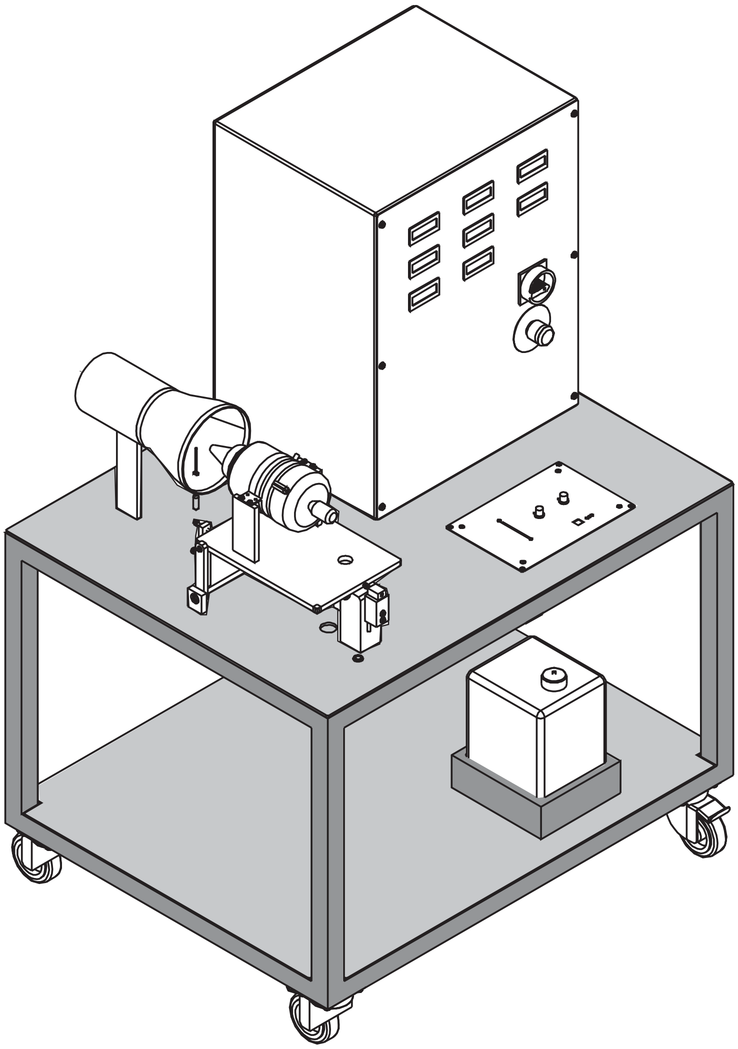
Instruction Manual

ET 796 Gas Turbine as Jet Engine

ET 796 | GAS TURBINE AS JET ENGINE



Instruction Manual

Please read and follow the safety regulations before the first installation!

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1 Introduction

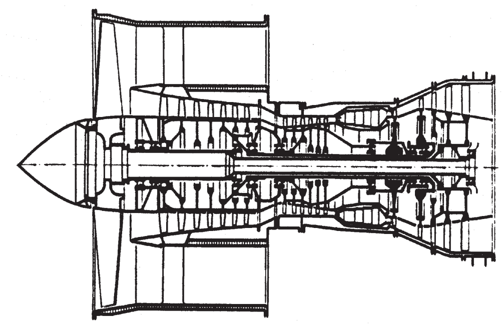


Fig. 1.1 Jet engine for the propulsion of an aircraft

With the ET796 experimental module the function and performance of a gas turbine can be demonstrated and studied on model scale. Gas turbine systems are used to generate mechanical and electrical energy:

- Driving electricity generators in power stations
- Driving compressors and pumps in oil and gas production
- Driving ships, locomotives and heavy vehicles
- For the propulsion of aircraft with propeller and jet engines

Gas turbines are always used when high power density, low weight and quick starting are required. Contrary to piston engines, as fluid flow machines they permit high material flow rates with small dimensions. In this way lightweight, powerful drives can be realised.

As the moving parts of a gas turbine only perform rotary motion, almost vibration free running can be achieved if the turbine is well balanced. Disadvantages are the high gas speeds and high noise emissions due to the simultaneous connection to the atmosphere.

In comparison to steam turbines, gas turbines work at higher temperatures but with lower pressures. The high temperatures particularly in the area of the turbine require particularly heat resistant materials.

The experimental module includes a one-shaft system. All components necessary for the operation of the system are combined in a compact arrangement on a trolley on castors.

The system is of straightforward construction and is specially designed for training purposes. The control and display of all important process parameters is combined on a control panel.

Computerised data acquisition with evaluation software permits online logging and graphical representation of all relevant process variables.

As well as demonstrating how the system works, the set-up can also be used to undertake qualitative studies such as to determine the thrust, and other characteristic data of the gas turbine.

2 System description

The experimental module includes a complete gas turbine system with the following subsystems:

– **Model gas jet turbine** comprising compressor (1), turbine (2), combustion chamber (3) and thrust nozzle with thrust gauge (4).

– **Fuel system** comprising tank (6), fuel pump (7), quick-acting gate valve (8) and control electronics (9).

– **Starter and ignition system** with starter motor (10), auxiliary fuel valve (11) and glow plug (12).

– **Measuring instruments and controls** with temperature, flow rate, speed and pressure measuring points and associated displays. These also include the safety elements such as temperature and speed governors.

A process schematic with all subsystems is given on the next page.

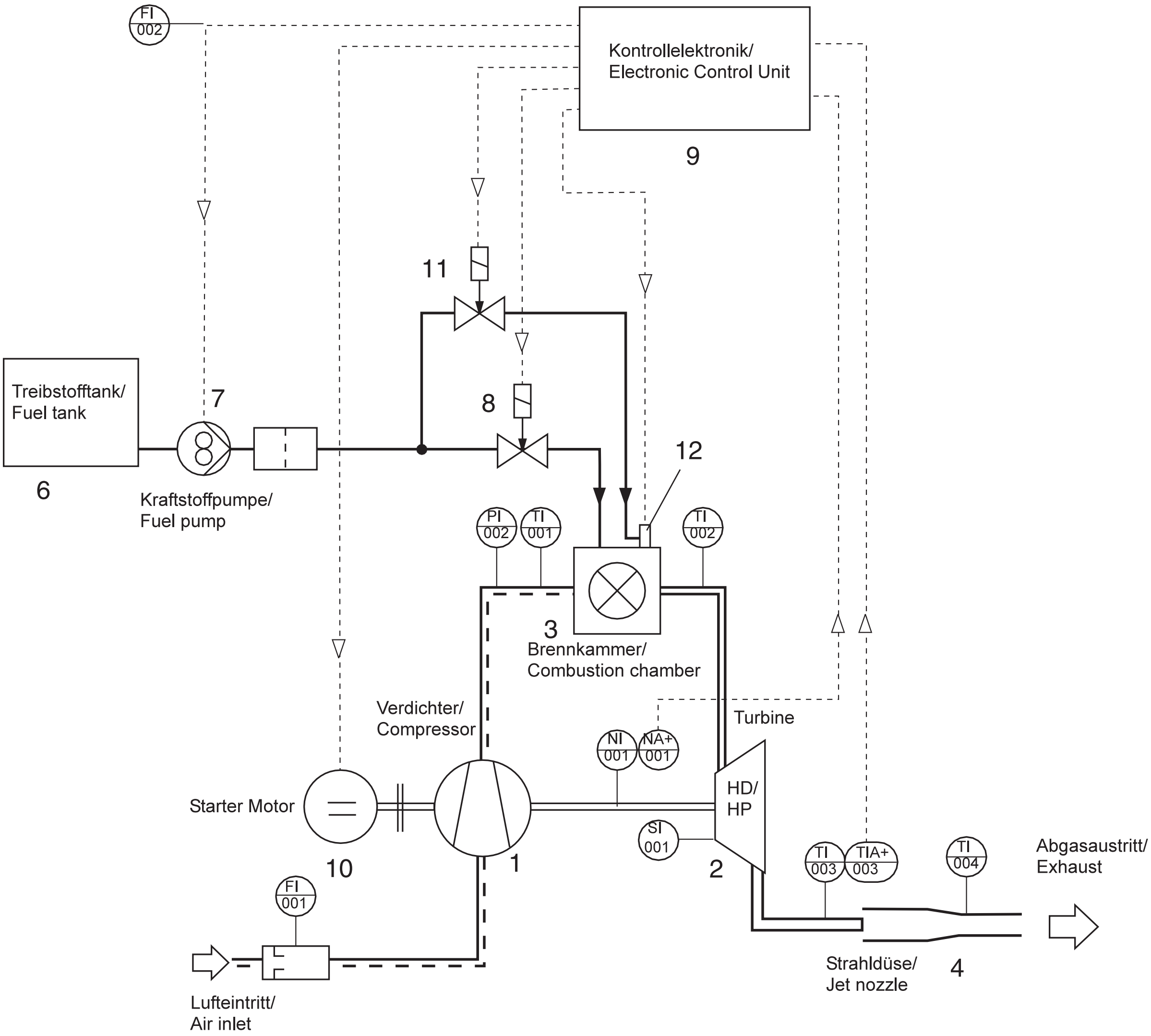


Fig. 2.1 Prozessdiagram Gasturbine

2.1 Function

2.1.1 Jet turbine

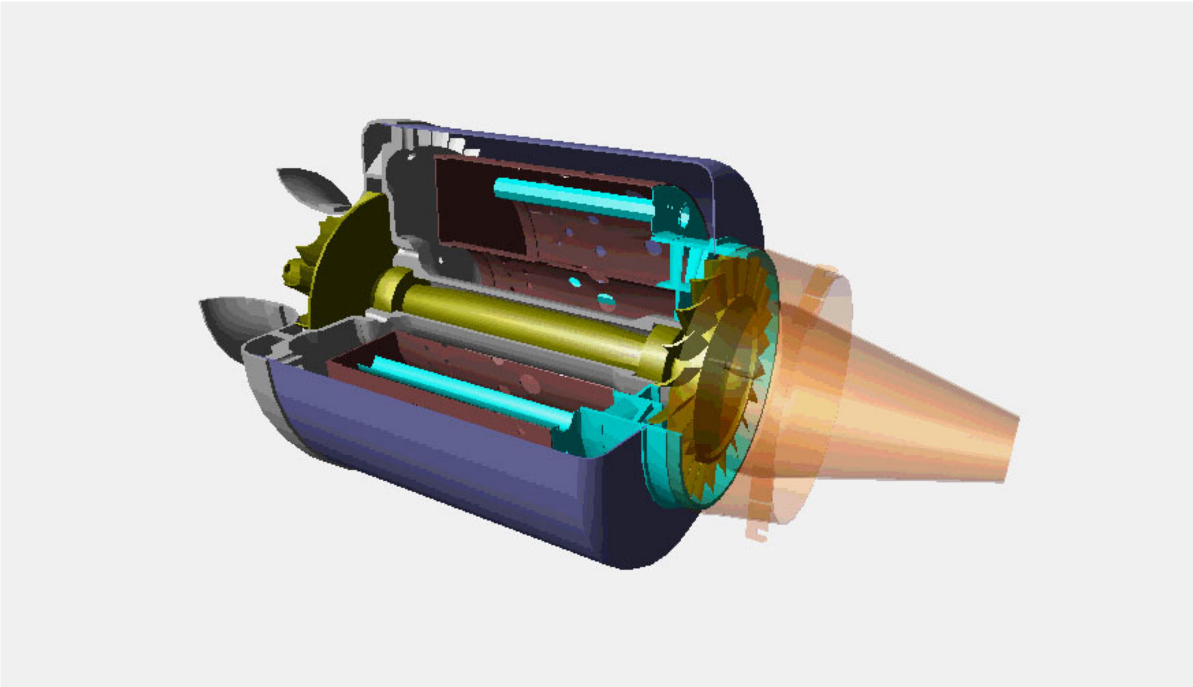


Fig. 2.2 Model jet turbine

It consists of an axial turbine with a direct coupled radial compressor and an annular combustion chamber. The turbine and compressor, together with the bearing housing in-between, form a compact unit. This unit was originally used as the propulsion unit for model aeroplanes.

