- **complete laboratory-sized steam power plant**
- **closed steam-water circuit**
- **GUNT software for data acquisition**
- **plant monitored and controlled with PLC**

In steam power plants, thermal energy is first converted into mechanical energy and then into electrical energy. A steam power plant essentially consists of a heat source for generating steam, a turbine with load, and a cooling mechanism for condensing the steam.

ET 830 has been designed specifically for engineering education in the field of power plant technology, and driving and driven machines. It offers a wide range of experiments to learn about the operational processes in a steam power plant.

An oil-fired once-through steam boiler produces wet steam that is turned into superheated steam by means of a superheater. The boiler's short heat-up time means rapid steam generation is possible. Load is applied to the turbine with a generator. The turbine output is determined by speed and torque.

Downstream of the turbine, the steam is condensed and returned to the boiler. The feedwater circuit is fitted with a complete water treatment system, which consists of a regenerable ion exchanger and chemical dosing. Sensors record the temperature, pressure, speed, and flow rate at all relevant points. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included. The control panel includes a clear process schematic of the plant. The system is monitored and controlled by a programmable logic controller (PLC).

The experimental plant is built in accordance with statutory safety regulations and includes the mandatory safety facilities. The steam generator is type tested and does not require specific permissions.

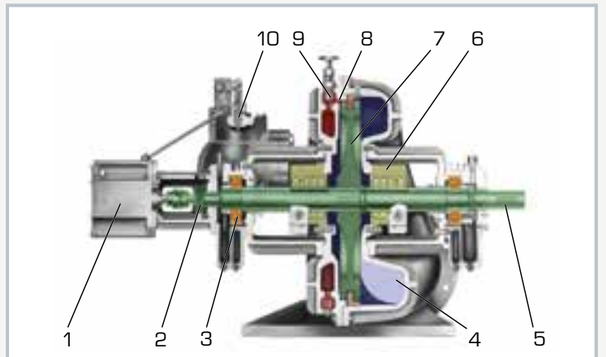
The plant can optionally be operated with the cooling tower ET 830.01 or ET 830.02 to supply cooling water.

Learning objectives/experiments

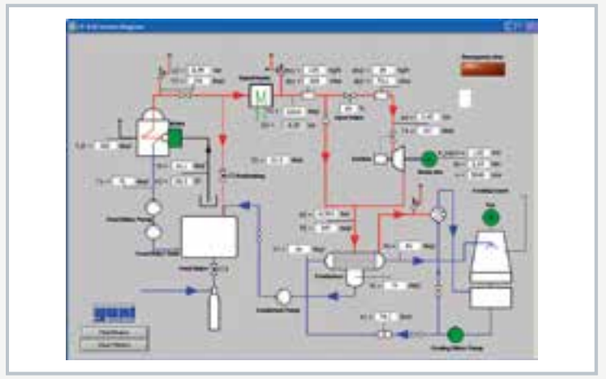
- steam power plant and its components
- start-up, operation and shut down of a steam power plant
- closed steam-water circuit with feedwater treatment
- among others, determining:
  - boiler efficiency
  - mechanical/thermal efficiency of the turbine
  - condenser efficiency
  - specific fuel consumption of the plant

ET 830
Steam power plant, 1,5kW

1 superheater, 2 burner, 3 boiler, 4 condenser, 5 condensate pump, 6 turbine, 7 displays and controls, 8 feedwater tank with feedwater treatment



Sectional representation of the steam turbine used: 1 speed regulator, 2 tripping function, 3 bearing, 4 exhaust nozzle, 5 shaft, 6 shaft seal, 7 Curtis wheel, 8 nozzle, 9 nozzle valve, 10 control valve



Software screenshot: process schematic

Specification

[1] laboratory-sized steam power plant
[2] oil-fired steam generator with electric superheater
[3] single-stage axial turbine with Curtis wheel, vacuum or exhaust operation
[4] DC generator as turbine load
[5] water-cooled condenser
[6] feedwater treatment
[7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
[8] plant monitored and controlled with integrated PLC
[9] cooling water connection 10m³/h or cooling tower ET 830.01/ET 830.02 required

