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Non-linear Transformation of Signals in Software Design of Digital Control Systems Complex

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Abstract. Dependencies between signals and dependence of signals on time are strictly non-linear. Non-linear elements, commonly used in the synthesis of automatic control systems, include: a two-point link, a two-point link with hysteresis, a three-point link, a three-point link with hysteresis, a module, saturation with insensitivity.

Keywords: three-position controller, three-position controller with hysteresis, two-position controller, two-position controller with hysteresis.

I. INTRODUCTION

Currently, link-off, three-position with or without hysteresis, saturation types of nonlinear links are widely used in the automatic control systems of technological processes [1-3].

International standard IEC 61131-3 does not contain a single integrated means for developing complex systems of automatic control of technological processes with nonlinear links in the control device. Such a tool was created by SIEMENS. However, it is intended exclusively for its specialists working with the equipment of this firm [4].

The software-hardware SDSDC complex provides the possibility of software implementation of nonlinearities in the tasks of developing, modeling and creating complex systems for automatic control of technological processes with nonlinear links [5].

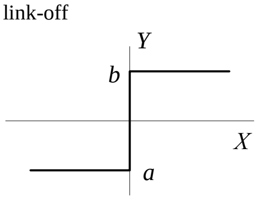
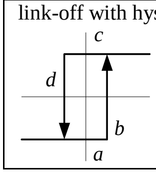
II. POSITION CONTROLLER

Let us consider the mathematical description and software implementation of typical nonlinearities.

Dependencies between signals and the dependence of signals on time are strictly non-linear. In general, a distinction is made between single-valued and multi-valued non-linear dependences, as well as between non-linear dependences with memory and without memory, analytically described and piecewise linearly approximated.

To non-linear links, commonly used in the synthesis of automatic control systems (ACS) refer nonlinearities [1-3] shown in a summary form in Table. 1.

Table I
Non-Linear Links

Graphic symbol	Dependence
link-off 	$Y = \begin{cases} b \text{ by } X \ge 0 \\ -a \text{ by } X < 0 \end{cases}$
link-off with hysteresis 	$Y = \begin{cases} \left.\begin{matrix} c \text{ at } X \ge b \\ -a \text{ at } X < b \end{matrix}\right\} \text{ at } X(k) - X(k-1) \ge 0 \\ \left.\begin{matrix} c \text{ at } X \ge -d \\ -a \text{ at } X < -d \end{matrix}\right\} \text{ at } X(k) - X(k-1) < 0 \end{cases}$

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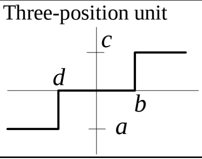
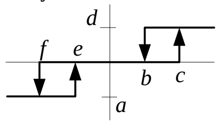
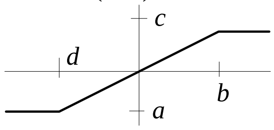
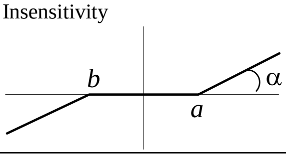
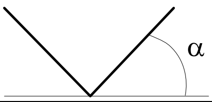
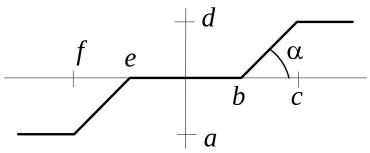
Graphic symbol	Dependence
Three-position unit 	$Y=\begin{cases} c & \text{at} \quad X \ge b \\ 0 & \text{at} \quad (X<b)\&(X \ge -d) \\ -a & \text{at} \quad X<-d \end{cases}$
Three-position unit with hysteresis 	$Y=\begin{cases} \left.\begin{matrix} -a & \text{at } X \le e \\ 0 & \text{at } e<X<c \\ d & \text{at } X \ge c \end{matrix}\right\} \text{at } X(k)-X(k-1) \ge 0 \\ \left.\begin{matrix} d & \text{at } X \ge b \\ 0 & \text{at } f<X<b \\ -a & \text{at } X \le -f \end{matrix}\right\} \text{at } X(k)-X(k-1)<0 \end{cases}$
Saturation (limit) 	$Y=\begin{cases} -a & \text{at} \quad X<-d \\ c & \text{at} \quad X>b \\ kX & \text{at} \quad (X \ge -d)\&(X \le b) \end{cases}$ $k=tg(\alpha)$
Insensitivity 	$Y=\begin{cases} 0 & \text{at} \quad (X \ge -b)\&(X \le a) \\ kX & \text{at} \quad (X>a)\vee(X<-b) \end{cases}$ $k=tg(\alpha)$
Module 	$Y=\begin{cases} kX & \text{at} \quad X \ge 0 \\ -kX & \text{at} \quad X<0 \end{cases}$ $k=tg(\alpha)$
Saturation with insensitivity 	$Y=\begin{cases} -a & \text{at} \quad X<-f \\ -kX & \text{at} \quad (X \ge -f)\&(X<-e) \\ 0 & \text{at} \quad (X \ge -e)\&(X<b) \\ kX & \text{at} \quad (X \ge b)\&(X \le c) \\ d & \text{at} \quad X>c \end{cases}$ $k=tg(\alpha)$