The intake air is slung by the fast-rotating compressor wheel (1) (35000 - 115000 rpm) into the aluminium diffuser housing (2). Here the speed of the air is converted into pressure. At the combustion chamber (3) inlet part of the air is branched off and fed to the front face of the flame tube (4). The liquid fuel is passed from the rear into so-called evaporator tubes (5). In them the fuel is gasified, and in the front part of the combustion chamber it is mixed with the primary air and combusted. The flame tube is cooled from the outside by the secondary air. It is routed to the flame tube by way of bores(6) in order to cool the very hot combustion gases (approx. 2000°C) down to the permissible turbine inlet temperature of 600 - 800°C. A glow plug (7) ignites the air/fuel mixture during starting.

From the combustion chamber, the combustion gases flow into the diffuser (8) of the turbine and are accelerated before entering the axial wheel (9). In the turbine, the gases discharge their energy to the wheel to drive the compressor. In the process, they are partially relaxed and cooled. They are emitted into the thrust nozzle (10) at approximately 600°C.

The turbine and compressor wheels are fitted to a common shaft (11) such that they are overhanging. The shaft is guided on ball bearings(12) in the bearing housing.

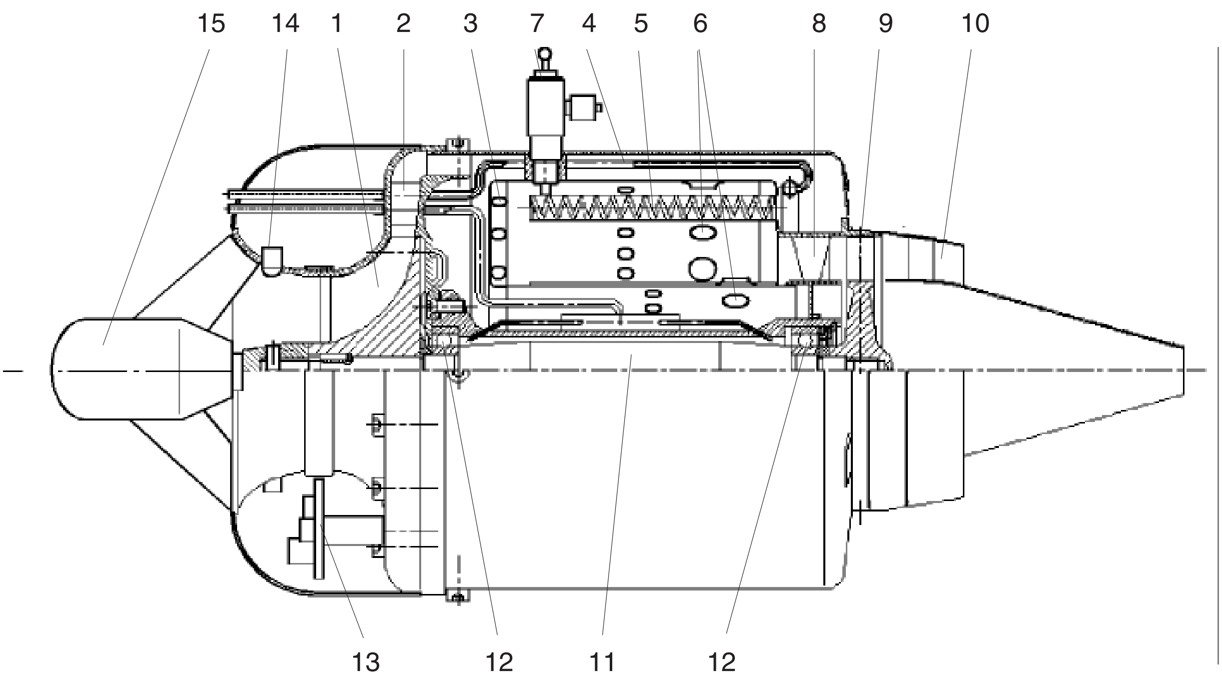


Fig. 2.3 Model-jetturbine

The bearings are cooled by the compressor air and The electronics (13) for the starter motor (15), temperature monitoring and speed measurement (14) are located under the front hood.

The exhaust gas jet draws additional secondary air through the thrust tube by injection. This is mixed with the exhaust gas jet in the thrust tube (17) and reduces the inlet temperature for the power turbine.

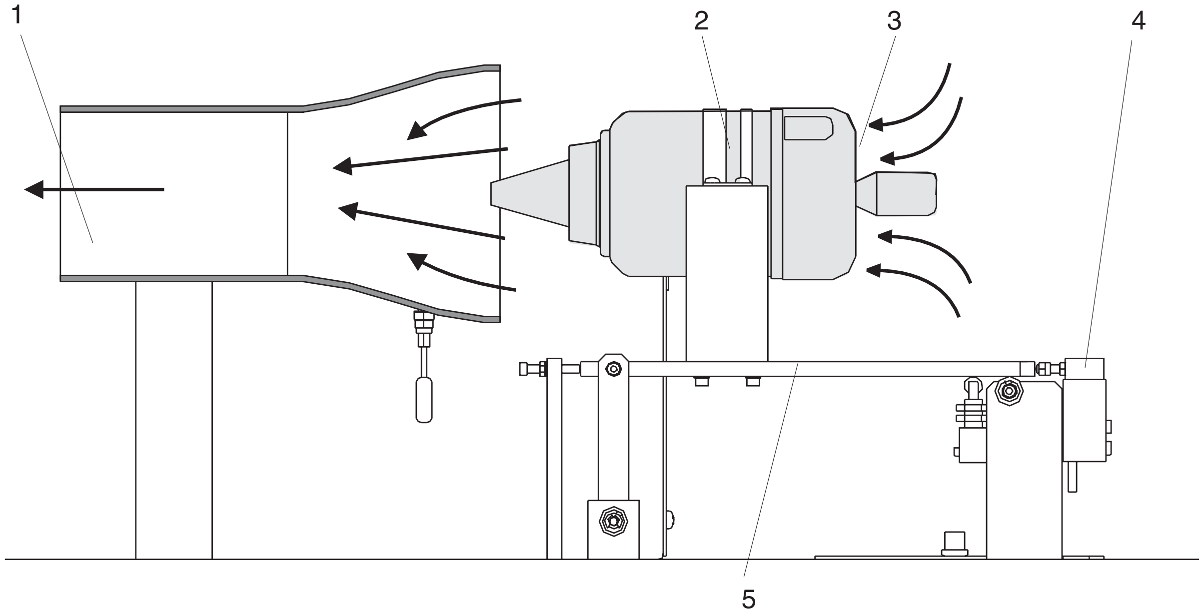


Fig. 2.4 Jet turbine with mixing tube and thrust measurement

1 mixing tube
2 turbine
3 measurering nozzle
4 force sensor
5 turbine desk

The entire turbine with the turbine desk (4) is supported on moving bearings, so that the thrust of the turbine can be measured by means of a force sensor (5). The intake air quantity is measured by way of a measuring nozzle (3) in the inlet of the turbine.

2.1.2 Fuel system

Kerosene or petroleum is used as the fuel. To lubricate the turbine bearings a little oil is added to the fuel (ratio: 1:20). The turbine has a vacuum system with an evaporator. An electric fuel pump delivers the fuel to the turbine's evaporator tubes. The rotation speed of the pump, and thus the fuel quantity, is controlled and monitored by the control electronics. A quick-acting gate valve shuts off the fuel flow in an emergency. When the turbine starts up, combustion is initiated by an auxiliary fuel (butane gas).

2.1.3 Starter and ignition system

The automatic starter system consists of a high-power dc motor. It drives the compressor wheel by way of an automatic cone clutch. At a specific minimum speed the glow plug is activated and the auxiliary fuel is fed in by way of a solenoid valve to the glow plug. After ignition, the electric motor accelerates the turbine. At a specific temperature in the combustion chamber the main fuel supply is activated and the auxiliary fuel is shut off. The electric motor continues to assist the start-up. The entire start-up process is monitored by way of the speed and turbine temperature and electronically controlled.

2.2 Controls

All the indicators, the master switch and the emergency-off switch are located on the front panel.

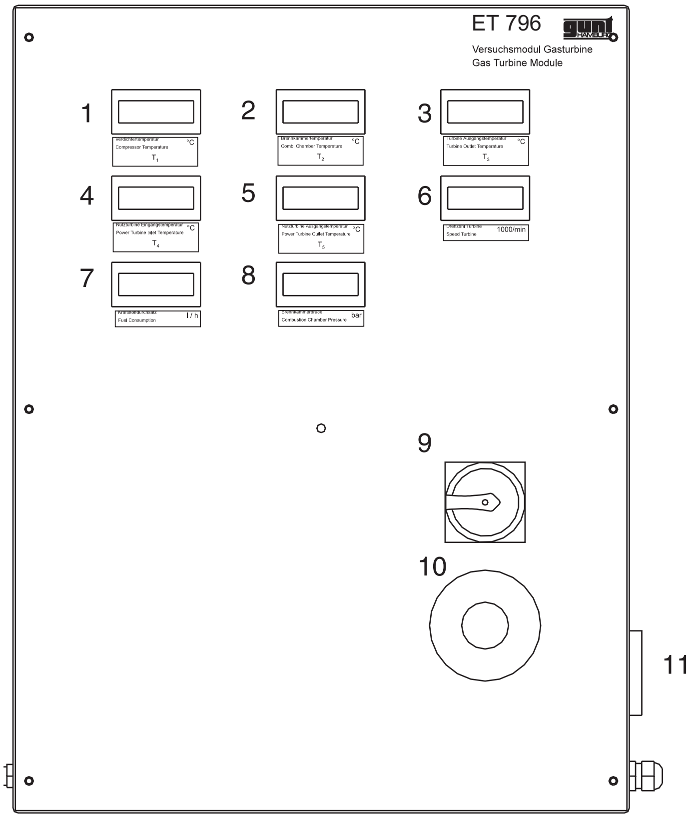


Fig. 2.5 Front panel with indicators

1 Compressor temperature T_1
2 Combustion chamber temperature T_2
3 Turbine output temperature T_3
4 Turbine speed n_1 [1/min]
5 Thrust S [N]
6 Fuel flow [ltr./h]
7 Combustion chamber pressure p [bar]
8 Air flow measured with orifice gauge at the hood [l/s]
9 Master switch
10 Emergency-off switch
11 Computerised data acquisition port

The turbine is operated from a control panel positioned in front of the turbine. It contains the status displays of the control electronics (1) as well as a port for the turbine's display and programming unit GSU (2). Connection of the display and programming unit provides other useful information about the state of the turbine via the Jet-tronic Remote GSU display. In no case is connection of the Jet-tronic required for operation of the turbine. The turbine power output is adjusted by way of the Throttle slide control. The turbine can be shut down by way of the "Throttle Trim" switch. The "AuxChan." switch is used to switch the turbine on and off.

