Optimization of Analog Signal Filtration Process

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The goal of this work is to present the developed technique for designing the optimal value of the exponential filter time constant with taking into account the dynamic properties of the controlled plant.

I. Problem formulation

The analog signal filtration is often used in the up-to-date automated measurement and control systems. The main purpose of the filtration process is to eliminate the disturbances (noise) and to allow the useful signal to pass. When designing a filter there is often a problem of choosing the filter structure and defining the numerical values of its tuning parameters. Nowadays the following two types of filters are most widely applied in the industrial automation systems based on microprocessor controllers: exponential filter and moving average filter. The structures of these filters are known and their tuning parameters can be set in a definite range depending on the process for which the technological parameter is measured. Setting a too small value of the time constant for the exponential filter will lead to a low quality of the filtration process because not all the disturbances (noises) will be filtered (removed). Setting a too big value of the filter time constant will provide a good quality of filtration, however it will lead to a significant delay of the filtered signal which, in turn, will cause a big value of the dynamic error in the filtered signal. That is why there is a problem of defining such value of the filter time constant at which a good quality of the filtration process would be provided together with a small dynamic error of the filtered signal.

II. The proposed technique of the exponential filter optimization

In order to design the optimal value of the time constant for the exponential filter according to the developed technique the following eight steps should be accomplished. The technique was developed on the basis of the results of experimental study of the transient processes in a thermal plant.

Step 1

Computation of the smoothed analog signal by means of the non-causal moving average filter using the following formula:

$$y_n^s = \frac{1}{5}\left(y_{n-2}^e + y_{n-1}^e + y_n^e + y_{n+1}^e + y_{n+2}^e\right)$$

where y^s and y^e are smoothed and experimental samples respectively.

Step 2

Computation of the mean square of the experimental samples deviation from the smoothed experimental samples using the following formula:

$$D = \frac{1}{N-4}\sum_{i=3}^{N-2}\left(y_i^e - y_{i-2}^s\right)^2$$

where N is the number of registered experimental samples of the analog signal

Step 3

Filtration of the experimental analog signal by means of the exponential filter with the time constant $T_f = 1$ s.

Step 4

Computation of the smoothed filtered signal by means of the non-causal moving average filter using the following formula:

$$y_n^{s1} = \frac{1}{5}\left(y_{n-2}^{f1} + y_{n-1}^{f1} + y_n^{f1} + y_{n+1}^{f1} + y_{n+2}^{f1}\right)$$

where y^{f1} are smoothed filtered with 1 second time constant samples

Step 5

Computation of the mean square of the filtered samples (y^{f1}) deviation from the smoothed filtered samples (y^{s1}) using the following formula:

$$D = \frac{1}{N-4}\sum_{i=3}^{N-2}\left(y_i^{f1} - y_{i-2}^{s1}\right)^2$$

Step 6

Computation of the maximum dynamic error of the smoothed filtered samples (y^{s1}, obtained in step 4) with respect to the smoothed experimental samples (y^s, obtained in step 1) by using the formula:

$$\delta_{\max} = \max(|y^{s1} - y^s| \times 100)$$

Step 7

Accomplish steps 3-6 for the exponential filter time constant $T_f = 2, 3, 4, \ldots, n$ s.

Step 8

Computation of the objective function on the basis of the obtained arrays of the deviation mean square D and the maximum dynamic error δmax using the following formula:

$$I(T_f) = D'(T_f) + \delta'_{\max}(T_f)$$

where $D'(T_f)$ is the reduced mean square of the deviation; $\delta'_{\max}(T_f)$ is the reduced maximum dynamic error.

The optimal time constant is such a value of the time constant for which the objective function is minimal:

$$T_f^{opt} = T_f\big|_{I=\min(I)}$$

III. Results of the exponential filter optimization

Based on the calculated values of the objective function the optimal time constant of the exponential filter can be defined. The optimal time constant is such a value of the time constant for which the objective function is minimal (see Eq. 1). The curve of the objective function I versus the filter time constant T_f for the experimental step response curve from reference [2] is presented in Figure 1. The comparison of the experimental step response curve and the filtered curve by means of the filter with the optimal time constant T_f^{opt} = 2 s is presented in Figure 2.