Technical data

Steam generator
- steam output: 200kg/h at 11bar
- max. fuel consumption: 12L/h
- heat-up time: 8min
- max. pressure: 13bar

Superheater
- power: 7kW

Single-stage axial turbine with Curtis wheel and hydraulic speed regulator
- power: max. 1,5kW at 3000min^{-1}

Water-cooled condenser
- cooling capacity: 98kW
- transfer surface: 2,5m^2

Measuring ranges
- temperature: 9x 0...400°C, 2x 0...100°C
- flow rate: 0...167L/min (cooling water)
- pressure: 3x 0...16bar, 1x ±1bar
- torque: 0...20Nm
- speed: 0...4000min^{-1}

400V, 50Hz, 3 phases
400V, 60Hz, 3 phases
230V, 60Hz, 3 phases
LxWxH: 3500x2000x2450mm
Weight: approx. 1950kg

Required for operation

cooling water 10m³/h, drain or ET 830.01/ET 830.02
Compressed air connection: 4,5bar, 150L/h
ventilation & exhaust gas routing required
PC with Windows recommended

Scope of delivery

1 experimental plant
1 GUNT software CD + USB cable
1 set of instructional material including detailed operating manual

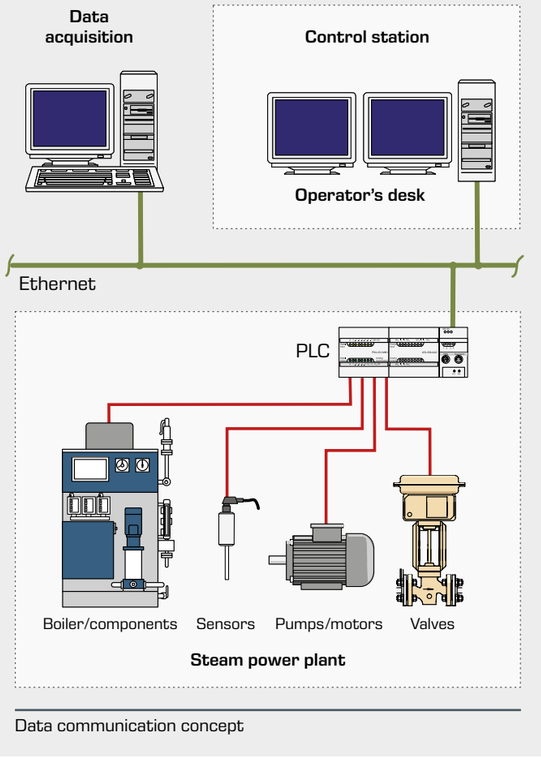
ET 833 Steam power plant 1,5 kW with process control system

Complete, fully functional steam power plant based on ET 830

High performance steam generator heated with fuel oil, steam output of 200 kg/h	Control station with complete instrumentation on LCD monitors
Electrically heated superheater	Operation via touch screen
Single-stage industrial steam turbine, power 1.5 kW at 3000 min^{-1}	Modern, digital process control system based on field bus and PLC
Water-cooled condenser with condensate and vacuum pumps	Integrated data acquisition and calculation of performance parameters
Feed water treatment with water softening	Safety monitoring and emergency shut-down via PLC with alarm and warning logger
Separate wet cooling tower with high-capacity cooling water pump	Extensive manual and instructional material
Plant remote control via actuating valves	

ET 833 features a broad variety of learning objectives

- design and function of steam power plant consisting of feed water treatment, steam generator, superheater, steam turbine, condenser and cooling tower
- start-up, operation and shut-down of a steam power plant
- determination of optimal operating parameters
- determination of power input and output
- determination of component efficiencies and overall plant efficiency
- familiarisation with modern plant control via PLC
- familiarisation with pressure, level, flow and temperature control loops
- maintenance and monitoring procedures



Data communication concept

1 steam generator,
2 feed water pump,
3 condenser,
4 steam turbine,
5 feed water tank,
6 generator,
7 control station,
8 cooling tower,
9 cooling water pump

ET 833
Steam power plant 1,5kW with process control system

The illustration shows the steam power plant together with the cooling tower ET 833.01.