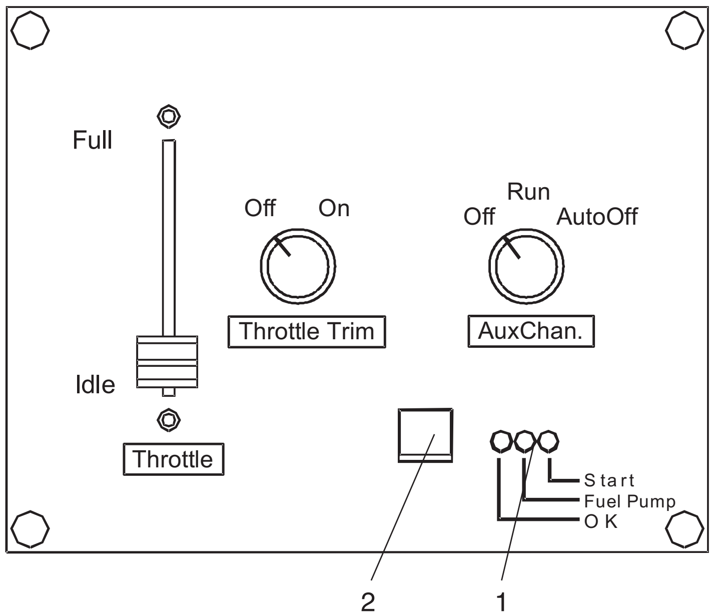
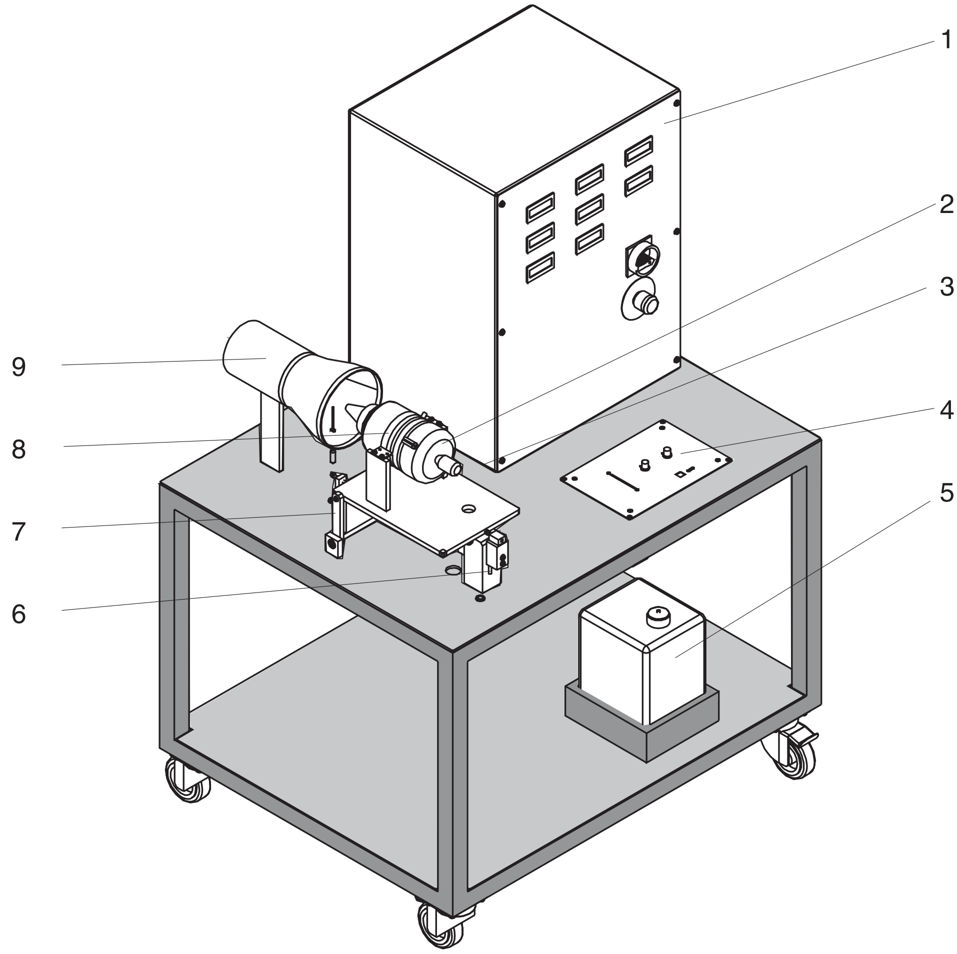


Fig. 2.6 Turbine control panel

2.3 Layout of the experimental module

All the system parts are set up on a benchtop frame. Only the fuel tank and the holder for the disposable gas cylinder with EN417 connector are located underneath the bench.



1 Switch cupboard with indicators
2 Inlet nozzle for air flow measurement
3 Turbine desk
4 Gas turbine control panel
5 Fuel tank
6 Force sensor for thrust measurement
7 Bearing of the turbine desk
8 Jet turbine
9 Mixing tube

Fig. 2.7 Components of the experimental module

2.4 Setting up and maintaining the gas turbine

2.4.1 Checking the gas turbine

Before the gas turbine is run for the first time, it must be checked for damage in transit and maladjustment.

If a training course or commissioning by G.U.N.T. has been ordered, this check is carried out by G.U.N.T. staff.

- Check all bolts are tight.
- Check all hoses are fitted tight.
- Check all cables are fitted tight and are not chafed.

The supply cables and the hoses directly on the turbine are especially important. Loose parts may be sucked in during operation and severely damage the turbine.

- Check the turbine wheel is moving freely. The wheel must turn with no resistance, and must spin freely for a lengthy period of time when compressed air is blown onto it.

If the wheel appears not to be running smoothly, there may be foreign bodies in the compressor.

- The power turbine must rotate freely without the V-belt fitted. There must be no grinding noise as it does so.

2.4.2 Setting up

Owing to the large amount of fresh air it requires (approx. 500 m^3/h), the gas turbine must only be operated in large, well ventilated premises. There should be a facility to discharge the exhaust gases directly to the outside, or to connect an exhaust pipe. An exhaust pipe longer than 3 m is to be avoided due to the high pressure loss. The exhaust pipe should be dimensioned so that no buildup of pressure can occur. It is recommended operating the unit in rooms with sizable openings to outside so that the exhaust gases can be discharged to the atmosphere.

A compressed air port to blow through the turbine is useful.

Owing to the high sound level of the turbine (110dB/1m), special sound-proofing measures may be required.

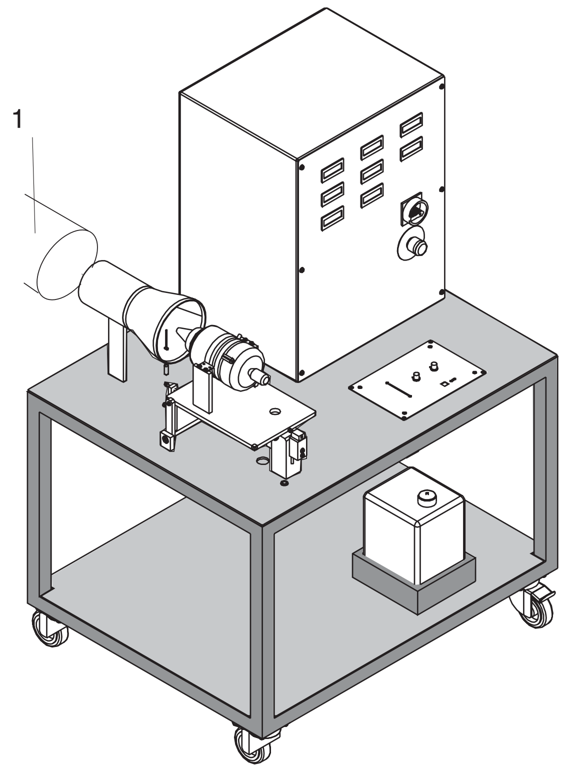


Fig. 2.8 Turbine with exhaust pipe (1)

- Secure the assembly against rolling by actuating the castor brakes.
- To ensure maintenance and service accessibility, there should be a clearance of at least 1 metre around the experimental module.
- If an exhaust pipe or hose is to be fitted, attach it to the Ø 300 mm port. The exhaust pipe should be installed so that the measurement of thrust is not impaired. Exhaust pipe must be temperature resistant. Exhaust gases reach temperatures of up to 300°C. If there is a risk of someone being able to touch the exhaust pipe, it should be protected by a cage. If radiated heat is considered undesirable, the exhaust pipe must be insulated with temperature resistant insulation. Contact of the exhaust pipe with flammable material must be avoided. Do not use any brackets or seals made of plastic.
- In open, well ventilated halls with good clearance height, the assembly may be operated without an exhaust pipe. In such cases it is imperative to ensure that there is no flammable material in the area of the exhaust jet.
- An approved and tested fire extinguisher with a minimum capacity of 6 kg is to be placed in the immediate vicinity of the gas turbine.
- Connect the electric power. Attach the supplied data cable for computerised data acquisition to the data acquisition card on the PC. For details of how to install the PC card and the software refer to the software installation.

2.5 Operation of the gas turbine

2.5.1 Preparations for starting

Before starting the gas turbine, the following tasks are to be carried out:

– Check the fuel tank level. If fuel is topped up, the corresponding amount of lubricating oil must be added.
  Mixture ratio: 1:20.
  Example: Fill available tank with 4.75 ltr. petroleum and 0.25 ltr. turbine oil..

– Use only ultra-clean kerosene or petroleum fuel. If the fuel is of a poor grade deposits will form in the turbine's evaporator system and cause disturbance in the combustion chamber.

– Use only fully synthetic lubricating oil, e.g.
  Aeroshell Turbine Oil 500 / 560 with specification MIL-PRF 23699 Grade HTS or **Mobil Jet 1**.
  Exxon Turbine Oil is only suitable for kerosene.

  ATTENTION! Castrol TTS is not suitable, because it cannot be mixed with the fuels.

– Connect the control unit “Jet-tronik Remote GSU” to the turbine control panel

– Settings of the turbine control panel:
  Gas lever “Throttle”: down
  Throttle Trim: Off
  Set the Turbine (AuxChan) mode switch to: Off

– Switch on master switch.

– Vent fuel line! For trouble free operation it must be ensured that there is no air in the fuel line.

– Venting is carried out in test mode using the "Jet-tronic" control unit of the turbine provided for connection at the control panel (see JetCat instructions).

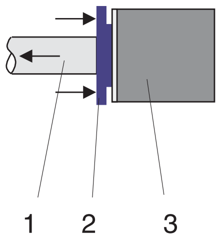


Fig. 2.9 Hose coupling of fuel line
1 Tube
2 Blue ring
3 Connecting piece

Release fuel hoses:

Hold down the blue ring on the hose couplings and pull on hose.

