Pneumatic Probes / Pressure Measurements
Paper 8

INTERMITTENT PURGING FOR PRESSURE MEASUREMENTS AT WET STEAM CONDITIONS

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1. Introduction

The measurement of steady state pressures at wet steam conditions (wall pressures or pneumatic probe pressures in steam turbines for instance) causes some specific problems. For it is still a common practice to place the transducers outside of the turbine in a friendly atmosphere, the pressures have to be transmitted via small diameter tubes. This fact leads to problems concerning the blockage of tubes caused by ingested water or by condensation of steam at the walls of the tubes. However, an undefined state of blockage has to be strictly avoided in order to guarantee reliant measurement results. In the past, various procedures have been investigated and tested concerning this problem.

1. Water filled lines: In this case, the lines connecting the pressure tap and the transducer are filled with water. But restrictive geometry of the arrangement lines and evaporation of water at low pressure reduces its application /1/.
2. Continuous purging with dry air: A small flow of dry purging air, defined by a needle valve close to the transducer, may be continuously blown into the tubing. This flow must keep the lines free of water but has to be minimized at the same time in order to reduce errors due to both frictional pressure drop between the injection point and the pressure tap as well as distortion of the flow field at the tap itself by the leaving purge air. These errors have to be taken into account by a calibration of the arrangement /1,2/.
3. Intermittent purging with dry air: Before each measurement, the line is purged with dry air from an injection point close to the pressure device towards the tap. During a period of waiting, the pressure in the line recovers according to the line pressure at the tap and measurements can be taken free of errors as along as the line is not plugged again. Therefore, the measurements have to be carefully observed and the pressure values checked on their validity /1/.
4. Continuous purging, interrupted by the measurements: A mixture of the above methods is given by continuous purging with dry air which is interrupted during the time when the measurements are taken. Less purging air is required to keep the lines free but the measurements also have to be carefully observed /3/.

2. Measuring concept for intermittent purging

In our application, the condensate is removed by intermittent purging to ensure reliable pressure measurements. The reason for this decision is the high number of pressure taps (several hundred) which requires an automatic data acquisition and control system. Furthermore, the measurements should be taken without any erroneous influence or the necessity of calibration and correction.

2.1 Description of the pressure curve

The intermittent purging procedure leads to a measuring cycle, which consists of rezeroing, purging, waiting, measuring, and postpurging (Fig. 1). The figure shows the curve of the absolute pressure in two pressure lines which are connected to a differential pressure sensor. The abscissa represents the time axis while on the ordinate the typical curve of pressure variation in the line during a measuring cycle is plotted.

At the beginning of a measuring cycle rezeroing of the transducers takes place and all tubes are purged to blow out any condensate. When the end of the waiting phase is detected, the actual measurement time starts, which is devided into a transient state and the real measurement window. During this phase, all transducers are connected to their pressure taps in the turbine. It can be stopped either by a normal or an abnormal criteria (as a result of plugged lines for instance) which will be described in more detail lateron. In order to blow out any droplets close to the sensors, all lines are purged again at the end of the cycle.

The entire cycle is controlled on-line by a sophisticated data acquisition system, which is supported by solenoids and the applied pressure instrumentation. It yields all the readings of the measurement time. During post-processing, the readings of the measurement window are separated from the transient state and the plausibility of the data is analyzed.

2.2 Hardware arrangement

In our application we are using different types of pressure transducers:

- Standard precision 16-channel true differential scanner: A benefit of this type of scanner is its integrated purge function.
- High-precision 1-channel true differential scanner: The reference port of the sensor is connected to vacuum and delivers therefore the absolute pressure level. This device may also be used as a calibrator.
- Standard precision all-media scanner for purpose of control instrumentation.

In addition:

- A Personal Computer with the data acquisition and control software.
- A Valve control unit.
- Solenoids: The measuring tubes are normally blocked close to the turbine by solenoids. They are only opened during purging or measuring.
- The vacuum at the reference port of the high-precision scanner is produced by a turbo pumping unit.

The described hardware set-up is schematically shown in Fig. 2.

2.3 Control of the measurement cycle

2.3.1 Control by real-time calculations

As mentioned already before, the main problem of intermittent purging is to control the different phases of the measurement cycle, i.e. to locate the measurement time when the differential pressure transducers can be connected to the pressure taps without any risk of overloading. Therefore, control instrumentation is required which remains active over the entire measuring cycle. All-media transducers are chosen for this purpose. They are responsible for the start of the measurement period.