Description

- **complete laboratory-sized steam power plant**
- **process control system based on Ethernet and PLC**
- **plant monitored and controlled via touchscreen control station**

Nowadays large process engineering systems, such as steam power plants, are managed with process control systems (PCS). The entire system is monitored, actuators regulated and controlled, measurements recorded and displayed via the process control system.

The steam power plant ET 833 is specifically designed for training purposes in the field of power plant engineering with process control systems. The system operates very similarly to real large-scale plants due to the high degree of complexity.

An oil-fired once-through steam boiler and a downstream electric superheater generate superheated steam for the single-stage industrial turbine, which is subjected to load via a DC generator. The energy generated is fed back into the grid. The exhaust steam from the turbine is condensed and fed back to the steam boiler.

The feedwater circuit is equipped with a complete water treatment system with ion exchangers and chemical dosing. Sensors capture all relevant parameters. The measured values are both output to the process control system with programmable logic controller and sent to a PC for data acquisition, where they are presented and analysed with GUNT software. Operation of the plant is fully monitored and controlled by the process control system. If necessary, the process control system initiates activation of the corresponding actuators. It is operated via modern touchscreen technology on the control station. A safety system ensures the relevant components are shut-down and error conditions detected in critical operating states.

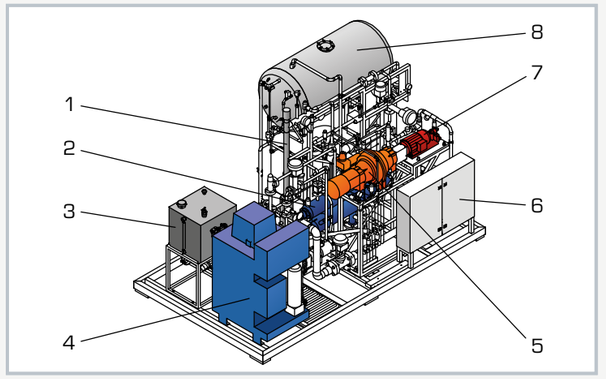
The experimental plant is built in accordance with statutory safety regulations and includes the mandatory safety facilities. The steam generator is type tested and does not require specific permissions.

The plant can optionally be operated with the cooling tower ET 833.01 or ET 833.02 to supply cooling water.

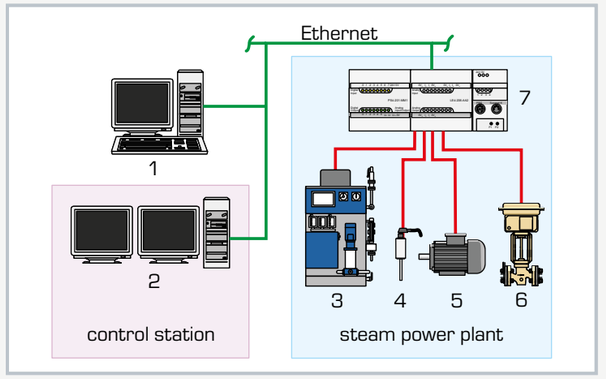
Learning objectives/experiments

- steam power plant and its components with control and regulation system
- start-up, operation and shut down of a steam power plant
- familiarisation with system control and monitoring via a process control system
- monitoring, servicing and maintenance tasks
- determining: input and output power, component and system efficiency, specific fuel consumption of the system

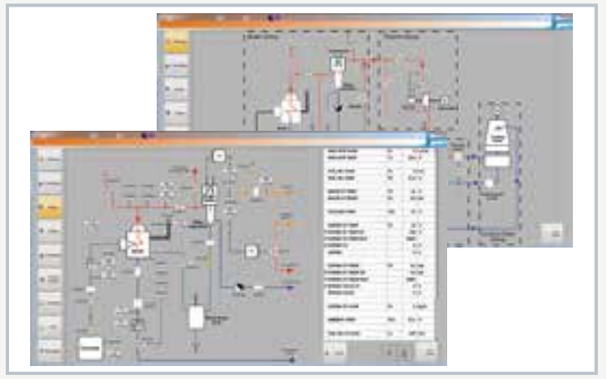
ET 833
Steam power plant 1,5kW with process control system



1 superheater, 2 condenser, 3 fuel tank, 4 boiler with switch cabinet, 5 turbine, 6 switch cabinet, 7 generator, 8 feedwater tank with feedwater treatment