A. A two-position controller

A variety of a two-position controller is a relationship [6-9]

$$u(k)=\begin{cases} U1 & \text{at } (w(k)-\Delta w)>y(k) \\ U2 & \text{at } (w(k)+\Delta w)<y(k) \\ u(k-1) & \text{at } (w(k)-\Delta w)\le y(k)\le(w(k)+\Delta w), \end{cases} \quad (1)$$

where $u(k)$ – the value of the manipulated variable;

$w(k)$ – the value of the reference variable;

$y(k)$ – the value of the controlled variable;

Δw – dead zone;

*U*1, *U*2 – the value of the manipulated variable outside the dead zone;

$u(k-1)$ – the value of the manipulated variable in the preceding control cycle.

If we assume $\Delta w = 0$ then the manipulated variable can be displayed through a two-position actuator. In this case, U1 and U2 are the inverse values of the logic signal. A two-position unit of general form is used as a two-position controller (Table 1), at a≅ «0», b≅ «1»; here ≅ symbol indicates correspondence of parameters a and b to the inverse values of the logic signal:

$$\left.\begin{matrix} u=\begin{cases} 1 \text{ at } e \ge 0 \\ 0 \text{ at } e<0 \end{cases} \\ e=w-y \end{matrix}\right\}, \quad (2)$$

where *u* – the value of the manipulated variable;
w – the value of the reference variable;
y – the value of the controlled variable;
e – control error.

The block diagram and the program of a two-position controller are shown in Fig. 1 and 2.

The block diagram of a two-position controller

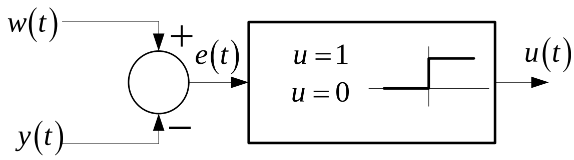


Fig.1

The program of a two-position controller

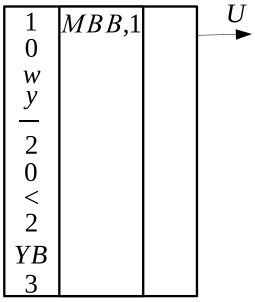


Fig.2

B. A two-position controller with hysteresis

A two-point link with hysteresis of general form is used as a two-position controller with hysteresis (Table 1), [9-14]: at a≅«0», c≅«1», $d+b=H$

$$u=\begin{cases}\left.\begin{matrix}1 \text{ at } e(k)\geq H/2\\ 0 \text{ at } e(k)<H/2\end{matrix}\right\} \text{ at } \quad e(k)-e(k-1)\geq 0\\ \left.\begin{matrix}1 \text{ at } e(k)\geq -H/2\\ 0 \text{ at } e(k)<-H/2\end{matrix}\right\} \text{ at } \quad e(k)-e(k-1)<0\end{cases} \quad (3)$$

$$e(k)=w(k)-y(k),$$

where *u* – the value of the manipulated variable;
w – the value of the reference variable;
y – the value of the controlled variable;
e – control error;
H – the value of hysteresis.

The block diagram and the program of a two-position controller with hysteresis are shown in Fig. 3 and 4.

The block diagram of a two-position controller with hysteresis

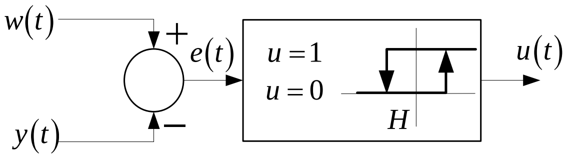


Fig.3

The program of a two-position controller with hysteresis

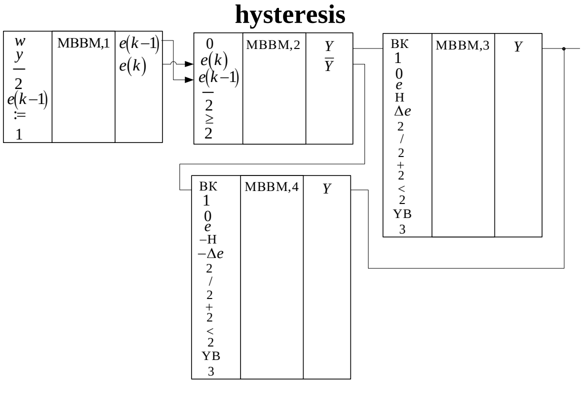


Fig.4

C. A three-position controller

A three-point link of general form is used as a three-position controller (Table 1) [5, 15-21],

$a\cong u_2,\ c\cong u_1,\ |d+b|=\Delta e$:

$$\left.\begin{matrix}u_1=\begin{cases}1 \text{ at } e(k)\geq \Delta e/2\\ 0 \text{ at } e(k)<\Delta e/2\end{cases}\\ u_2=\begin{cases}1 \text{ at } e(k)\geq -\Delta e/2\\ 0 \text{ at } e(k)<-\Delta e/2\end{cases}\end{matrix}\right\} \quad (4)$$

$$e=w-y,$$

where u_1, u_2 – the value of the manipulated variable;

w – the value of the reference variable;
y – the value of the controlled variable;
e – control error;
Δe – dead zone.

