Plants that produce electrical power with the aid of turbine generators are designed to ensure maximum reliability and cost-effectiveness in production. To achieve these objectives, the conditions of turbine generators must be monitored precisely and deviations from normal operating behavior must be identified.

**STUDIS** – the Stationary Turbine Generator Diagnostic System – is designed to ensure early detection of system errors/defects as a prerequisite for condition-based preventive maintenance. Based upon values recorded by a monitoring system, deviations from normal behavior and possible errors/defects are identified and reported by an expert system.

In addition to the primary functions of condition monitoring, early error detection and error/defect analysis, **STUDIS** also assists the operator in maintaining optimum system operations, avoiding undesirable operating conditions and establishing a reliable and economical mode of operation.

Furthermore, stored data can be accessed at any time for use in analysis.

**STUDIS** is not intended to replace the expert but relieves him of the routine task of evaluating conditions whose symptoms and effects are familiar, thus enabling him to organize his work more effectively.
The illustration below shows an example of a possible configuration of the system. The measurements for the turbines shown in the diagram are recorded and evaluated by highspeed frontends (MDS-100) and forwarded to a central server. Data are then analyzed for diagnostic purposes on the server. In addition, an online diagnosis option is available at any time via a link to our Service Computer.

In addition to machine signals, signals generated at the process control level can also be read by STUDIS. The process control system is linked to STUDIS through the existing standard process control system interfaces.

Stringent requirements with respect to handling and ease of operation apply to turbine generator diagnostic systems. Less experienced users should be able to access important information quickly and easily. Experts must have a highly flexible, extensive toolbox at their disposal for the purpose of performing detailed analyses without complicated procedures.

Inexperienced users of STUDIS move by mouse click from an overview diagram to a display which illustrates the most important relationships and time curves of measurements or key values. Based on template images, the expert can modify detailed configurations as desired using a procedure involving only a few simple steps. Any diagram in the system serves as a template. In the case of preconfigured criteria (e.g. turbine-generator run-down), the user is guided through entire groups of diagrams. These are compiled easily by the user and are available, accompanied by the appropriate data for the relevant time period, if and when the event occurs.

Fig. 1: Sample system configuration
Modular Structure

Modular scaleable system

All modules can access the central STUDIS core (Fig. 2). The configuration of the modules is oriented to the functional groups of the turbine generator.

Modules from systems supplied by other manufacturers can also be integrated. The modular configuration of the system provides an ideal basis from which to plan investments and later system upgrades. The interfaces are open and conform to current standards.

The modular, scaleable STUDIS system contains the following modules:

- Data recording
- Data qualification
- Data display
- Analysis
- Diagnosis

Fig. 2: Modular, scaleable configuration
Data Acquisition Hardware

Rapid data recording with the MDS-100 frontend
The timely recording of vibration signals is accomplished by a frontend system (MDS-100), which transmits data via a 100-Mbit network to the STUDIS computer. Measurement points used to monitor operations from the control room are also used for STUDIS. The STUDIS computer is responsible for further processing of recorded data as well as visualization, storage and diagnosis.

Continuous data recording
The system is capable of recording any number of process channels via the control interface or a local A-D converter continuously in real time. Up to 40 machine planes, each with four vibration sensors and a large number of digital channels can be monitored at intervals of approx. one second (adjustable).

Continuous data recording is effected specifically for vibration values at the shaft and bearings, with 1024/256 scans per revolution, respectively. Scans are distributed uniformly over a shaft revolution and are controlled by a key phaser signal. The measurements recorded in the process are stored in a ring buffer.

Intelligent data compression
Intelligent, operating-state-based data compression provides for long-term monitoring and enhances the reproducibility of system conditions. This feature makes it possible to document machine behavior over an unlimited period of time and to identify gradual changes caused by system errors or defects. Data sets (momentary data) recorded at one-second intervals can also be kept available for additional in-depth analysis.

Data from each revolution can be retrieved from the ring buffer and saved to permanent memory for selected time periods automatically, on the basis of preconfigured criteria or manually.
Monitoring

Early error detection and long-term monitoring

In order to ensure optimum control of turboset operations, it is important that gradual changes in values are detected and evaluated. Such changes do not necessarily indicate errors or defects but may be caused by soiling, for example. In order to ensure early detection of these gradual changes, the system must have access to quality-controlled, load-point-adjusted evaluation criteria over a sufficiently long period of time. Because STUDIS facilitates this process, operating personnel receive support in selecting optimum time for maintenance.

