FULLY AUTOMATED TEST-PLANT FOR CALIBRATION OF FLOW-/HEAT-METERS

Andreas Dedinak, Wolfgang Studecker, Alfons Witt

ARC Seibersdorf research GmbH
Mechatronic Automation Systems
A-2444 Seibersdorf, Austria
Tel. ++43 50550 2250, Fax ++43 50550 2204
{andreas.dedinak, wolfgang.studecker, alfons.witt}@arcs.ac.at

Abstract: In autumn 2002 ARC Seibersdorf research GmbH was awarded a contract from GEW Rheinenergie Köln GmbH covering supply and erection of a heat-meter test plant. It is designed for fully automated operation and maximum flexibility so that all heat-meters on the market can be tested on a maximum uncertainty of flow-measurement less than 0,1%. The newly developed interfaces VMK2000+ were selected as interface between specimens and the network based process control. Integrated databases for static and streaming real time data serve not only the test process- and result-data, but as well the complete administrative data for tests and QM. *Copyright © 2005 IFAC*

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1. INTRODUCTION

A heat-meter consists of three components:

- a flow-meter for water as medium for heat-transport (volume per time-unit)
- two temperature sensors for measurement of the temperature-difference between in- and out-going line of the heat-consumer
- a computer for calculation of the consumed thermal energy based upon temperature difference and flow

The calibration of the heat-meters is performed by measurements based upon national and international standards for the physical base units. These are mass, time and temperature. The mass is determined by weighing, time by electronic time-counters and temperature by using exactly calibrated reference-thermometers.

Usually there is a separate test for each component of a heat-meter:

- The procedure of testing a flow-meter is as follows: The specimens under test are clamped in a row. Then an extremely stable flow is established and the flow-meter is calibrated by comparison with electronic balances as primary reference.
- The computer of a heat-meter is tested by evaluation of its calculation-results when flow and temperature are simulated.
- The temperature-sensors are put in extremely stable thermostat-baths and compared to reference –thermometers.

The errors of all three components have to be within the limits given by regulations and national laws.

The following article describes the new test-plant built for GEW Rheinenergie Köln/Germany. It consists of 2 test-benches for heat-meters: Bank no.1, designed as double-row-bank, is for flows between 6 litres/hr and 12 m³/hr (nominal-diameter of specimens DN15 up to DN50), bank no.2 in single-row arrangement is for flows between 150 litres/hr and 60 m³/hr (nominal-diameter of specimens DN50 up to DN100). Both banks are operated with water-temperatures from 25 to 90°C, the hydraulic pressure at the banks' inlet is maximum 10 bars.

The erection-works at site started in September 2003 and – after an intense phase of testing and optimisation – the commercial operation began in April 2004.

2. MECHANICAL / HYDRAULIC SYSTEMS

2.1 System Overview

The following Fig. 1 shows the flow-diagram of the double-row-plant's testing-cycle (diameter of heat-meters maximum DN50). The design of the plant for heat-meters up to DN100 is similar. The storage tanks and the heating system are common for both banks. While the water-supply system (tanks, pumps, heat-exchangers) is situated in the basement of the building, both test-banks are arranged in an air-conditioned room at the first floor.

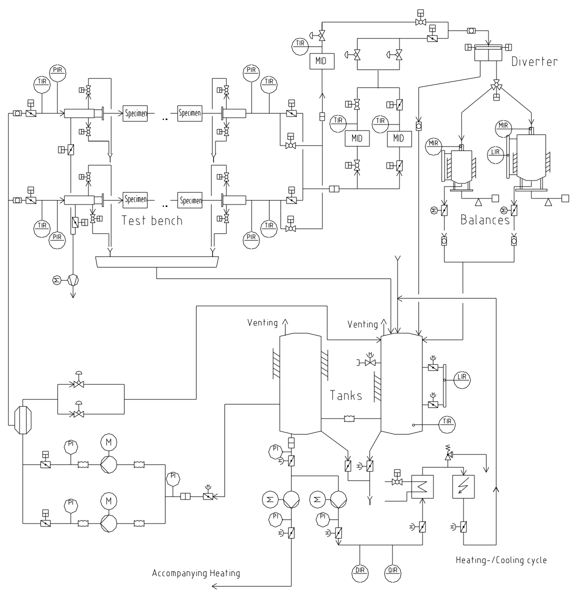

Fig. 1. Flow-diagram

2.2 Test Bench

The test bench is designed for testing the specimens in a double-row-arrangement (bank no.1) respectively in a single-row arrangement (bank no.2). A row consists of maximum 8 heat-meters which can be tested simultaneously. The row of specimens is clamped pneumatically between water-inlet- and outlet header of the bank: The outlet headers of the banks are fixed, whereas the inlet headers are equipped with pneumatic tensioning devices and can be moved in axial direction. The tensioning-force is adjustable according the hydraulic pressure in the system. All inlet- and outlet-headers of the test bench are of double-shell design to assure a constant temperature by accompanying heating.