Connect fuel hoses:

Simply insert hose tube into hose coupling and check secure position by pulling lightly on hose.

– Check the displays are working properly.

The gas turbine is now ready for use

2.5.2 Starting up the gas turbine

The gas turbine is started by following a set procedure. This is typical for all gas turbines. Differences only arise due to variations in the degree of automation. In the following sketch the procedure is shown schematically over time.

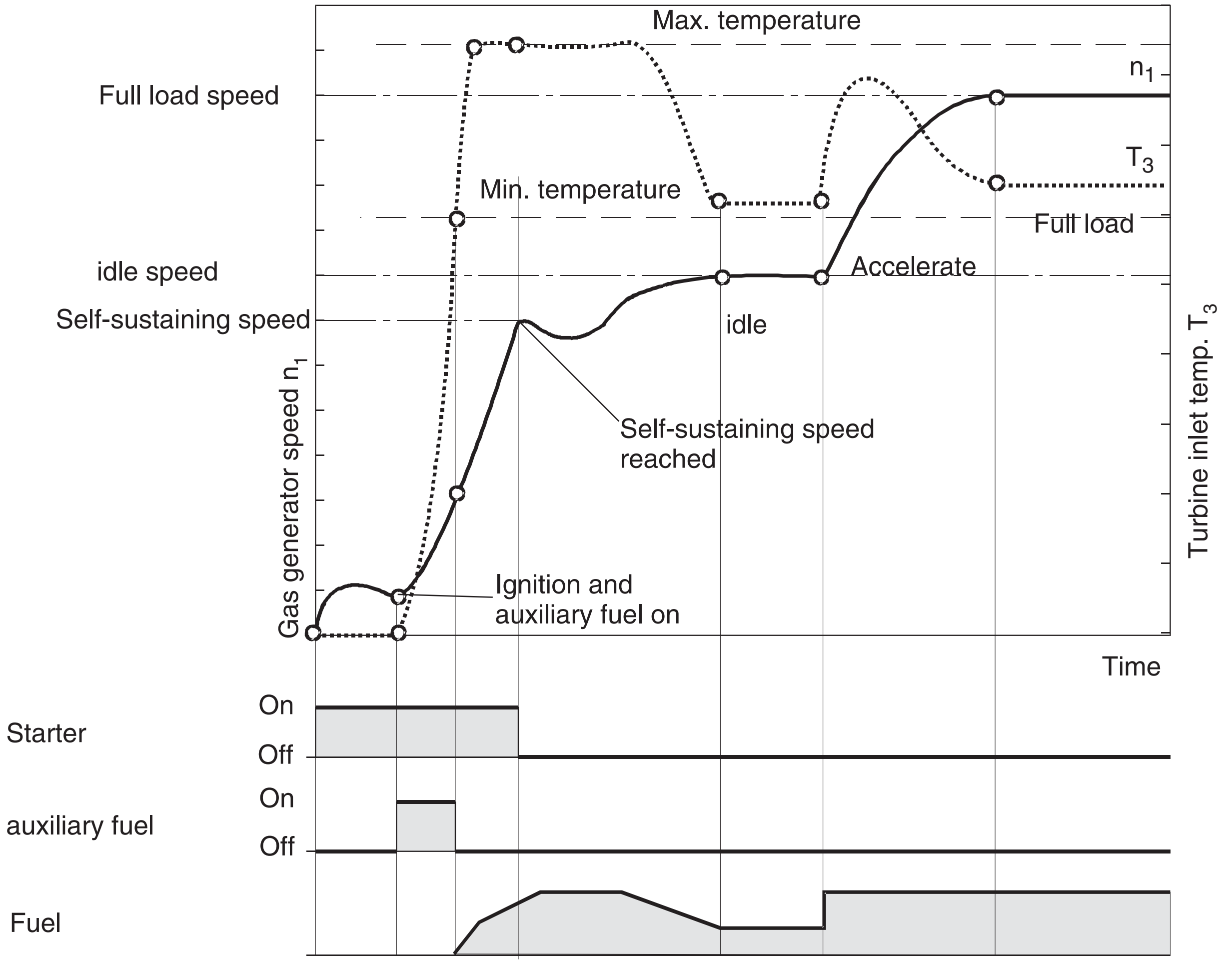


Fig. 2.10 Start-up procedure

It is advisable to carefully read through and digest the description of the starting procedure before performing the experiment.

It is advisable to monitor the speed and temperature curves on the turbine's GSU display and programming unit (see instructions to JetCat turbine).

The designations of the controls relate to Section 2.2.

– To reset the control electronics on the gas turbine, switch off the ET796 at the master switch.

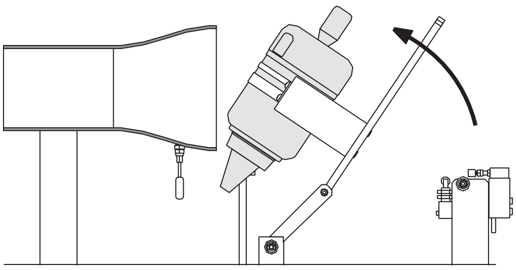


Fig. 2.11 Swivel turbine to remove residuel fuel

– **ATTENTION! Check very thoroughly whether there is still unburned fuel in the guide pipe or in the gas turbine. Uncontrolled combustion of unburned fuel may destroy the gas turbine.**
If there is still fuel in turbine, lift the turbine desk at the front end to enable fuel comming out. Blow-dry the turbine with compressed air and wipe off the fuel with a cloth.

– Set the Turbine (AuxChan) mode switch to "off".

– Set the Throttle Trim switch to "on".

– Set the Throttle lever to idle.

– Switch on the ET796 at the master switch.

– Set the Turbine (AuxChan) mode switch to "run". The three LEDs light up in sequence.

– Start the automatic starting process by fully opening the throttle lever.

Automatic starting process for gas turbine

- The starter motor brings the turbine up to starting speed (yellow LED lit).
- The glow plug is activated and auxiliary fuel is given to the glow plug. The turbine ignites. Ignition is identifiable by a rise in temperature and rotation speed.
- The main fuel solenoid valve opens (red LED lit) and the turbine is run up to approximately 50000 rpm. The temperature rises significantly in the process.
- After a short time at 50000 rpm, the turbine is automatically run down to the idle speed of 35000 rpm. The Throttle control lever must now be reset to idle. The green "ready" indicator LED is lit.
- The power output of the turbine can now be set by way of the Throttle control lever.

2.5.3 Operation of the gas turbine

ATTENTION! The gas turbine must not be operated unsupervised.

Check the speed and turbine outlet temperature displays from time to time.

- The speed and turbine outlet temperature are automatically monitored by the control electronics.

The idle speed is 35000 rpm.

The full load (wide open throttle) speed should not exceed 116000 rpm.

2.5.4 Shutting down the gas turbine

The gas turbine is shut down by way of the gas turbine's mode switch (AuxChan).

– Regular shutdown by setting auto off. The turbine speed is set for a short time to 50000 - 60000 rpm. Then the fuel pump is switched off, the combustion chamber goes out and the turbine comes to a standstill. To cool the turbine bearings, the starter motor continues running until a temperature of below 100°C is reached. The green LED flashes while this is happening.

– In emergencies, the turbine can also be shut down by setting the mode switch to off.

– Once the turbine has cooled down, switch the Turbine (AuxChan) mode switch to "off".

For more detailed information refer to the turbine manufacturers' operating instructions.

2.6 Maintenance

2.6.1 Glow plug

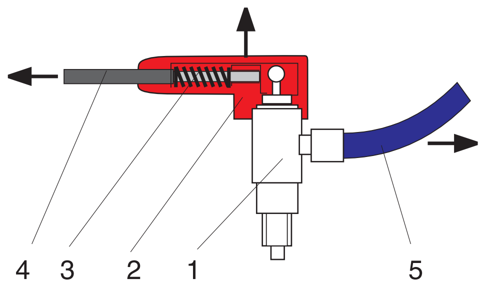


Fig. 2.12 Glow plug connection
1 Glow plug
2 Rubber jack
3 Spring
4 Cable
5 Fuel line

In case of starting problems, check the glow plug for damage or dirt clogging.

Glow plug burn-out is indicated by the control electronics.

- Hold rubber jack and pull lightly on the cable to retract the spring in the jack and then detach the jack from the glow plug.
- Detach the fuel line and unscrew the glow plug by hand.
- Screw in new glow plug and tighten it by hand only. ATTENTION! Don't use a wrench! Glow plug may be damaged.
- Put on fuel line and jack again.

2.6.2 Inspecting the turbine

After 50 hours in service, an inspection of the turbine by the manufacturer is recommended. The turbine bearings are then also replaced.

Manufacturer of turbine type: JetCat-P80

Ing.Bro CATM.Zipperer GmbH
Etzenberg 16
D-79129 Staufen /Germany
Tel.: 07636-78030Fax.:07636-7208
Internet: www.cat-ing.de

The manufacturer can also assist with specific turbine problems.

2.7 Faults and fault rectification

This section deals with any problems occurring in the system, and their causes. Turbine-specific faults and the meanings of the fault messages are detailed in the turbine manufacturers' instructions.

Gas turbine does not start	
No response when mode switch set to run.	- Master switch not on - No mains power - Conductive connection between turbine and bench
No ignition	- Auxiliary fuel valve defective - Auxiliary fuel line not connected to the glow plug - Glow plug defective.
Ignition completed but start-up precedure is abborted at low speed	
Flame produced on startup	- Pump injecting too much fuel
Start is aborted at mid-range speed (10 - 20000 rpm).	- No fuel
Starting motor failing to attain its req. speed	- Clutch slipping => clean with alcohol
Malfunctions	
Gas turbine stops	- No fuel - Mode switch off or auto off - Master switch off - Trim off - No mains power

DANGER! After an aborted start there may still be unburned fuel in the turbine. The fuel may combust in an uncontrolled manner on restart and result in destruction of the turbine by overheating.

Consequently, when restarting after an aborted start it must be ensured that there is no unburned fuel in the gas turbine.

Lift the turbine desk at the front end to enable fuel comming out of the turbine at the rear end. Blow-dry the turbine with compressed air to remove the remaining fuel.

Wipe off the fuel with a cloth very carefully.

2.8 Software

The software should be installed in line with the separate installation instructions. After starting the program, the language must be selected once.

The program has four tasks:

- Clear display of important variables
- Plotting of measured values
- Graphical display of values
- Subsequent correction of measured values in graphical display

Program structure

The menu items are context-dependent, i.e. not all menu items are always enabled. The menu bar contains 5 options with the following sub-items:

- ***Start***
  - ***charts***

    This view shows the measured values plotted in graphical form. The plot button (4) can be used to manually add the current measured value to the measured value list once a data set for a curve has been created. The green field lights up when the measured data are read in.

    The second plot button (5) can be used to automatically plot measured values in the specified interval. Settings for automatic plotting can be made after pressing the settings button (7).

