Pressure transducer's response to step function

Measurement technique of processes (BMEVGAG03)

1. The aim of the measurement

The aim of the measurement is to specify the characteristics of a membrane pressure transducer, which is a second-order measuring device. We would like to determine the settling time, the rise time, the damped frequency and from these the damping ratio and the natural frequency of the system.

2. Description of the measurement

A system that is modelled by a second-order differential equation is called a second-order system. Examples of these systems are e.g. the accelerometers and diaphragm pressure transducers. The natural frequency and damping ratio of a second-order system are depending on the physical parameters of the system, and are used to describe the behaviour of the system. Second-order systems may be divided into three main classes: underdamped, critically damped and overdamped systems.

The determination of the parameters associated with underdamped systems is typically performed by applying a transient input to it and recording the response with time. In our measurement, we will investigate an underdamped, second-order diaphragm pressure transducer's response to a step function. We will process the output signal, and determine the characteristic parameters.
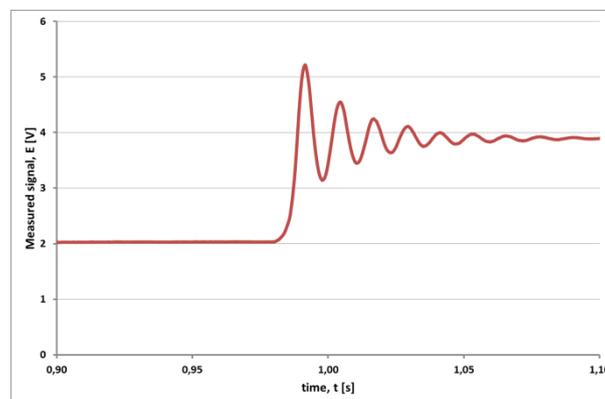

Figure 1.: Underdamped system's time response to a step function

Figure 1. shows an overview of a measured signal. The constant pressure signal steps into a higher value at the moment of a sudden intervention (opening a tap), and after damped oscillations it comes to a steady state.

The difference between the initial and the steady value is the amplitude of the step function. (E_∞-E_0 on Figure 2.). The **rise time** is defined as the time required to achieve a value within 90 % of the step input (E_∞-E_0).

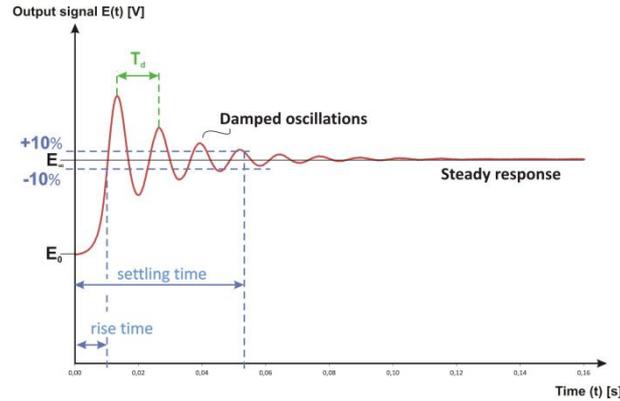The **settling time** is the time required for a measurement system's oscillations to settle within ± 10%.

**Figure 2.: Rise time, settling time and the period of the oscillations at a
typical output signal**

The oscillatory output signal's ***period time*** is: T_d.

3. Test rig

The test rig can be seen on Figure 3.. The membrane pressure transducer P (type Keller PA21SR, measuring range 0-16 bar) is built in the pipeline system. The system is delivered from the domestic water network, and could be closed with the T1 ball valve. The T pressure tank is connected to the system with a T2 valve. At the end of the water system there is a free outflow to the end reservoir, here atmospheric pressure is assumable. The output voltage signal from the transducer is acquisited by LabView software.
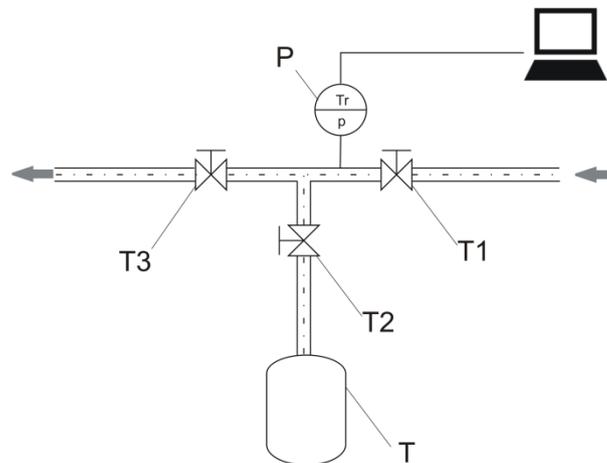