All metal parts of the test bench are made of stainless steel. Rail-based carriages allow easy and fast installation of the adapters between the specimens. For accompanying heating, the test bench is equipped with a hot-water forward- and return-line. Integrated in the bank are the supports for installation of the connecting-interfaces VMK2000+ (see section 3.3).

The adapters clamped between the specimens are also a double-shell construction to allow accompanying heating.

High attention is paid to establish a flow with minimum disturbances and to achieve long sections for flow-stabilization.

2.3 Storage Tanks for Water

Two storage tanks under atmospheric pressure are installed. Both vessels have a connection with a pipe of large diameter to ensure the same level in both tanks. The tank for the return flow is equipped with special internals to improve removal of air and to achieve a smooth flow of the water. From the other tank the water is directed to the circulation-pumps. The level of water in the tanks is controlled by a magnetic level-sensor.

2.4 Temperature Control System

An electric heating device is foreseen for heating-up the water in the test plant. The water is pumped in a separate heating cycle (see figure 1) constantly from the first storage tank via the heating device back to the second tank. This ensures always a homogeneous temperature profile in the storage tanks. A heat-exchanger fed with cold water allows fast cooling down of the water temperature if required.

After switching-on the plant, a separate, independent control-loop brings the water-temperature up to the pre-selected value. Start-up of the heating can also be controlled by a timer to reach the desired operating temperature before the operating-personnel's arrival.

A separate accompanying heating system (with separate pump) feeds the heated water to critical piping sections and ensures a constant temperature profile even at small flows.

2.5 Pumps, Control of Flow

Each test bench is fed by a separate set of pumps (there are two pumps per bench). The pump for operation is selected automatically according the required flow. Frequency converters control the speed of each circulating pump. In addition, a bypass valve enables the pumps to work in their optimum operating-range with high efficiency and less pulsation.

The hydraulic pressure on the test bench is controlled by a set of regulating-valves situated at the outlet of the bank. Based upon the selected flow and pressure, the appropriate control valve is adjusted according its characteristic. When the flow is established, a fine regulation of the valves is performed. The inlet-pressure to the test bench is measured and the optimum operation point for the pumps determined and adjusted by the bypass-valves. Then the final, exact regulation of the flow is done by control of the pumps' speed.

2.6 Piping System

All piping is made of stainless steel with appropriate thermal insulation. The piping system is equipped with all required accessories to allow automated operation: Remote controlled shut-off dampers, ball valves, control-valves, venting-/dewatering devices and measuring instruments. The design of the piping avoids deposition of air in the pipes (e.g. all pipes are sloped from pumps up to diverter).

To improve measurement quality, the pipes between the test bench and the diverters are equipped with an accompanying heating system: In this critical piping section, there are copper-tubes of small diameter wound around the piping. They are fixed by insulation-foam and constantly fed with hot water from the accompanying heating system to reduce the loss of temperature in the testing-cycle.

A vacuum system consisting of a vacuum-pump and the respective piping up to the test-bench is installed to allow removal of air from the meters before testing.

3. ACCQUISITION OF MEASUREMENT DATA

3.1 References

The plant’s primary references are electronic balances. These balances are force-compensating scales, which operate in the high-range mode. Measured calibration curves of the balances are saved in the PC and are considered automatically for determining the weighing-value. Moisture sensors installed in the tanks on the balances allow a correction of the evaporation losses and of the buoyancy.

In the piping after the test bench magneto-inductive flow-meters (MIDs) are installed as secondary reference for operation. The vertical arrangement of the MIDs avoids depositions on the electrodes. The output-signal’s frequency of up to 10 kHz guarantees a high resolution of results. The verification of the MIDs by means of the balances is performed simultaneously at each testing cycle. Therefore, the measurement of volume is done always with the accuracy of the balances.

3.2 Diverters

For determining the error of the secondary references (MIDs), a diverter directs the flow in a very fast way to the balances. The switching-behaviour of the diverter is a decisive criterion for the total uncertainty of the test-plant.