In order to compute the remaining estimated service life of steam-turbine components subject to heavy loads, the operator must have access to data on pressure and temperature loads over time. This data is ordinarily obtained by evaluating printed records. STUDIS enables the operator to obtain load and time data online. This provides operators, manufacturers and inspectors with significantly more precise load statistics.

Monitoring and diagnosis

All measurement values are recorded by the monitoring system within a given measurement cycle. The monitoring system also performs frequency and order analyses as well as quality tests. In addition, measured values are checked and evaluated, and a load-point-based comparison of expected and actual behavior is performed.

The results of comparative analysis are forwarded to the expert system. The expert system allocates detected deviations to error diagnoses on the basis of preconfigured rules.
Error diagnosis with a rule-based expert system

One of the essential features of STUDIS is its rule-based expert system. Unlike many diagnostic systems produced by other manufacturers, in which all error rules are processed on an event- or time-controlled basis, STUDIS process only error-hypothesis rules in which the premise values show a significant deviation from an expected value. This makes it possible to verify error hypotheses effectively online.

Processing is performed initially for periods of stationary operation of the turbine generator in condition of thermal balance. The measured and reference values are subject to a multi-level quality control procedure, the results of which are recorded in a status. The status is taken into consideration in all further evaluations of the diagnosis.

The results of diagnosis are documented, to include all information obtained during the diagnostic sequence, for evaluation by an expert. This ensures that the diagnosis can be reconstructed at a later point in time or that diagnostic rules can be adjusted in response to new insights.

The expert system makes it possible to detect errors at an early point in time, even if selected tolerance bands are unfavorable or the knowledge of an error hypothesis is imprecise.

Fig. 4 presents a schematic diagram of the diagnostic process. The different results of comparison between expected and actual values are linked to rules. Depending upon the level of conformity with the rules, a diagnostic result is issued. This ensures that only relevant errors, defects or disruptions are displayed.

Fig. 4: Schematic diagram of the diagnostic process
Compact Information Display

Detection of machine behavior

**STUDIS** employs primarily automatic mechanisms for the purpose of detecting unexpected machine behavior. For example, criteria can be formulated to control the evaluation process and dispatch messages to authorized personnel. As long as the turbine generator behaves as expected, no expert input is required. When deviations occur, **STUDIS** supports the expert with a wide range of analytical tools.

Operating-point-based confidence interval

Measured and computed values are standardized in conformity with their operating-point-based confidence interval. Dynamic, operating-point-based confidence interval monitoring facilitates the early detection of even small deviations resulting from machine malfunction.

**STUDIS „Magic Eye“**

In support of online evaluation of current machine status, a high-compression data display, the **STUDIS „Magic Eye“** (Fig. 5) provides a standardized display of every configured value relative to its specific tolerance band.

The Magic Eye is capable of displaying up to 1200 values, showing a representation of the value, the confidence interval and deviations from confidence limits. Colored markers in the outer ring indicate that a deviation from tolerance has occurred within the past 24 hours.

![STUDIS „Magic Eye“](image-url)
Samples for Visualization

Modern display philosophy with a high level of flexibility
All measured and computed values can be displayed as time functions or as functions of other selected values. Data can be displayed in accordance with individualized selection criteria.

Data can also be displayed in combination with characteristic curves and reference periods. It is displayed on the basis of individual criteria on authorized network PC. Every diagram created remains available as a template for use in other freely configurable graphs.

Waterfall diagram
In the waterfall diagram, frequency analyses of vibration signals are displayed as a time sequence. The diagram can be revolved as desired. It is possible to examine every frequency line individually in a separate window.

Spectrogram
A variation on the waterfall diagram is the spectrogram, in which amplitude patterns are represented by colors. Logarithmic, quadratic or exponential color scales can be selected. The scale spread can also be adjusted manually.

Weekly-, monthly- and quarterly report
The reports show deviations of parameters from expected values. Parameters and time frame can be defined manually.
**Frequency analysis**

The time signal or the frequency analysis can be displayed in the upper section of the diagram. The path of the theoretical shaft midpoint during shaft revolution is shown in the lower section (orbit). The orbit can be displayed with inserted references, as an online orbit or as animation over selected periods of time.