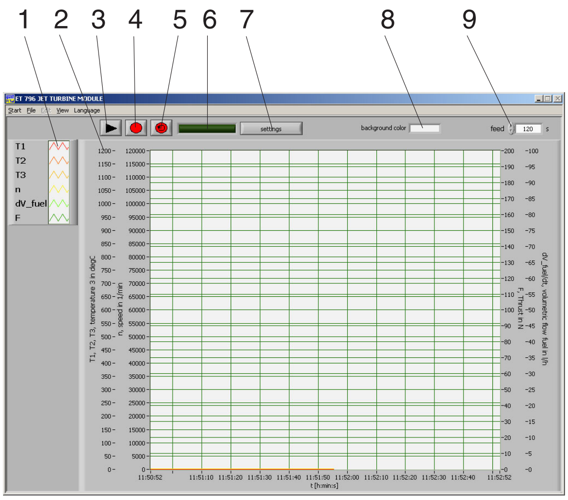


Fig. 2.13 charts

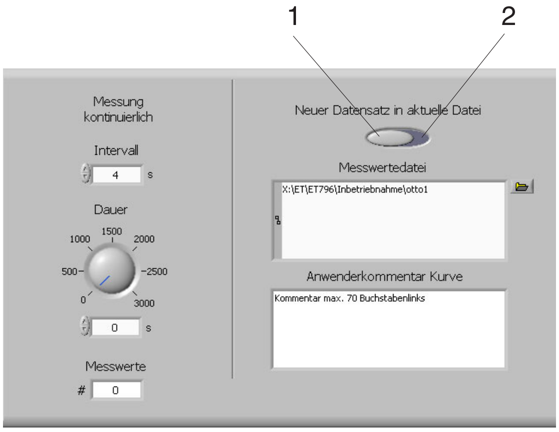


Fig. 2.15 Window after pushing the setting button
1: Measuring points are attached to existing data set
2: New data set is attached to existing file

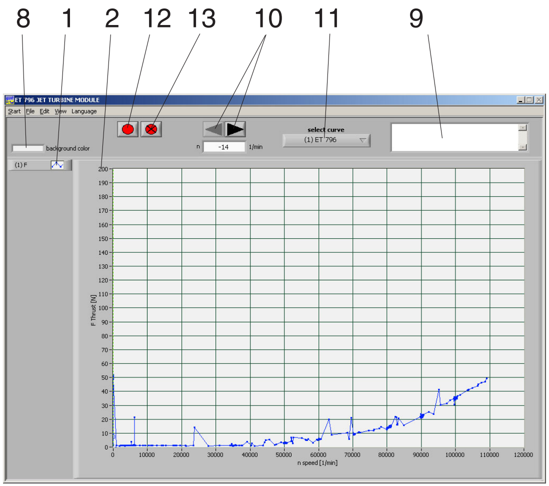


Fig. 2.14 measurement diagram

Left-hand side of new window:

- time interval
- number of measured values

Right-hand side:

- switch

  on left: attach measuring points to existing data set

  on right: attach data set to existing file
- memory location and file name
- comment for data set

The button (3) can be used to stop and restart the advance. The advance is set using both keys (9).

Left-clicking on the fields for the background (8) and the characteristic curves (1) allows you to change the properties. Graphs are scaled by left-clicking once on the initial or final value (2) on the axis.

– ***measurement diagram***

The display of the characteristic curves, background and scaling can be adjusted as in the Time elapsed window. Here you can load and subsequently process data sets that have already been plotted, i.e. you can add to (12) or delete (13) measured values. Data points are selected using the arrow keys (10). In addition, the logged variables of the x and y axes can be assigned here (11). It is also possible to load more than one data set. The comment field (9) shows the comment entered on creation of the data set.

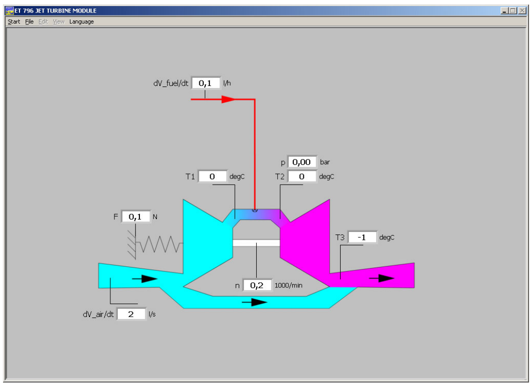


Fig. 2.16 System diagram

– ***system diagram***

  This view shows the current measured values in a clear process diagram.

– ***About GUNT***

  Shows information about GUNT.

– ***EXIT***

  Exits the program.

- ***File***

  – ***New***

    (only with “charts”)

    Creates a new data set.

  – ***Open..***

    (only with “charts”)

    Opens a saved data set and allows the data to be viewed in "measurement diagram" or measured values to be added.

  – ***Print***

    (only with “charts”)

    Prints out the time lapse graphs on the standard printer.

  – ***print window***

    (only with “charts”)

    Prints out a hardcopy on the standard printer.

– ***new curve***

(only with “measurement diagram”)

Creates a new data set.

– ***load curve***

(only with “measurement diagram”)

Loads a saved data set.

– ***save curve***

(only with “measurement diagram”)

Saves a data set.

– ***print curve***

(only with “measurement diagram”)

Prints out a "measurement diagram" on the standard printer.

– ***delete curve***

(only with “measurement diagram”)

Deletes the data set displayed under Select curve from the working memory.

– ***save all curves***

(only with “measurement diagram”)

Saves all curves.

– ***delete all curves***

(only with “measurement diagram”)

Deletes all curves.

– ***print window***

(only with “system diagram”)

Prints out the system diagram currently displayed on the standard printer.

- ***Edit*** (only with “measurement diagram”)
  - ***take measuring point***

    The current measured value is added to the measured value list, the data set.
  - ***delete measuring point***

    The selected measuring point is deleted from the measured value list.

- ***View***
  - ***clear graph***

    (only with “charts”)

    Deletes the graph on the screen.
  - ***play/ pause***

    (only with “charts”)

    Starts / stops the advance of the display.
  - ***choose axis***

    (only with “measurement diagram”)

    The measured variables of the display for the x and y axes (maximum 4) can be selected here.

- ***Language***
  - ***Deutsch***
  - ***English***
  - ***Francais***
  - ***Espanol***

Create a data set and plot first measured value:

-Start- -chart- -File- -new- -name & path- -ok-

Measured points are plotted in the graph using the buttons. Plotting can either be performed manually by plotting individual operating points or via an automatic time-controlled process. For this purpose the measurement time and interval length are specified under Settings.

3 Safety instructions

It is imperative that the following instructions are observed for the hazard-free and safe operation of the unit.

All persons involved in the use of this unit, particularly students, are to be made aware of these safety instructions.

The enclosed operating instructions to the model jet engine must be carefully observed. Gas turbines, even on a model scale, are sensitive machines. Incorrect operation or negligent maintenance can lead to destruction of the turbine within a short space of time. Consequently, the operating instructions should be studied thoroughly prior to initial operation.

If you have any queries, consult the manufacturers.

No liability can be accepted for damage arising from incorrect operation.

3.1 Hazards for life and limb

DANGER OF ELECTRIC SHOCK!

Caution, high voltage.

- Prior to opening the switch cupboard, unplug from the mains.
- Work on the electrical system is only to be performed by suitably qualified personnel.
- Protect electrical system from moisture, splashes and melt water.

RISK OF BURNS!

- The power turbine housing and the exhaust gas port and the exhaust pipe, if fitted, of the gas turbine become very hot in operation. Do not touch!
- Exercise caution in respect of the hot exhaust jet during operation without an exhaust pipe.
- In the case of operation as a jet engine, fit barriers at a distance of 5 metres. The exhaust gas jet reaches high temperatures of 200 - 300°C.

DANGER OF POISONING!

Danger of CO or CO_2 poisoning!

Do not operate the system without an exhaust pipe in enclosed, unventilated rooms.

DANGER OF HEARING DAMAGE!

When the system is operated as a jet engine (open outlet from thrust nozzle), the design means that very high noise levels occur<(110 dB (A)). Suitable ear defenders must be worn in such cases.

HAZARD AREA!

It must always be ensured that when the turbine is running, no-one is at the run level of the turbine. Staff should either position themselves in front of or behind the turbine, and not to the side.

DANGER!

When the turbine is operating, the air inlet opening is subject to extreme suction, which can suck in the light things like paper and cloth.

This can block the suction strainer and can cause overheating of the turbine. For this reasons persons should not enter an area of 1m in front of the turbine

3.2 Special safety rules for handling kerosene

DANGER OF EXPLOSION!

If kerosene escapes, do not use open flames and avoid sparks. Do not switch electrical loads on or off.

– Before operating for the first time, check the system for leaks in fuel lines.

– Wipe up leaking kerosene. Note that cloths soaked in kerosene may spontaneously combust (provide adequate ventilation).

3.3 Hazards for unit and function

DANGER OF FIRE! Do not bring flammable materials into contact with the hot exhaust gas pipe or place them in the exhaust jet.

Flammable or heat-sensitive materials must be kept well away from the outlet area.

Minimum clearance distance of flammable materials from exhaust jet: 4 metres.

DANGER OF FIRE! If fuel leaks from the turbine, kerosene on the hot turbine housing may ignite.

ATTENTION! During operation of the system, keep a suitable fire extinguisher to hand.

ATTENTION! The system must not be operated unsupervised.

ATTENTION! Operate the turbine only with clean kerosene or petroleum.

Unsuitable fuel may result in overheating or cause deposits to form.

ATTENTION! To lubricate the turbine bearings, an admixture of 5% lubricating oil must be added to the fuel.

Use only suitable synthetic oils such as:

> Aeroshell Turbine Oil 500 / 560 with specification MIL-PRF 23699 Grade HTS or Mobil Jet 1.

Exxon Turbine Oil is only suitable for kerosene.

ATTENTION! Castrol TTS is not suitable, because it cannot be mixed with the fuels.

ATTENTION! The turbine must not draw in any foreign bodies or dust.

Dust will deposit in the turbine bearings and destroy them. The intake area and the interior of the hood must be kept free of loose objects.

ATTENTION! The turbine must be overhauled every 50 operating hours.

This work must be carried out at the premises of the turbine manufacturer JETCAT.

ATTENTION! If critical operating states occur (excessive speed, overheating, leakage etc.), always set the mode switch to off first.

ATTENTION! The system is not suitable for setting up in the open. The system is to be operated in dry, dust-free and well ventilated rooms.

In particular, attention is to be paid to good ventilation as the system has an air consumption of 500 m^3/h.

ATTENTION! The turbine and turbine desk are installed on the bench with electric insulation. There is a potential of +12 V at the turbine housing. It must be ensured that no electrically conductive connections are made between the turbine and bench.

4 The open gas turbine process

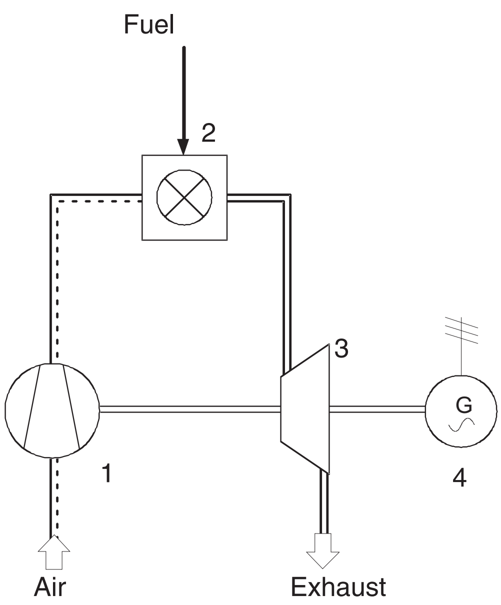


Fig. 4.1 Simple, open gas turbine system

The gas turbine demonstration stand operates according to the open **circuit process**, in which the working medium is taken from the environment and returned to it.