The diverter is operating according the „method of the cut stream“. It consists of collecting chambers with radial walls for separation. A part of the collecting chambers empties directly to the tank on the balance. The other chambers have a common return line to the storage-tank. A movable (rotating) plate, equipped with nozzles, directs the water flow either to the balance or to the return line. The system described above assures, that switching has no influence on the flow and is independent from the piping design.

The time for switching (from balance to return line or vice-versa) is less than 50 ms, even at large flows. The uncertainty of the trigger-point for switching is less than 10 ms because the exact moment of switching is defined with a code disk.

3.3 Connecting Interfaces for the Specimens

The plant in Köln is the first erected test-system, where the new generation of interfaces, so called "VMK2000+" ("Volumenmeßkopf2000+"), is installed. These interfaces between meters under test and control system of the plant are a basic requirement for high-precision measurements. Each specimen is connected to its own interface, so totally 20 VMK2000+ are installed.

The VMK2000+ is consisting of a low-power single board computer, specialized developed hardware and common, multi-polar plugs. The plugs are coded in a way, which enables the interface to detect the type of the connected specimen automatically.

The interface supplies the specimen with up to 4 adjustable voltages simultaneously, the range can freely be selected between approx. -12 and +12 V. Each of these outputs can deliver maximum approx. 400 mA. In addition, there are logic-outputs, whereby for each output the Low- and High-level is adjustable individually. The maximum input-frequency is 1 MHz. There are also logic-inputs, whereby for each input the switching-threshold is adjustable individually between –12 and +12 V. Each input is connected to a fast 16bit analog-digital-converter, so recording of analogous signals is also possbile. The interfaces are equipped with a display (4-lines) to show important information locally.

Depending on the type of the specimen, the PC selects automatically the required test-programs and each interface is performing the testing cycle individually and independently. At specimen using digital communication, the signals of the flow-meter are read in the specific code of the specimen. As data of the flow-meter like serial number, type, calibration parameters etc. can be read and also be written back, fully automated adjustment for these types of flow-meters is possible.

With the VMK2000+ - concept, testing of flow-meters of different type or manufacturer at the same time is possible (as long as the mechanical properties like diameter, flow etc. are the same).

4. PROCESS CONTROL AND ELECTRIC SYSTEMS

The process control of the complete test stand is based on a high performance standard industrial control system (PLC) connected to a Windows based PC network. This network on his side is bridged to a Linux based PC and microPC network hosting the VMK2000+ interface system to the specimens.

4.1 Electric Layout

Due to highest requirements on the accuracy of the measured data on one hand and the risk of interference (i.e. by the frequency converter based pump control with high power input) on the other hand, following measures have been taken to stick strictly to EMC directives:

- On account of core grids in walls and ceilings an intermeshed grounding concept is implemented with a star-like earth of the main components
- Measurement and control equipment is separated from power components in different cabinets
- Critical data connections are realized in optical fibre
- All cables are implemented in a shielded version
- All power supply cables run in a star-like design

4.2 Industrial Control

All test field components like pumps, valves, frequency converters, switches, etc. are controlled and monitored by a centralised industrial control system.

The measurement equipment for flow, pressure and temperature is connected to that PLC system via transmitters. The transmitters are located directly at the point of measurement to convert the raw sensor signal to a current signal insensitive for influences by interferences. These signals are used directly in PLC for performing control loop tasks and generate derived process data or being transmitted to the PCs for result generation or process data logging.

The four balance systems are the primary calibration references. Failures in the read out affect the final uncertainty of the test stand in spades. Hence, the balance systems are connected to the PLC via the industrial bus system Profibus, no signal conversion is necessary to avoid additional variance.

Beside the control system is equipped with an Ethernet interface to fit in the network structure.
While the control system hardware serves both test benches, the program tasks for each bench run independently.

4.3 Component based Programming

Although PLCs are normally programmed in a procedural way, the program structure for the flow/heat meter test stand is component based.

All test stand components or component groups are mapped into software objects. Such a software object can be addressed by its attributes and methods. By linking these objects, the functional test procedures can be implemented in a modular way yielding to two advantages:

- Different test stand layouts can be realised easily as only the binding of the existing component objects have to be changed.
- On the other hand, changes of component types with similar functional characteristics are effortless. The methods and attributes of the associated object represent only the functional behaviour and not the physical implementation. So only the implementation of the object has to be changed by leaving untouched the test procedures themselves.