The block diagram and the program of a three-position controller are shown in Fig. 5 and 6.

The block diagram of a three-position controller

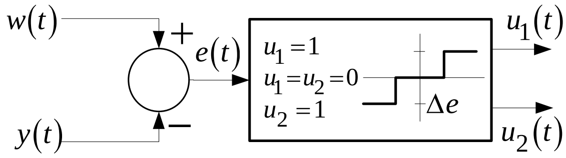


Fig.5

The program of a three-position controller

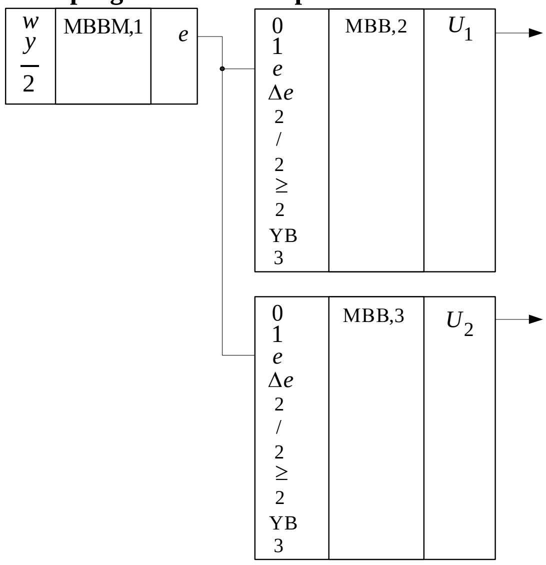


Fig.6

D. A three-position controller with hysteresis

A three-point link with hysteresis of general form is used as a three-position controller with hysteresis (Table. 1),

$a\cong u_2,\ c\cong u_1,\ |f+e|=|c-b|=H,\ |e|+|b|=\Delta e$:

$$\begin{matrix}u_1=\begin{cases}1 \text{ at } e(k)\geq \Delta e/2\\ 0 \text{ at } e(k)<H+\Delta e/2\end{cases}\Bigg\} \text{at } e(k)-e(k-1)\geq 0\\ u_2=\begin{cases}0 \text{ at } e(k)\geq -H-\Delta e/2\\ 1 \text{ at } e(k)<-\Delta e/2\end{cases}\Bigg\} \text{at } e(k)-e(k-1)<0\end{matrix}$$

$$e(k)=w(k)-y(k),$$

(5)

where u – the value of the manipulated variable;
w– the value of the reference variable;
y– the value of the controlled variable;
e – control error;
H – the value of hysteresis;
Δe – dead zone.

The block diagram and the program of a three-position controller with hysteresis are shown in Fig. 7 and 8.

The block diagram of a three-position controller with hysteresis

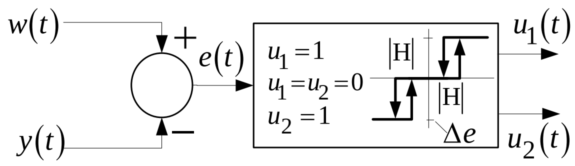


Fig.7

The program of a three-position controller with hysteresis

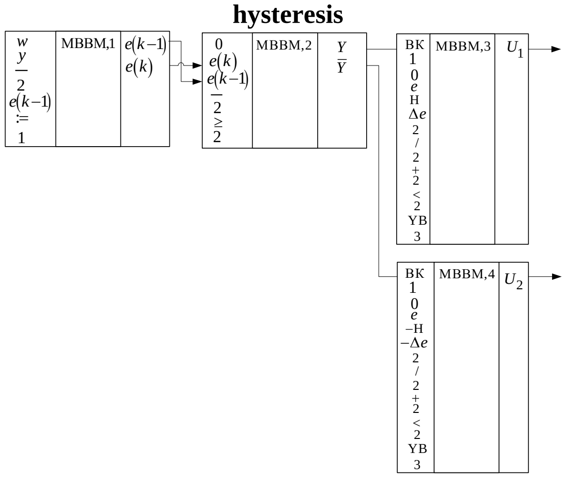


Fig.8

Thus, the software and hardware SDSDC complex provides the possibility of a unified approach for the synthesis of automatic control systems for technological processes with linear and nonlinear links in the control device based on their software implementation.

III. CONCLUSION

A comparative evaluation of the standardized properties of the nonlinearities of the SDSDC complex (a two-position link with and without hysteresis, a three-position link with and without hysteresis) makes it possible to expand the composition of the nonlinearities of the SDSDC complex without any significant expenditure. This is especially easy to implement due to the application of the abovementioned expression evaluation modules.

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