Start of measurement phase

If the absolute pressures, measured by the control instrumentation, drop below the selected pressure limits (thresholds), the start criteria for the beginning of the measuring time is fulfilled and all differential pressure transducers will be connected to the pressure taps.

End of measurement time

The measuring time is stopped by one of the following four criteria:

- Criterion 1: The measuring is stopped, if the number of readings exceeds a predefined number of readings. That's the normal end of a measuring cycle.
- Criterion 2: The measuring is stopped, if the absolute pressures, monitored by the control instrumentation (all media transducers) exceed the defined pressure limits (thresholds).
- Criterion 3: The measuring is also stopped, if any measured values of the differential pressure transducers exceed their permitted limits.
- Criterion 4: During the measuring time, the differential quotient of each pressure signal is calculated on-line. The value of this differential quotient must be below a predefined limit (Gradient 1). Point to point determination of the quotient between two readings is not possible because the measurands are subject to fluctuation. Therefore, lowpass filtering becomes necessary (Table 1). This filter has the property of smoothing out measuring errors caused by elevated frequency and fluctuations. Usually, a filter of 5th order is sufficient for this purpose. The criterion for termination of the measuring cycle is satisfied as soon as Gradient 1 is exceeded.

Up to this point all calculations are performed on-line.

2.3.2 Control by post-processing

During post-processing, first the transient phase and the measuring window are located each. In a second step, the conditioning of the readings within the measuring window takes place in order to generate validated values. Both steps must be completed prior to the beginning of the next measuring cycle.

2.3.2.1 Locating the transient phase

Some of the readings within the measuring time represent the transient phase. The rest are the desired measurands within the measuring window (Fig. 3). The pressure curve in the transient phase is a slowly decaying function with disturbing superposed oscillations. With a lowpass filter, like that used for the termination - criterion 4 -, but with different coefficients, the low-frequency part of the curve is filtered (Table 2). As soon as the differential quotient drops below a predefined value (Gradient 2), the transient phase ends and the measuring window begins. Only the readings following this transient phase are used for further processing.

2.3.3.2 Conditioning the pressure measurands

Suppose the desired measurands of the window are located (Fig. 5). Then, the mean value x, the empirical standard deviation s and the standard error *Std.err* are calculated (Table 3). The standard error is the empirical standard deviation normalized by the number of readings.

This statistical quantity is now compared with a predefined value K. Only if K is bigger than the standard error *Std.err*, the measurement is valid and stored in a data file. Usually, these calculations are based on 20 to 30 readings.

3. Summary

Steady state pressures are measured at wet steam conditions by using intermittent purging. This leads to a measuring cycle consisting of rezeroing, purging, waiting, measuring, and postpurging. It is fully controlled by an automatic data acquisition system, which is supported by solenoids and the applied pressure instrumentation. Both, pressure control instrumentation as well as data conditioning during on-line operation and postprocessing are used to define the actual measurement window and to achieve validated values.

First, the complete measuring cycle with all needed plausibility criteria was tested with the help of simulated pressure values. Then in a second step, tests were performed with real steam conditions produced by a small steam boiler.

Finally, the system was verified at a steam tunnel and an original steam turbine. We could prove, that the presented procedure of intermittent purging is working under real operating conditions. In an automatic process, the measurements can be taken without any systematic erroneous influence or the necessity of calibration and correction.

4. References

/1/ Moore, M. Instrumentation for Wet Steam, van Karman Institute for Fluid Dynamics, Lecture Series 70, 1974

/2/ Heneka, A. Strömungmessung mit kontinuierlich belüfteten Sonden, Arbeitsbericht SFB 157, Universität Stuttgart, 1981

/3/ Schmidt, D. et al. Strömungsuntersuchungen an HKW-Turbinen im Heiz- und Schwachlastbetrieb

Figure 1:

Sketch of the pressure trend in 2 pressure measuring tubes during one measuring cycle