$$T_f^{opt} = T_f\big|_{I=\min(I)} = 2\ s \qquad (1)$$

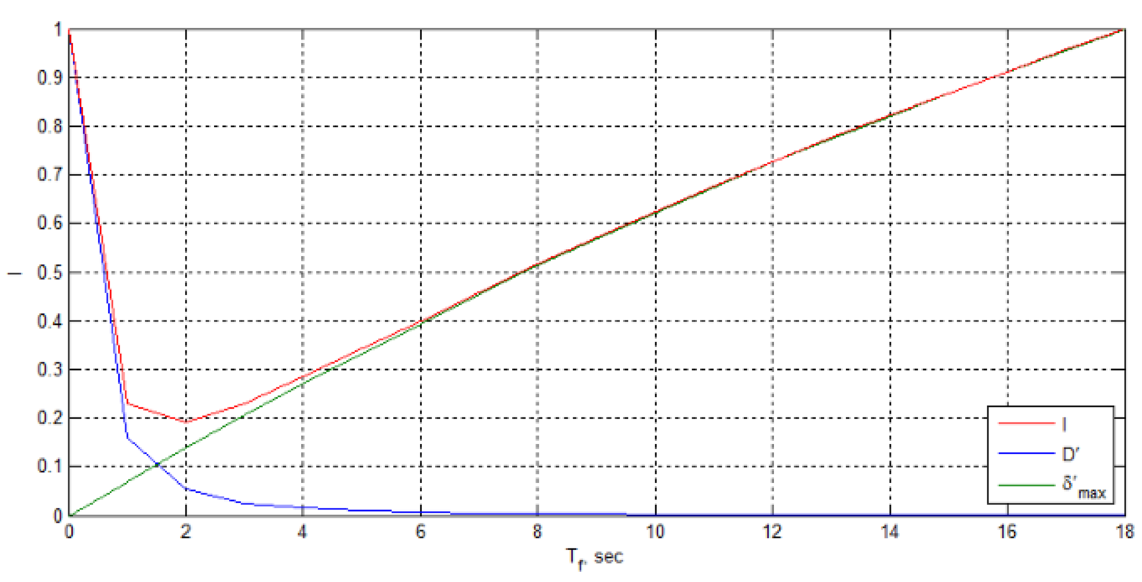

Fig.1. Curve of the objective function, the reduced mean square of the deviation and the reduced maximum dynamic error versus filter time constant.

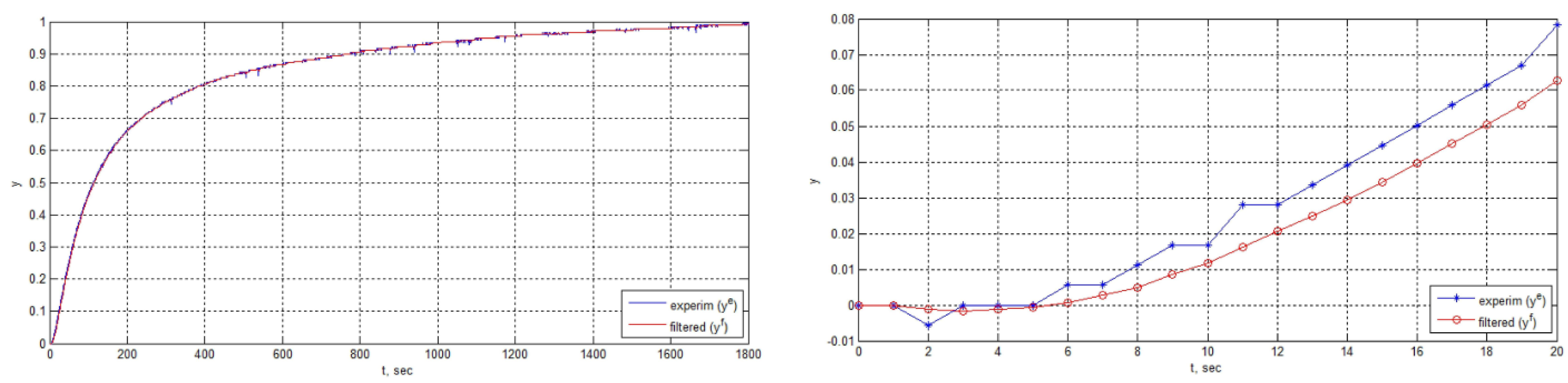

Fig.2. Comparison of the experimental step response curve and the filtered curve by means of the filter with the optimal time constant T_f^{opt} = 2 s
(a – whole curve; b – part of the curve in the time range from 0 to 20 s).

Conclusion

Application of the developed technique for designing the optimal value of the filter time constant in the automated measurement and control systems will provide high quality of the filtration process and small dynamic error of the filtered signal.

References

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