4.4 Networking the Subsystems

The large number of interacting subsystems based on heterogeneous communication methods, demand for a matching network structure diagrammed in figure 2.

The main communication is based on Ethernet in switching technology.

The database server is not only hosting the relational database for static data, but as well an OPC server for communication with the industrial controller. OPC (Object linking and embedding for Process Control) stands for an open object oriented communication between homogeneous and mainly heterogeneous systems primary in process and manufacturing automation.

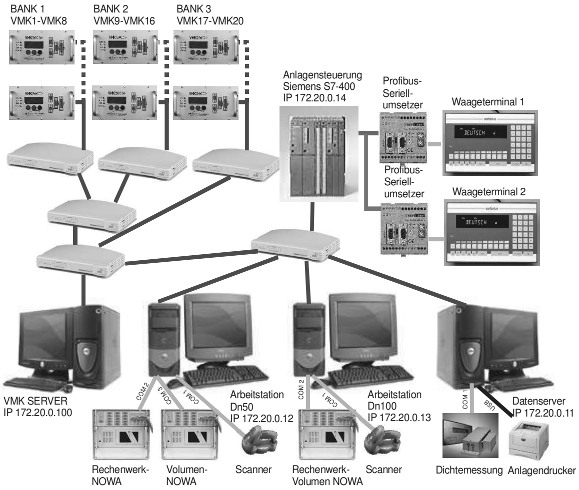

Fig. 2. Layout of the process control for the test stand of Cologne's power supply company.

Each test bench has its own operation PC. These computers are running the user interface, the supervisory control of the particular test process and a streaming database for process data logging. Aside it communicates with the NOWA system - a standard specimen interface - via serial connections. The two operation PCs communicate between each other and the database server on so-called remote tags (a set of variables write and / or readable across computers) based on Microsoft DCOM (Distributed Component Object Model) mechanisms.

The VMK2000+ interfaces (see paragraph 3.3) are Ethernet based. They are networked to a Linux based PC called the VMK server. This server works as a bridge to the Windows based computers, but hosts as well the complete software for the VMK2000+ interfaces. On power-up, each interface VMK2000+ boots directly from the VMK server. With this, configuration adaptations in VMK2000+ software (e.g. new specimen types) have only be loaded once to the VMK server in stead of 20 times to all single interfaces. The communication between the Linux and the Windows side of the network is executed by pure TCP/IP port read and write commands, so additional bridging overhead is not required.

5. USER INTERFACE AND DATA MANAGEMENT

The user interface is not only responsible for the test procedure itself, but acts as well as an interface to the database for managing all administrative data. In addition, it visualises the test bench and the peripheral equipment.

5.1 User Interface

Figure 3 depicts the main screen of the user interface. Beneath the visualisation of the test stand, the window shows time-stamped status changes and errors, as well as the test status of the specimens.

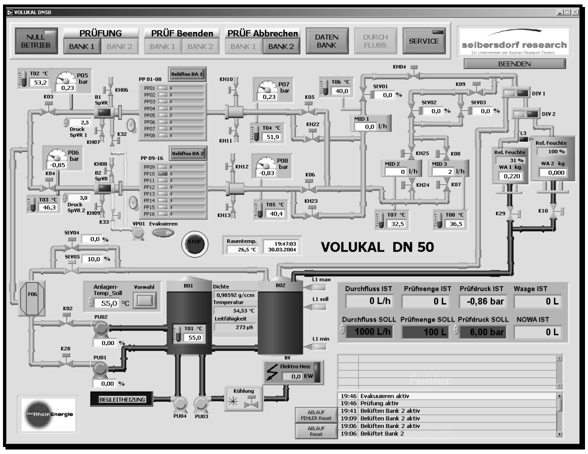

Fig. 3. User interface: Visualisation main screen of the test bench with the double-row-bank.

The operation of the user interface is intuitive without stacked menu structures. By clicking on the button bar at the top of the window, the operator can manage tests and data as well as additional service tasks (e.g. automated calibration of measurement equipment like temperature and pressure; manual control of all valves, pumps, etc.).

After defining the specimen by simply choosing the type out of a database list and reading the meters identification number by a wireless hand scanner, the tests can be started and will be automatically executed according the defined standard - resulting in test reports and test data stored in the databases.

5.2 Real Time Database

Beside the storage of static data for administrative management and test results, trend data streams of the test run are of interest, e.g. to analyse deviating phenomenon's. Standard relational databases are not optimised to store these trend data in real time (in particular on large data quantity).