Process control system: 1 data acquisition PC, 2 control PC, 3 steam generator, 4 sensors, 5 pumps/motors, 6 valves, 7 PLC programmable logic controller



Software screenshot: PCS process control system operated via touchscreen

Specification

[1] laboratory-sized steam power plant
[2] oil-fired once-through boiler with electrical superheater
[3] single-stage industrial steam turbine with DC generator as turbine load
[4] water-cooled condenser
[5] feedwater treatment
[6] process control system for monitoring, control and regulation of the plant
[7] control station with complete instrumentation on modern LCD monitors, touchscreen operation
[8] system equipped with sensors and actuators for monitoring and controlling the plant via integrated PLC and Ethernet
[9] cooling water connection 10m^3/h or cooling tower ET 833.01/ET 833.02 required

Technical data

Steam generator
- steam output: 200kg/h at 11bar
- max. fuel consumption: 12L/h
- heat-up time: 8min
- max. pressure: 13bar

Superheater
- power 7kW

Single-stage axial turbine with Curtis wheel and hydraulic speed regulator
- power: max. 1,5kW at 3000min^{-1}

Water-cooled condenser
- cooling capacity: 98kW
- transfer surface: 2,5m^2

Measuring ranges
- temperature: 12x -50...400°C, 1x 0...100°C
- flow rate: 0...167L/min (cooling water)
- pressure: 3x 0...16bar, 2x 0...4bar, 1x -1...1bar
- torque: 0...10Nm
- speed: 0...4000min^{-1}

400V, 50Hz, 3 phases
400V, 60Hz, 3 phases
LxWxH: 3500x2000x2400mm
Weight: approx. 2250kg

Required for operation

cooling water 10m^3/h or ET 833.01/ET 833.02
Compressed air connection: 4,5bar, 150L/h

Scope of delivery

1 experimental plant
1 control station including hardware and software
1 set of tools
1 set of instructional material

ET 805
Steam power plant 20kW with process control system

The illustration shows the ET 805 steam turbine assembly.

Description

- **complete steam power plant with process control system based on Ethernet and PLC**
- **plant monitored and controlled via touchscreen control station**

Nowadays large process engineering systems, such as steam power plants, are managed with process control systems. The ET 805 Steam Power Plant is specifically designed for training purposes in the field of power plant engineering with process control systems. Due to the size and complexity of the system, in many aspects the operating behaviour corresponds to that of actual large-scale plants, thereby enabling training that is as close to the real thing as possible. The plant consists of four separate modules and can therefore be flexibly adapted to the space available in the laboratory:

Module A steam generator assembly: a gas/oil-fired once-through steam boiler and a downstream electric superheater generate superheated steam. The feedwater circuit is equipped with a water treatment system with ion exchangers and chemical dosing.

Module B steam turbine assembly: the superheated steam is fed to a single-stage industrial turbine with speed control. This drives a synchronous generator which can be operated in grid connected or stand alone mode. The exhaust steam from the turbine is condensed and fed back to the feedwater circuit.

Module C wet cooling tower: with forced draught for operation outdoors.

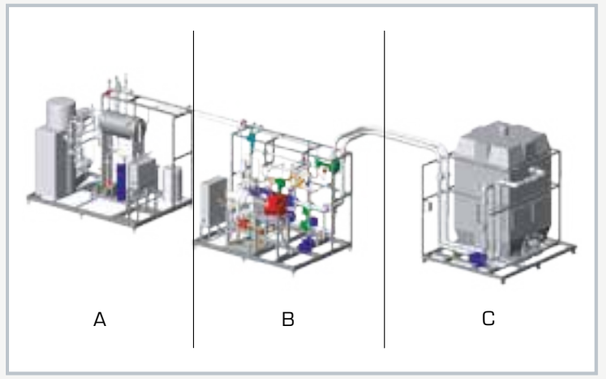
Module D control station: sensors capture all relevant plant parameters. The measured values are both output to the process control system with programmable logic controller and sent to a PC for data acquisition, where they are presented and analysed with GUNT software.

Operation of the plant is fully monitored and controlled by the process control system. It is operated via modern touchscreen technology on the control station. A safety system ensures the relevant components are shut-down and error conditions detected in critical operating states.