**Bar graph**

The bar graph shows the values Gap, 0.5f, 1f, 2f and 3f as well as the operating-point-based tolerance bands and tolerance band deviations for vibrations for each vibration sensor measurement.

**Bode diagram**

Up to five vibration values with magnitude and phase can be shown simultaneously as a function of rotation speed (rpm) in the Bode diagram. Reference and online values can also be inserted.
Nyquist plot

In the Nyquist plot, each vibration signal is shown with magnitude and phase. A difference vector can also be shown for the purposes of evaluation. Tolerance bands can be inserted in the online display, if desired. In addition to the standard tool bar, tools for limiting, selecting and evaluating results are also provided for the Nyquist plot.
Distribution of information in the case of turbo generator malfunction

Message can be transmitted to selected individuals by e-mail or SMS in order to ensure that the result of the expert system and relevant data are evaluated and analyzed by an expert without delay.

Integration in existing control systems

STUDIS is equipped with an open interface that provides for convenient integration into existing control systems.

STUDIS Highlights:

- Mobile and stationary STUDIS
- Modular, scaleable system
- Rapid data recording with frontend system (TCP/IP Ethernet)
- Data qualification / validation
- Dynamic, operating-point-based tolerance band monitoring
- High-compression information display ("STUDIS Magic Eye")
- Diagnosis with rule-based expert system
- Modern display philosophy with a high level of flexibility
- Frequency and order analysis
- Dynamic reporting feature (dynamic graphic display)
- Messaging (RMA, SMS, e-mail...)
- Operable from a competence or diagnostic center

Early detection of:

- Rubbing
- Bearing hot spots
- Shaft deformation, cracks, alignment errors
- Mass losses (e.g. loss of parts of blades)
- Atypical component behavior

Analysis of:

- Blade damage
- Transmission damage
- Shaft fractures
- Bearing damage

Services:

Our standard program of products and services includes basic support and guidance for the implementation of a STUDIS system. We also offer optional online diagnosis in support of day-to-day operations within the framework of a maintenance contract.

Every STUDIS package also includes one full day of training for up to 4 persons.

Blade damage
Source: VDI Report, June 2003
Technical data:

- Modular system configuration
- Continuous vibration monitoring without time gaps
- Supply voltage 24 – 38 VDC
- Frontend buffer depth up to 256 seconds
- Each frontend unit (MDS-100) is equipped with 4 high-speed and 4 low-speed inputs:
  - High-speed inputs per card: 16,000 scans per second for key phaser; controlled measurement up to 1,024 samples per revolution
  - Low-speed inputs: 4 samples per second
- Resolution: 12 bit for low-speed inputs / 16 bit for high-speed inputs
- 2 free process-data inputs
- ± 10 V/0 ... 20 mA
- Input resistance: 0.5 MV/1 MV at 30 pF input capacitance
- Galvanic separation for all inputs and outputs
- 100-Mbit Ethernet interface
- Permanent server memory: >140 GB
- Ring buffer capacity: >140 GB
- Fully network capable (Windows, Unix, VMS, etc.)
- Firmware updates and software modifications available on the Internet
- Upgrades are fully compatible with older systems

Selected STUDIS references:

Stationary Diagnostic and Optimization Systems
- Weisweiler Power Plant, Blocks E – H, VGTs G and H, since 2008
- Huckingen Power Plant, since 2008
- Gersteinwerk Power Plant, Blocks F – K, since 2008
- Emsland Power Plant, Blocks B and C, since 2007
- Westfalen Power Plant, Blocks B and C, since 2007
- Goldenbergwerk Power Plant, Block F and E, since 2006 resp. since 2008
- GuD BASF Antwerpen 2005
- Neurath Power Plant, (B:1991) since 2002 all 5 Blocks
- Niederaußem Power Plant, (H:1994) since 2002 all 8 Blocks
- BOA Niederaussem, since 2002 HT, SPT, TSP, FL, SZ
- GuD Bayer Dormagen, since 2000 GT1, GT2, DT, HKP
- Frimmersdorf Power Plant, Block P and Q, since 1998 resp. since 2008
- Ibbenbüren Power Plant, Block B, since 1998
- GuD BASF Ludwigshafen, since 1997
- Solvay GmbH, Rheinberg, since 1997

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