For that reason, each test bench's operator PC additionally hosts a streaming database. This data base stores process values in a compressed form only if the observed value has changed beyond a defined dead band (a minimal increment of interest). The change of value is time stamped. By accessing the database via a special interface, the data can be read out again in a time equivalent format.

These data bases are used for statistical analyses (like averages and standard deviation) needed for the test results themselves and also for analysing the historical trend diagrams with special tools depicted in figure 4.

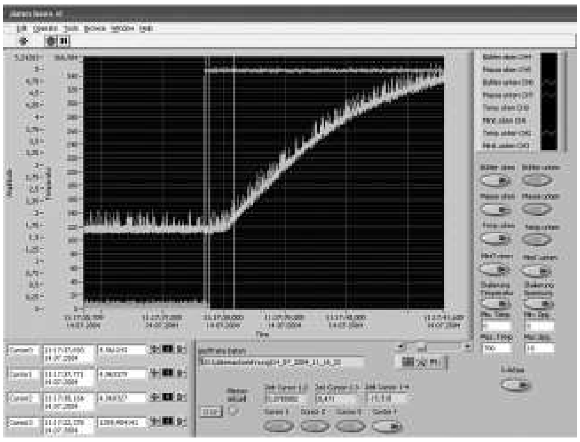

Fig. 4. Viewing and analysing historical trend data from the streaming database.

5.3 Data Management

To cover the highest desires of the customers comfort, the increasing demands of QM regulations and - for test stand specifically - the requirements of the bureau of standards, the test stand has to manage not only the test procedures, but as well the peripheral data administration.

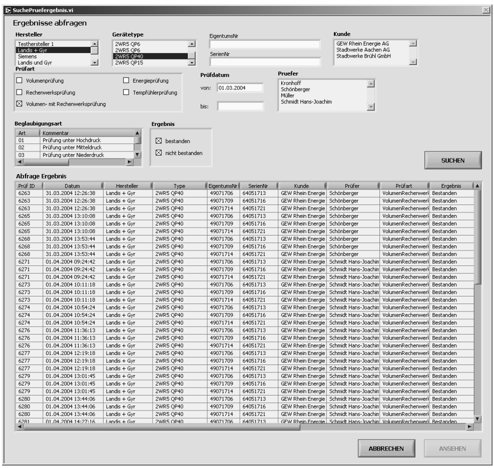

Fig. 5. Example of an integrated database inquiry of executed specimen tests by specific criteria.

This includes data of customers, of producers of meters, of meter types, of test defaults, of operators, of the calibrations of the test equipment, of test orders and finally of the test results. Additionally an automated report generation has to be included. These data are stored in a central SQL server. The access is fully integrated in the user interface (see figure 5) allowing the operator to manipulate the data without any database knowledge.

As the customer runs a companywide SAP system for his ERP tasks, several test and administrative data per specimen have to be transferred (exported) from the test stand to this system.

6 FIRST RESULTS FROM THE PLANT'S OPERATION, CONCLUSION

6.1 Uncertainty of Measurement

A requirement of the contract was an analysis of uncertainty based upon the method described in the "GUM" (Guide to the Expression of Uncertainty in Measurement).

The main influence factors on the plant's total uncertainty are

- the resolution and stability of the master-meter
- the temperature-difference between specimen and master-meter
- temperature-changes or air in the piping system
- uncertainty of the balances
- influence of the switching-device (diverter)
- influence by the way of correction of buoyancy and evaporation
- influence of density-measurement

The mathematical description, established for these influence-factors, is a complex expression. The parameters of the influence factors were determined and checked by intensive testing of the plant during setting into operation and acceptance tests. Evaluation of the results showed, that the plant's uncertainty of measurement is better than 0,1%.

6.2 Conclusion

The tests performed during setting into operation and acceptance procedure proved the plant's functionality and the fulfilment respectively exceeding of all specifications. The operating-personnel of the plant pointed out its high flexibility and comfortable performance of measurements. Especially handling of the specimens as well as the graphical user interface proved to be very effective and reduce the required time for calibration of heat-meters significantly.

The plant's uncertainty of measurement is extremely good for plants in commercial operation, only special test-systems for research might exceed these values.

At the plant's design many measures were taken to improve testing-quality of flow-meters. These provisions assure, that also future requirements concerning measurement-accuracy will be met, whereas the high level of automation guarantees efficient and economical testing.

REFERENCES

International Organization for Standardization (ISO) (1993). *"Guide to the Expression of Uncertainty in Measurement"*