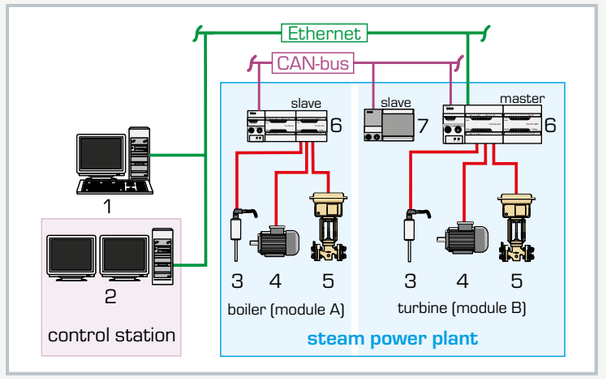
Learning objectives/experiments

- design and function of a complete steam power plant with control and regulation system
- start-up, operation, shut down, servicing and maintenance of a steam power plant
- system control and monitoring via a process control system
- recording and evaluation of the most important operating parameters
- determining: input and output power, component and system efficiency, specific fuel consumption

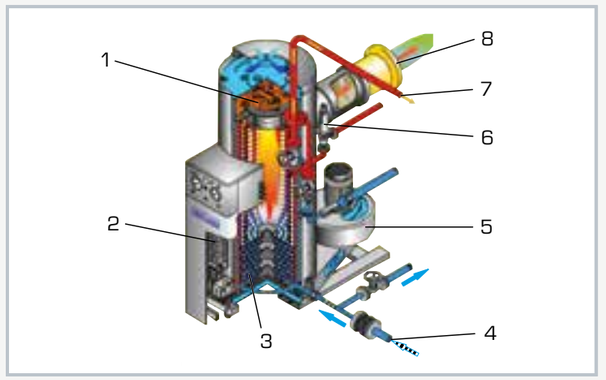
ET 805
Steam power plant 20kW with process control system



Steam power plant modules without control station: module A steam generator with superheater and feedwater treatment, module B steam turbine with generator and condenser, module C wet cooling tower



Process control system and module D control station: 1 data acquisition PC, 2 control PC, 3 sensors, 4 pumps/motors, 5 valves, 6 PLC programmable logic controller, 7 PPU synchronous generator



Sectional representation of once-through steam boiler: 1 oil/gas burner, 2 electrical controller, 3 evaporating coil, 4 feedwater supply, 5 combustion air fan, 6 safety valve, 7 steam extraction, 8 exhaust gas nozzle

Specification

[1] laboratory-sized steam power plant
[2] gas/oil-fired once-through steam boiler with electrical superheater
[3] single-stage industrial steam turbine with Curtis wheel
[4] electronic speed control with electro-pneumatic control valve
[5] synchronous generator with PPU synchronising device for grid connected or stand alone operation
[6] water-cooled condenser with cooling water circuit and wet cooling tower
[7] feedwater treatment with ion exchanger and chemical dosing
[8] modern digital system control via a process control system
[9] control station with complete instrumentation on modern LCD monitors, touchscreen operation

Technical data

Steam boiler
- max. steam output: 600kg/h at 13bar
- max. heat output: 393kW
- max. fuel consumption: 36,8kg/h

Superheater, capacity: 32kW, 250°C
Single-stage action turbine with Curtis wheel and electronic speed control
- max. power output: 20kW at 3600min^{-1}

Synchronous generator
- max. output: 17kVA with 400V, 60Hz

Water-cooled condenser
- cooling capacity: 389kW
- transfer surface: 5,5m^2

Cooling tower, max. cooling capacity: 540kW

400V, 50Hz, 3 phases
400V, 60Hz, 3 phases
LxWxH: 3100x2000x2500mm (steam generator)
LxWxH: 2400x2000x2500mm (steam turbine)
LxWxH: 2000x2000x2800mm (cooling tower)
Total weight: approx. 4500kg

Required for operation

water connection: 1,5m^3/h
ventilation, exhaust gas routing

Scope of delivery

1 steam generator assembly
1 steam turbine assembly
1 cooling tower
1 control station including hardware and software
1 set of tools
1 set of instructional material