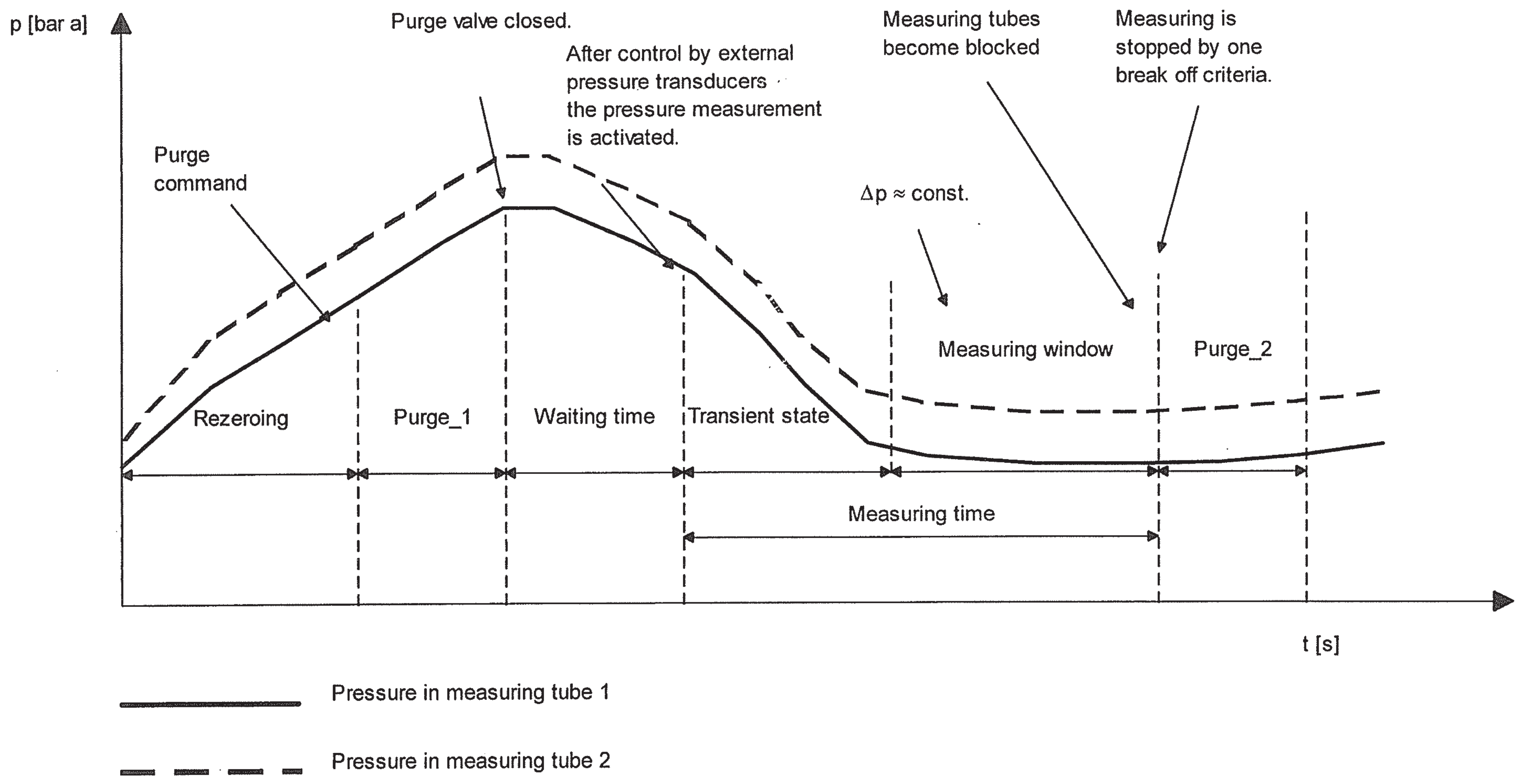

Figure 2:

Hardware Arrangement

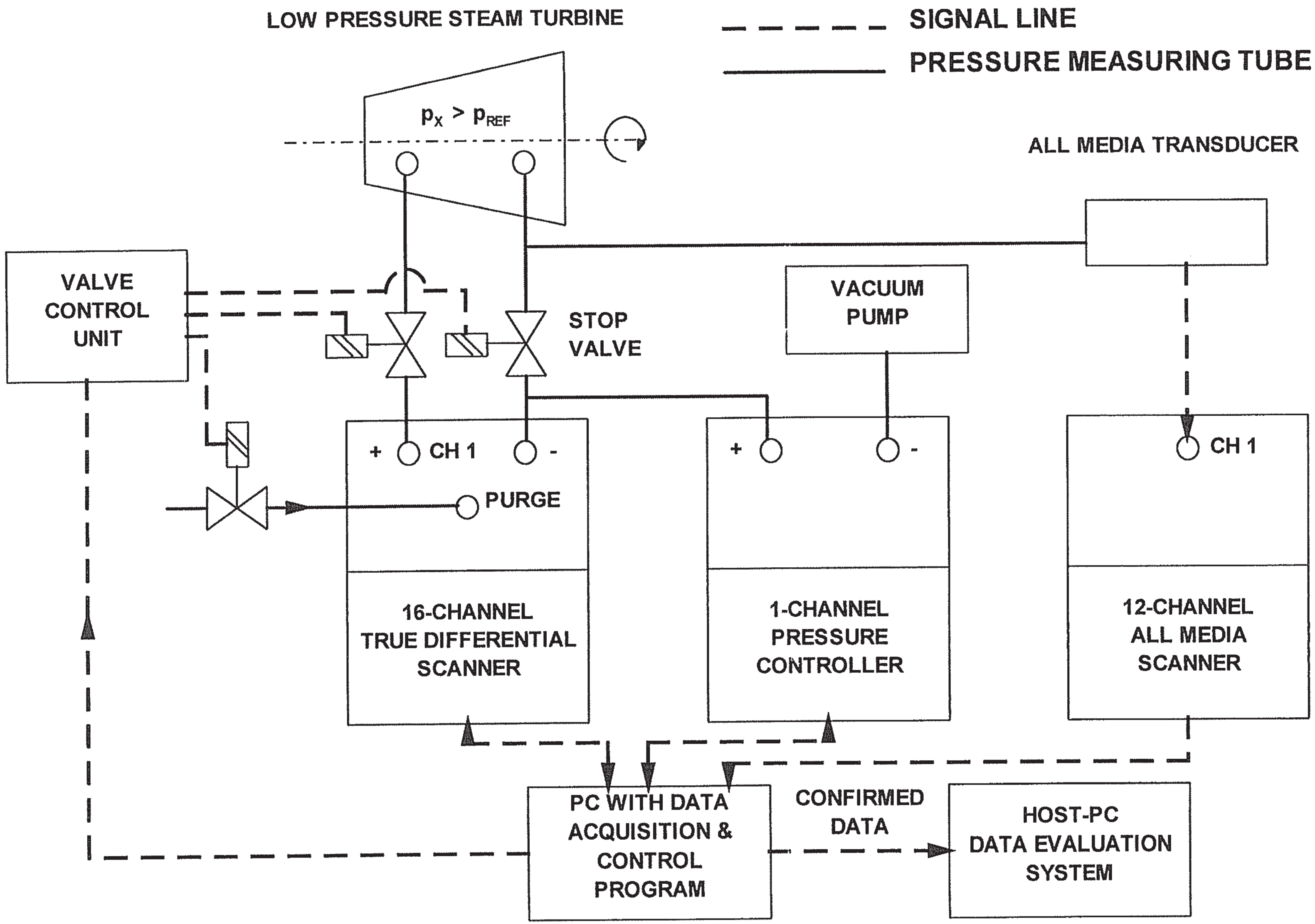

Figure 3:

Measuring Cycle

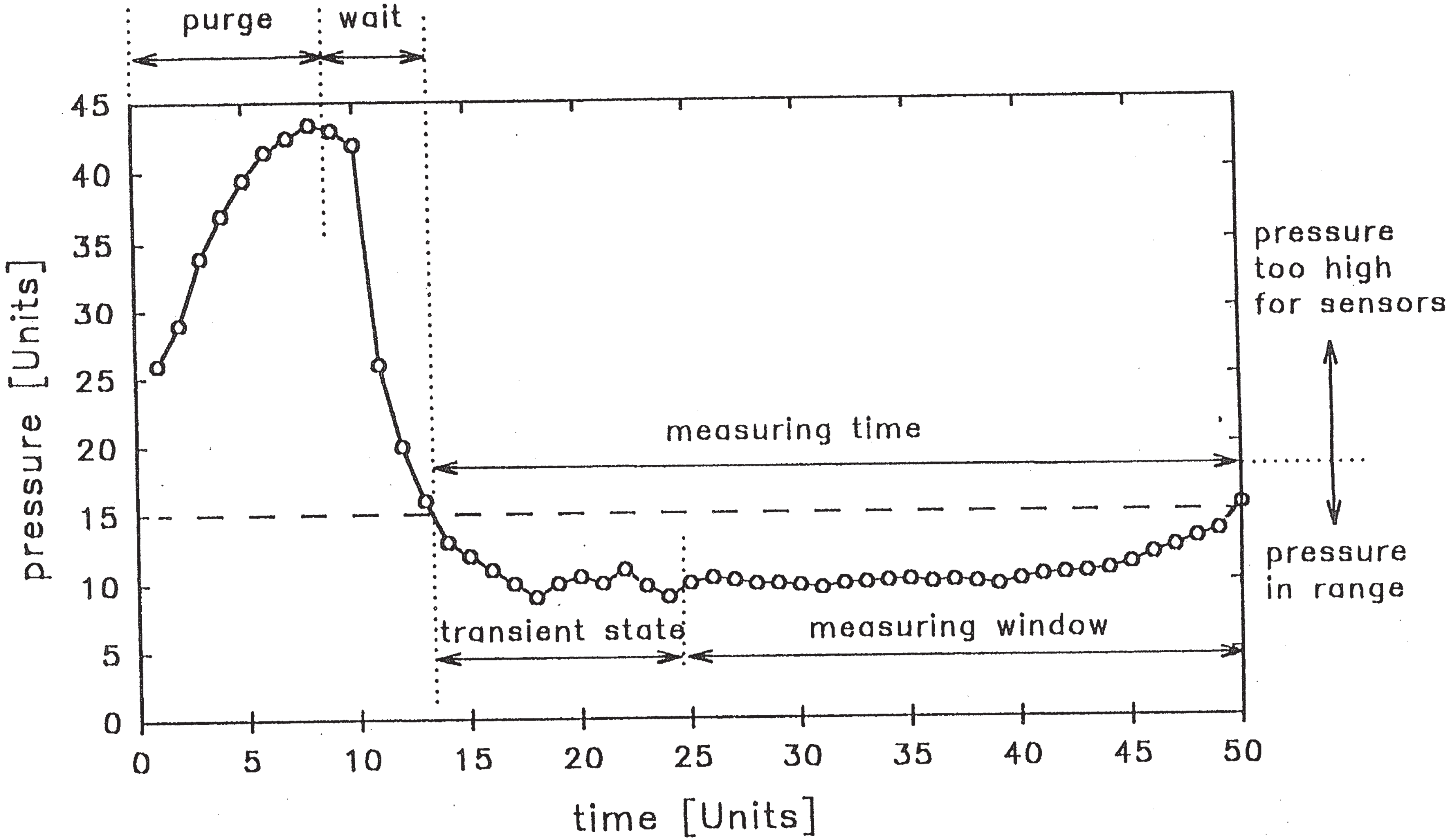

Figure 4:

Measuring Time

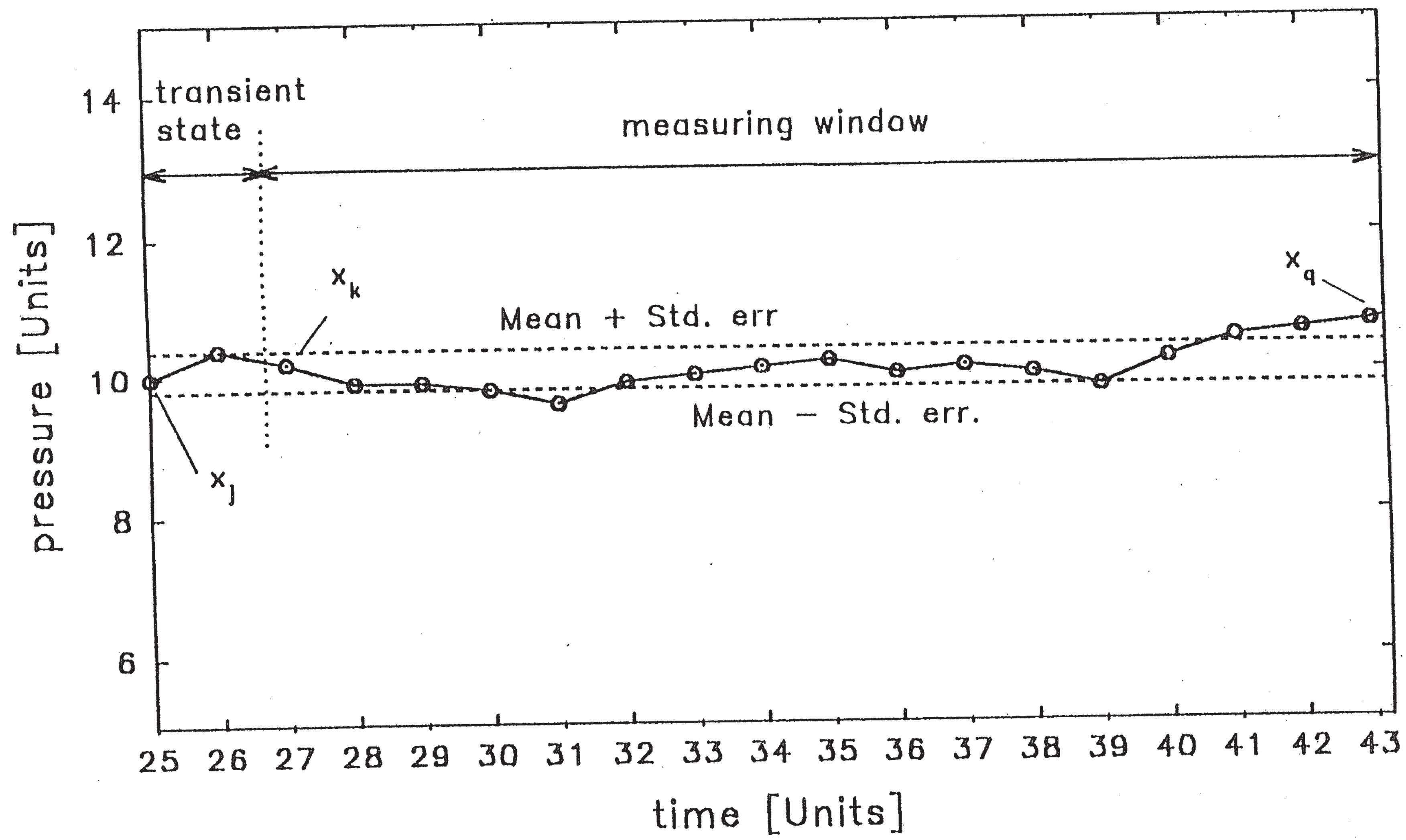

Table 1:

Lowpass filter for break off criterion 4 (end of measurement)

x_v are the succesive readings

x^*_v are the filtered measurands

The general form of the filter is:

$$x^*_v = \frac{1}{a_0} * \sum_{i=0}^{9} k_i \cdot x_{v-i}$$

For example a filter of 5th order has the following view:

$$x^*_v = 1/9*\left[x_v + 2*x_{v-1} + 3*x_{v-2} + 2*x_{v-3} + x_{v-4}\right],$$

Criterion for terminating the measuring cycle:

$$\left|x^*_v - x^*_{v+1}\right| > \text{Gradient\_1}.$$

Table 2:

Lowpass filter for determining the transient phase

The general form of the filter is:

$$x^*_v = \frac{1}{a_1} * \sum_{i=o}^{9} m_i \cdot x_{v-i}$$

Criterion for separating the transient phase from the desired measurands (measuring window):

$$\left|x^*_v - x^*_{v+1}\right| < \text{Gradient\_2}.$$

Table 3:

Conditioning the pressure measurands

Mean value: $$\overline{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i = \frac{1}{q-k+1} \cdot \sum_{p=k}^{q} x_p$$

Standard deviation: $$s = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(x_i - \overline{x}\right)^2} = \sqrt{\frac{1}{q-k} \cdot \sum_{p=k}^{q} \left(x_p - \overline{x}\right)^2}$$

Standard error: $$Std.err. = \frac{s}{\sqrt{n}} = \frac{s}{\sqrt{q-k+1}}$$

The predefined limit is K. If K > Std.err., the measurement is valid.