In the process, the working medium -air- is subjected to the following changes of state:

– **Adiabatic compression** of the cold air with a compressor (1) from ambient pressure p_1 to pressure p_2 and consequent temperature rise from T_1 to T_2.

– **Isobaric heating** of the air from T_2 to T_3 by heat input. The heat is supplied by combustion of fuel with the atmospheric oxygen in the combustion chamber (2).

– **Adiabatic expansion** of the hot air in a turbine (3) from pressure p_2 to p_1. In the process, the temperature falls from T_3 to T_4.

In a closed circuit process the working medium would have to be cooled down to the inlet temperature T_1 once again by isobaric cooling. In an open circuit process, too, the residual heat is discharged to the atmosphere.

The **mechanical output** drawn by the turbine serves in part to drive the compressor and is in part available as effective power. It can be used to power a generator (4) for example.

4.1 Representation in heat diagram

Representation in a heat diagram, a so-called T/s diagram, is suitable for assessment of the conditions in the circuit process. In it, the temperature of the working medium is plotted over the specific entropy.

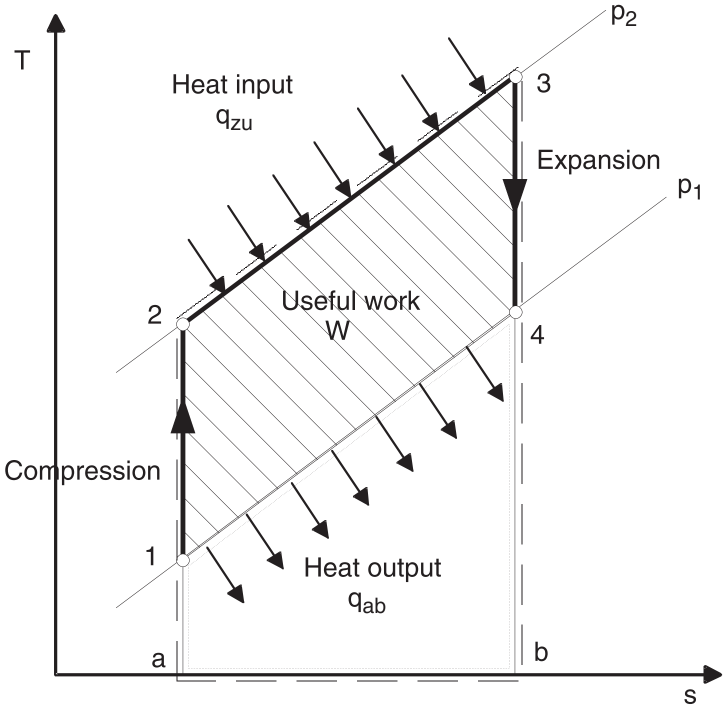


Fig. 4.2 T,s-diagram of gas turbine process

In the T/s diagram the heat quantities can be represented as areas. The useful work is produced from the difference between the input heat quantity in area a,2,3,b and the output heat quantity in area 4,b,a,1.

Based on the T/s diagram, questions concerning the thermal efficiency and the work capacity of the process can be examined. Temperature conditions and the compression ratio $\pi = p_2/p_1$ are of relevance in this.

4.1.1 Thermal efficiency (ideal)

The efficiency is produced from the ratio between the input heat and the mechanical work. Assuming a constant heat capacity of the working medium, the resultant thermal efficiency is:

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{\pi^{\frac{\kappa - 1}{\kappa}}}$$

With a mean value of $\kappa = 1.4$ for air and 2-atomic gases follows:

$$\eta_{th} = 1 - \frac{1}{\pi^{0.285}}$$

It can be seen that the efficiency is dependent only on the compression ratio π. The highest temperature in the process, the turbine inlet temperature T_3, has no influence on the thermal efficiency.

4.1.2 Specific work capacity

The following correlation applies to the specific work capacity:

$$w_N = c_p \cdot T_3 \cdot \left(1 - \frac{1}{\pi^{0.285}}\right) - c_p \cdot T_1 \cdot \left(\pi^{0.285} - 1\right)$$

It can be seen that, as well as the compression ratio, the intake and turbine inlet temperatures are of relevance. The intake temperature is generally predetermined by the ambient state. The turbine inlet temperature T_3 should be chosen as high as possible. In practice, it is limited by the temperature resistance of the turbine blades.
Consequently, here too the compression ratio π is the decisive factor.

The **power output** of the system is produced by multiplication by the mass flow.

$$P_N = \dot{m} \cdot w_N$$

The correlations presented here apply to a single-shaft system, so the results are not directly transferable to our gas turbine. They do provide help in understanding the operating performance. The compression ratio, for example, is root dependent on the rotation speed. Thus, the system is much more efficient at high speeds.

4.1.3 Representation in p/v diagram

The circuit process can also be represented in a p/v diagram. This demonstrates the compression and expansion process particularly clearly.

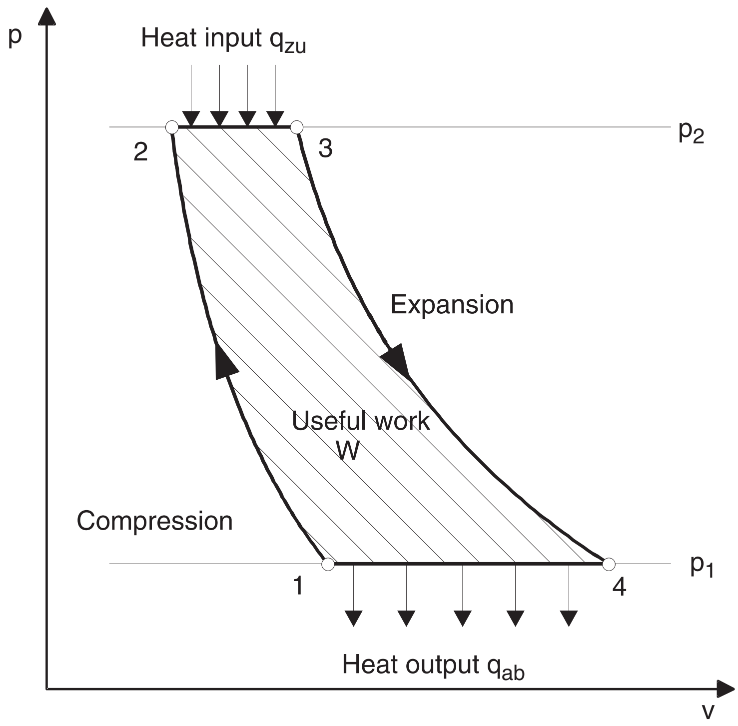


Fig. 4.3 p/v diagram of gas turbine process

Here, too, the mechanical work is produced as an enclosed area. In contrast to the T/s diagram, the areas in this diagram represent mechanical work. It can be seen that as a result of the heat input between 2 and 3 the specific volume - that is, the density - of the gas decreases. The surplus effective power output of the turbine results from the fact that it is able to process a higher volume subject to the same pressure difference as the compressor.

4.2 Gas turbine as jet engine

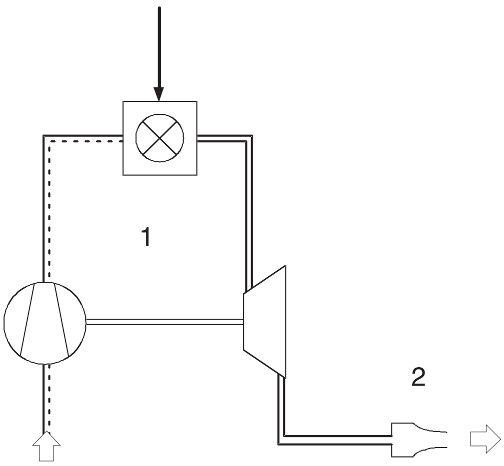


Fig. 4.4 Jet engine

In aircraft engines, above a certain air speed it is more favourable to utilise the exhaust gas jet directly to generate thrust. The simplest jet engine comprises of a single-shaft gas turbine (1) in an open process. The only partially utilised and still energy-containing exhaust gases of the turbine are accelerated in a thrust nozzle (2) and generate the necessary impetus to propel the aircraft. In an optimum nozzle configuration the exhaust gases are relaxed down to ambient pressure.

The thrust can be simply calculated according to the principle of linear momentum from the through-put mass flow and the speeds at the inlet (c_1) and outlet (c_2):

$$S = \dot{m} \cdot (c_2 - c_1)$$

It should be noted that the thrust is a vectorial variable, and only speed components in the direction of the thrust make a contribution.

5 Experiments

5.1 Recording of measurements

The measurements should only be taken with the turbine in a steady state. The following measurements are exemplary and subject to substantial spread, dependent on various factors including ambient conditions.

The measurement data can be recorded manually or by means of computerised data acquisition.

Four measurements are taken under no load, partial load and full load.

Experiment Gas Turbine Module	Date: Ambient Temperature °C: Air pressure in mbar: Air Humidity in %:		17.03.01 16 1020 40			
Experiment Nr.:	1	2	3	4	5	6
Compressor outlet T1 in °C	30	66	89	116		
Combustion chamber T2 in °C	756	690	714	768		
Turbine outlet T3 in °C	583	566	561	578		
Combustion chamber pressure p in bar	0.08	0.47	0.81	1,09		
Air flow dV_air/dt in ltr./s	45	215	293	327		
Air mass flow $\dot{m}_a$ in kg/s	0.055	0.263	0.358	0.4		
Fuel flow dV_fuel/dt in ltr./h	5.74	13.24	16.85	21.15		
Fuel mass flow $\dot{m}_b$ in g/s	1.293	2.982	3.79	4.765		
Turbine speed n1 in 1/min	35426	80000	101000	116000		
Thrust S in N	0.07	21.00	41.00	58.5		
Comments	idle	Part Load	Part Load	Full Load		

5.2 Air mass flow and fuel mass flow

The **air mass flow** $\dot{m}_a$ in kg/s is calculated as follows:

$$\dot{m}_a\left[\frac{kg}{s}\right] = \frac{\rho_0}{1000} \cdot \frac{T_0 \cdot p_1}{T_1 + 273} \cdot Display\left[\frac{ltr.}{s}\right]$$

with reference quantity $\rho_0 = 1.199\,\frac{kg}{m^3}$, $T_0 = 293\,K$

and $p_0 = 1.013\,bar$

$$\dot{m}_a\left[\frac{kg}{s}\right] = 0.347\,\frac{kg}{m} \cdot \frac{p_1}{T_1 + 273} \cdot Display\left[\frac{ltr.}{s}\right]$$

The T_1 intake temperature is given in °C and p_1 the ambient pressure in bar.

The **fuel mass flow** $\dot{m}_b$ in g/s is calculated as follows:

$$\dot{m}_b\left[\frac{g}{s}\right] = \frac{1000 \cdot \rho_b}{3600} \cdot Display\left[\frac{ltr.}{h}\right]$$

with ρ_b in kg/m³

$$\dot{m}_b\left[\frac{g}{s}\right] = \frac{1}{3.6} \cdot \rho_b \cdot Display\,\frac{ltr.}{h}$$

ρ_b is the density of the fuel at 20°C.