Figure 3.: Test rig

Before the measurement starts the system has to be vented with the T1 and T3 valves. After venting we close T3, and open T2, therefore in the tank the pressure will rise to approximately 4 bars, which is the operating pressure in the water network system. With opening T2, T3 and closing T1 at the installation point of the pressure transducer a reduced pressure can be adjusted. After closing T3, and suddenly opening T2 the pressure steps to a higher value at the transducer.

4. Measured data, signal processing

The output is a 5 sec long, with 5 kHz sampling frequency detected signal. A txt file includes the data in the following form: [time, voltage]. First of all, the relevant segment of the measured signal has to be chosen.

From the average value of the initial signal (time average before the step), and the steady response (time average after achieving the steady state) we can calculate E_0, and E_∞. From these two values the range of ±10% can be defined, and the **rise time** and the **settling time** can be determined.

The period of the oscillations can be detected by using the method of autocorrelation. As explained in the lectures, the essence of this method is that the signal has to be delayed increasingly with τ (tau – time delay), meanwhile investigating the correlation coefficient between the original and the delayed signal. (see Figure 4.)
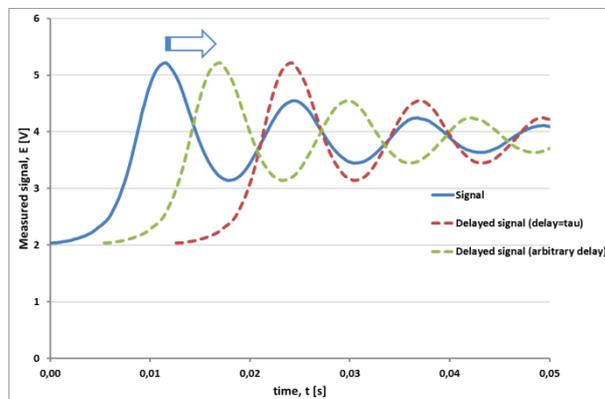

Figure 4.: Method of autocorrelation

The correlation function is seen on the Figure 5. The signal's correlation with itself is 1, so the function starts at this value. The following peak of the function (about 1) occurs at the time delay which is identical with the **period time of the oscillations** (T_d).
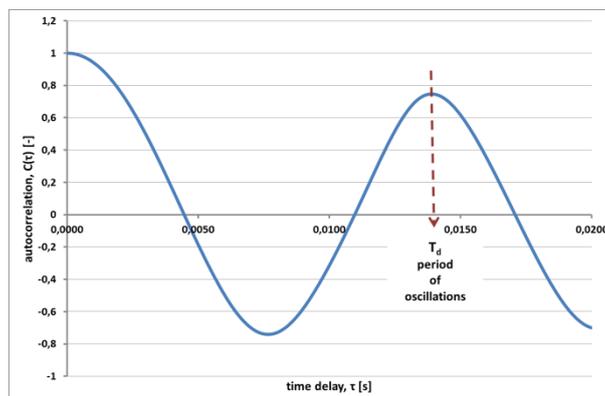

Figure 5.: Determination the period time with the method of autocorrelation

"CORREL" is a built in function in Microsoft Excel, or any other software with statistical analysis toolpack.

Figure 6.: Using CORREL function in MS Excel

The **ringing frequency** (ω_d) can be calculated from the period time:

$$T_d = \frac{2\pi}{\omega_d}$$

The correlation coefficient shows us a linear regression between the original and the delayed signal. The slope of the trend line (r) can be determined with curve fitting. The **damping ratio** (ξ) and the **natural frequency** (ω_n) of the second-order system can be calculated with the following equations:

$$r = e^{-\xi \omega_n T_d}$$

$$\omega_d = \omega_n \sqrt{1 - \xi^2}$$

5. Questions
- Define the overdamped, underdamped and critically damped second-order system based on the response on step function! Illustrate the answer with drawing!
- What do the rise time and the settling time mean? Show the parameters in a sketch graphic!
- Define the autocorrelation function! What is the typical usage of it?
- Define the damping ratio!
- What are the natural frequency and the ringing frequency? What is the connection between the two parameters according to a second order system?