5.3 Further characteristic quantities of an aeroplane jet turbine

Calculations based on full load.

specific thrust

$$f = \frac{S}{\dot{m}_a} \qquad \text{mit } \dot{m} = \dot{m}_a + \dot{m}_b \approx \dot{m}_a$$

$$f = \frac{58\ N}{0.4\ \frac{kg}{s}} = 145\frac{N \cdot s}{kg}$$

specific fuel consumption

$$b_S = \frac{\dot{m}_b}{S}$$

$$b_s = \frac{4.66 \cdot 10^{-3}\ \frac{kg}{s}}{58\ N} = 8.03\ \frac{kg}{N \cdot s}$$

thrust/ weight - ratio

$$f_G = \frac{S}{G}$$

G : weight in kg

$$f_G = \frac{58\ N}{1.3\ kg} = 44.61 \text{ N/kg}$$

available thermal output:

$$\dot{Q}_b = \dot{m}_b \cdot H_u$$

$$\dot{Q}_b = 0.429\ \frac{kg}{s} \cdot 42580\frac{kJ}{kg} = 198.7\ kW$$

H_u : calorific value 42580 kJ/kg

thermal efficiency (ideal)

$$\eta_{th} = 1 - \frac{1}{\pi^{\frac{\kappa-1}{\kappa}}} = 1 - \frac{1}{\pi^{0.285}} \quad \text{mit } \kappa = 1.4$$

with π: ratio of compression $\pi = \frac{p_2}{p_1}$

with p_1: pressure before compression

p_2: pressure after compression

$$\eta_{th} = 1 - \frac{1}{2.09^{0.285}} = 0.189$$

internal efficiency or efficiency(real)

$$\eta_i = \frac{\textit{useful power}}{\textit{available thermal output}} = \frac{P_i}{\dot{Q}_b}$$

with P_i: Internal power; kinetic energy transferred from fluid to engine;

$$P_i = \frac{\dot{m}_a}{2} \cdot \left(c_2^2 - c_1^2\right)$$

with c_1: inlet speed of air into engine (standing $c_1 = 0$)

c_2: outlet speed of air from engine

external efficiency or propulsive efficiency (real)

$$\eta_a = \frac{\textit{thrust power}}{\textit{useful power}} = \frac{P_N}{P_i}$$

with P_N: thrust power

$P_N = S \cdot c_3$ (c_3 = Air speed; standing=0)

overall efficiency

$$\eta_{ges} = \eta_i \cdot \eta_a$$

5.4 Evaluation of measurement results

5.4.1 Representation of measured data in diagrams

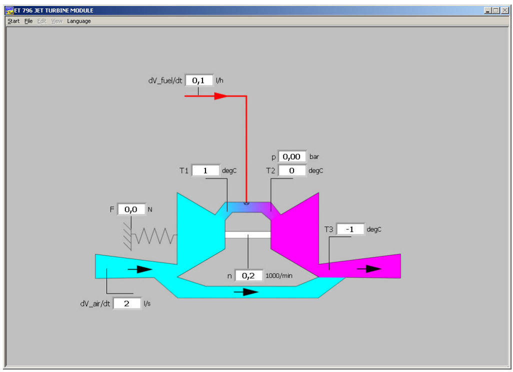


Fig. 5.1 System diagram of a gas turbine

The measured data can be displayed and stored online by means of computerised data acquisition. The measured values recorded can then be processed with the program item "measurement diagram". The data basis used is the *.dat files with the saved measurement data. The following measurements are contained in the dat file. Subsequent data processing with a text editor is possible. The data can also be imported and processed using a spreadsheet program,

e.g. Excel.

1	Time	in h:min:sec
2	Outlet temp. compressor	T1 in °C
3	Combustion chamber temp.	T2 in °C
4	Outlet temp. turbine	T3 in °C
5	Turbine speed	n_1 in 1/min
4	Fuel-Consumption	in l/h
5	Combustion chamber pressure	p chamber in bar
6	Thrust	S in N
7	Air-Consumption	in l/s

The following diagrams show a number of results recorded by computerised data acquisition.

The following diagram shows recorded data in the window "measurement diagram". It shows the thrust of the jet turbine as a function of speed. Thrust increases disproportionately to speed. At idle speed there is virtually no thrust. The measured values shown are recorded at a 2s interval.

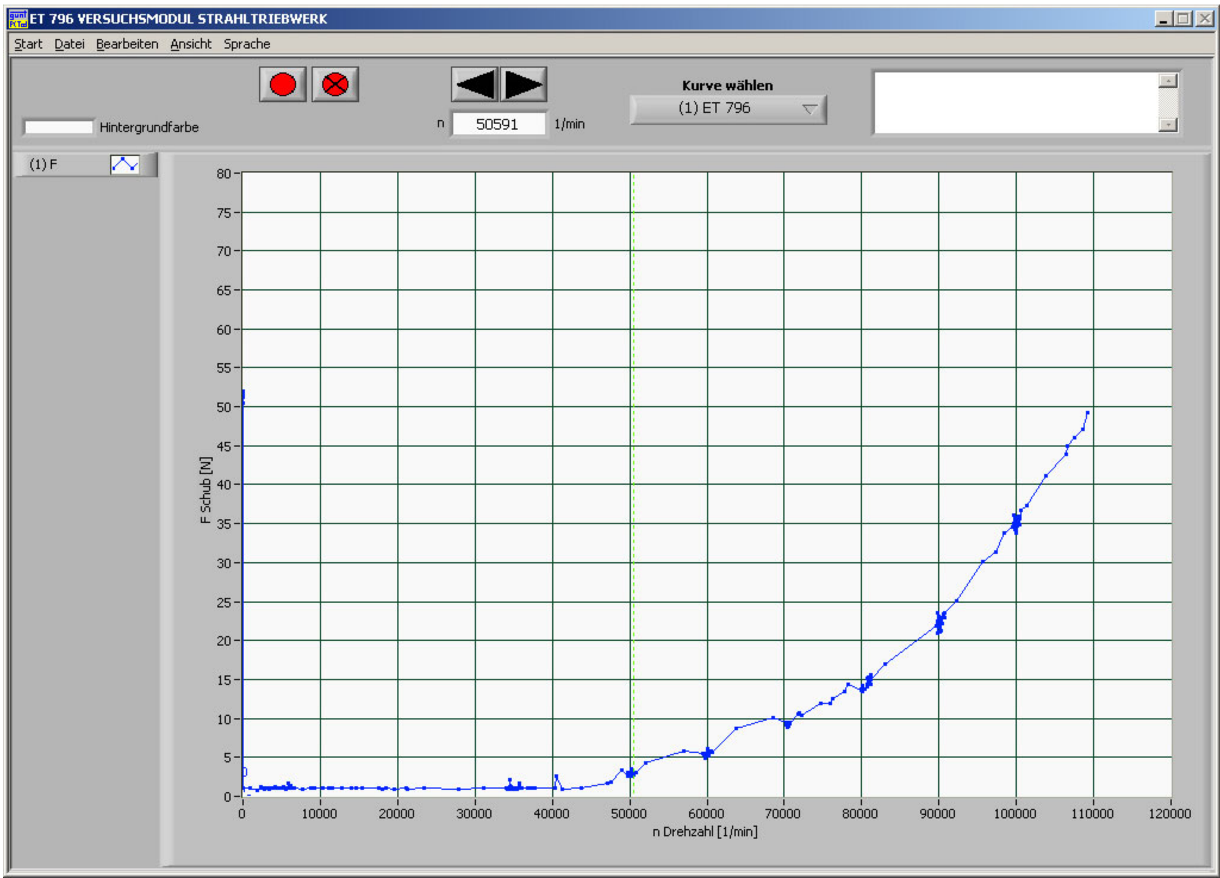


Fig. 5.2 Thrust of the jet turbine from start up to 120000 rpm.

The following diagram shows the influence between fuel-consumption and thrust.

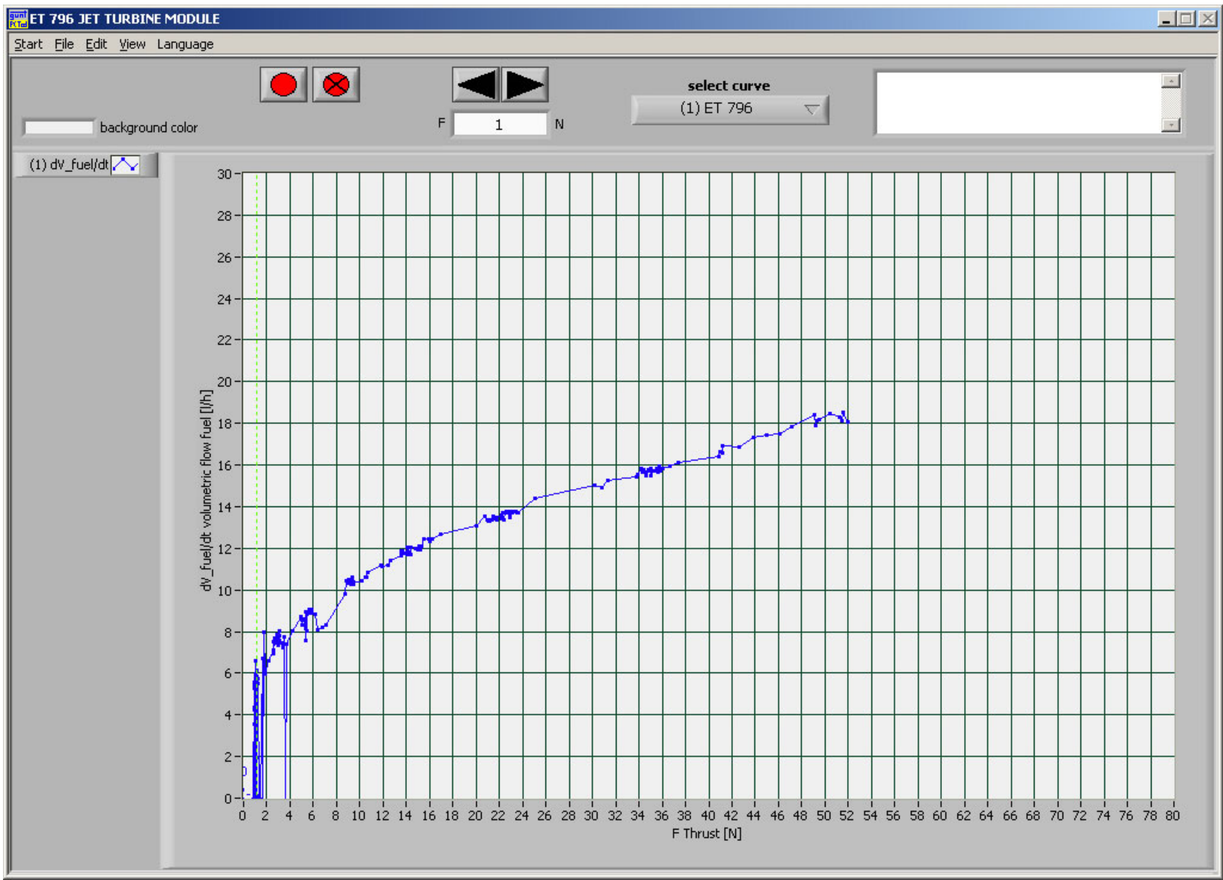


Fig. 5.3 Fuel-consumption dependance on thrust

The following diagram shows the relation between air consumption, thrust and some temperatures.

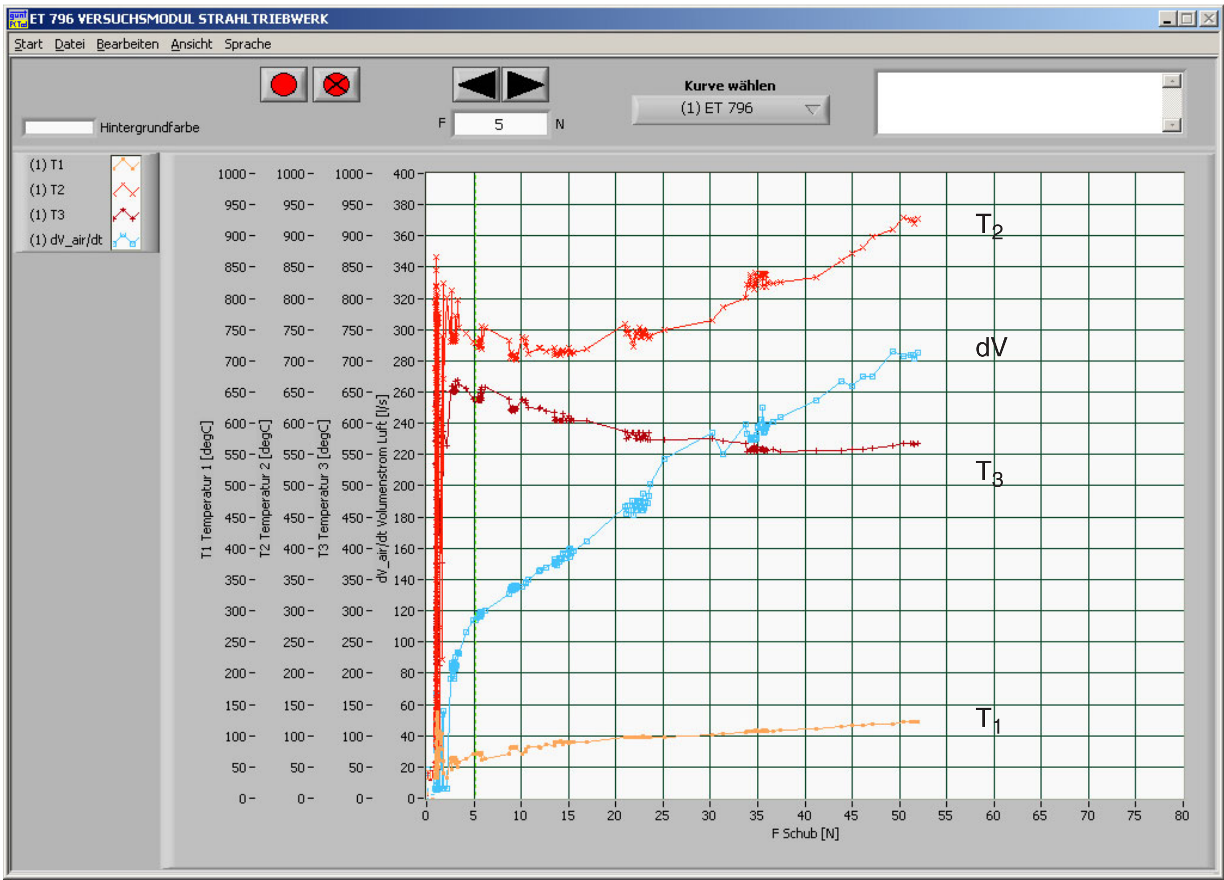


Fig. 5.4 Temperatures and air consumption of the jet turbine dependent on thrust
T_1 behind compressor
T_2 in the combustion chamber
T_3 turbine outlet temp.
dV air flow in ltr./s

The last diagram presents the combustion chamber pressure over the speed. A root dependency is created.

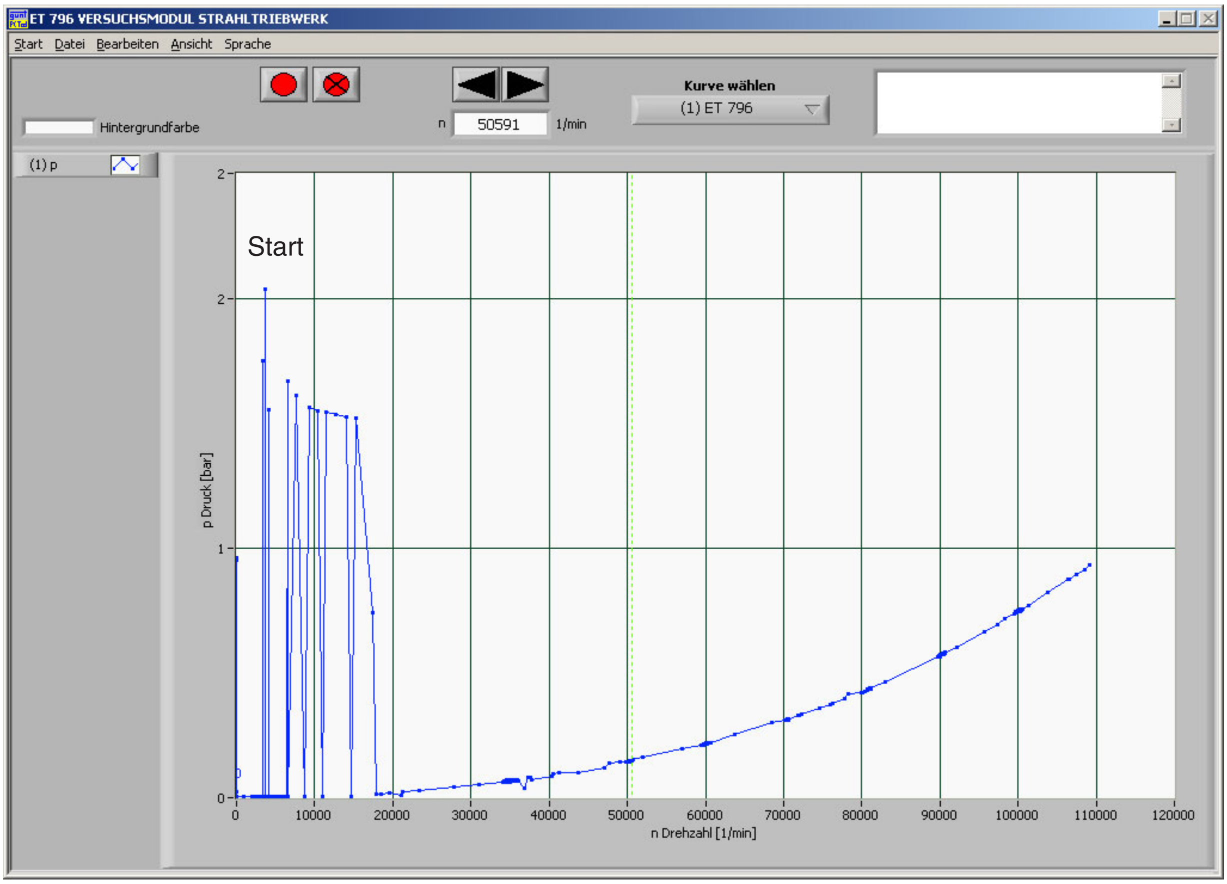


Fig. 5.5 Combustion chamber pressure of the jet turbine from start up to 120000 rpm.

5.4.2 Calculation of air ratio

The air ratio is given by the quotient of the actual amount of air drawn in and the amount of air necessary for the stoichiometric combustion of the fuel.

The quantity of air needed to combust kerosene is:

$$L_{min} = 14.2 \frac{kg_L}{kg_G}$$

From which the air ratio at full load is

$$\lambda = \frac{1}{L_{min}} \cdot \frac{\dot{m}_L}{\dot{m}_b} = 5.91$$

This very high air ratio results from the secondary air.

6 Appendix

6.1 Working sheet for recording measured values

Experiment Gas Turbine Module			Date: Ambient Temperature in °C: Air Pressure in bar: Air Humidity in %:			
Experiment no.:	1	2	3	4	5	6
Compressor outlet temp T1 in °C						
Combustion chamber temp. T2 in °C						
Turbine outlet temp. T3 in °C						
Combustion chamber pressure p in bar						
Air flow dV_air/dt in ltr./s						
Air mass flow ma in kg/s						
Fuel flow dV_fuel/dt in ltr./h						
Fuel mass flow mb in g/s						
Turbine speed n1 in 1/min						
Thrust S in N						
Comments						

6.2 Technical data

Dimensions

L x D x H : 1000 x 795 x1380 mm

Weight approx.: 155 kg

Power supply : 230 V/ 50 Hz

Other voltages optional, see type plate

Fuel: Kerosene, petroleum

5 litre-canister

Exhaust gas port: Tube Ø 300 mm

Sound level at 1 m distance: 110 dB(A)

Type of design

1-shaft jet turbine, open circuit process

Jet turbine P80

Type of design: Radial compressor and axial turbine

Annular combustion chamber

Speed range: 35000...116000 (max.) rpm

max. compression ratio: 2.2

max. fuel consumption: 0.4 litre/min

Ignition system

Special glow plug with auxiliary fuel 1.2 V

Starter system

Electric starter

Lubricating system

Oil vapour lubrication with 1:20 oil/ fuel mixture

Recommended oil grades:

Aeroshell Turbine Oil 500 / 560 with specification MIL-PRF 23699 Grade HTS

Mobil Jet 1

Usable subject to restrictions:

Exxon turbine oil is only suitable for kerosene

Not recommended:

Castrol TTS

Safety equipment

Shutdown in case of

- turbine inlet overheating
- excessive turbine speed

Instrumentation

Thermocouples and digital displays for measurement of the following temperatures:

Compressor outlet

Combustion chamber

Turbine outlet

Pressure sensors and digital display

Combustion chamber pressure 0 - 2 bar

Mass flow rates

Measuring nozzle at air inlet with root extracting pressure sensor and digital display

0 - 500 Ltr/s

Fuel from fuel pump actuator 0 - 25 Ltr/h

Digital tachometer

Turbine 0 - 199999 rpm

6.3 Symbols

b_s: Specific fuel consumption
f: Specific thrust
f_G: Thrust/ weight ratio
G: Weight
H_u: Calorific value
L_{min}: Necessary air volume for combustion
$\dot{m}_a$: Air mas flow
$\dot{m}_b$: Fuel mass flow
P_i: Internal power
P_N: Thrust power
$\dot{Q}_b$: Available thermal output
S: Thrust
w_N: Specific work capacity
λ: Air ratio
ρ_a: Air density
ρ_b: Fuel density
η_{th}: Thermal efficiency
η_i: Internal efficiency
η_a External efficiency
π: compression ratio
κ: Adiabatic exponent

6.4 Parts of delivery

1 x ET 796 Jet Turbine Module
1 x ET 796 Manual Jet Turbine Module

6.5 Index