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IDENTIFICATION OF IMPULSE RESPONSE BY *M*-SEQUENCE USING MICROPROCESSOR

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ABSTRACT

System identification using pseudo-random binary signal (*m*-sevuence) is an attractive method among the others. But the complexity and difficulty of its implementation limit the practical application.

This paper presents a new implementation method using a microprocessor. It avoids the use of delay sequence. Due to the use of digital integration, it can avoid the difficulty of long period of integration, while the plant has a large time constant. Due to the skill in the process of cross-correlation calculation, it can avoid the comprehensive multiplication and save the calculation time. The instrument uses only a small amount of IC chips which consist of microprocessor, RAM, ROM, I/O peripheral, and interface chips. It can either display the plant output and impulse response on the oscilloscope or record it on the digital plotter. We can monitor the system output to see if any saturation occurs. If it happens, then the input amplitude is adjusted. This paper describes the hardware and software of this new implementation method.

1. Introduction

For a control engineer, the system identification is a prerequisite to the successful design of an automatic control system. Among the various identification methods the most popularly used are the frequency response method, step function response method, etc. But these methods always bring a rather large disturbance to the system and are not appropriate for an on-line test. However, using pseudo-random *m*-sequence [1] makes it possible to use the signal of relatively small amplitudes and no more brings a remarkable disturbance to the system. At the same time, by means of the correlation method, the influence of noises can also be reduced. On the other hand, calculating the correlation function is a very trouble-some work and complicate to implement. With the rapid development of microcomputers, the price of them has become very cheap. Furthermore, the microcomputers being provided with the ability of memory, the input and output data can be written into the RAM and then, when calculating, can be

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read out from the appropriate addresses, so that it is not necessary to produce the delayed m-sequence [2], [3]. Because of using the digital integration, there is no limitation on the time of integral, so this method can be used to the plant with large time constants.

II. Theory

The cross-correlation function between a periodic input $I(t)$ and the resulting output $O(t)$ (Fig. 1) is

$$C_{12}(\tau)=\frac{1}{T}\int_{-T/2}^{T/2} I(t)O(t+\tau)dt$$

where the interval T is assumed to be a large constant. It is easy to show

$$F\{C_{12}(\tau)\}\omega_k=D_kC_{-k}$$

where $F\{C_{12}(\tau)\}\omega_k$ is the Fourier transform of $C_{12}(\tau)$ at frequency ω_k; on the other hand, C_k and D_k are the Fourier coefficients of $I(t)$ and $O(t)$, respectively; that is,

$$C_{12}=\frac{1}{T}\int_{-T/2}^{T/2} I(t)\exp(-i\omega_k t)dt\,, \qquad \omega_k=2k\pi/T\,,$$

$$D_{12}=\frac{1}{T}\int_{-T/2}^{T/2} O(t)\exp(-i\omega_k t)dt\,, \qquad \omega_k=2k\pi/T\,.$$

Since $D_k=G(i\omega_k)C_k$, where $G(i\omega_k)$ is the system frequency response at frequency ω_k, and so

$$F\{C_{12}(\tau)\}\omega_k=C_kC_{-k}G(i\omega_k)$$

then

$$C_{12}(\tau)=F^{-1}\{C_kC_{-k}G(i\omega_k)\}$$

The convolution theorem may be used to interpret this. The result is

$$C_{12}(\tau)=\int_0^\tau h(p)C_{11}(\tau-p)dp$$

where $h(p)=F^{-1}\{G(i\omega)\}$. $C_{11}(p)$ is the autocorrelation function of the input. If the input signal had an autocorrelation function that was the delta function, then the result would be

$$C_{12}(t)=h(t)$$

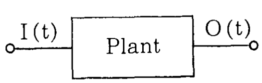

Fig. 1

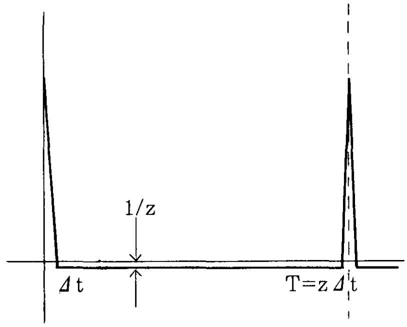

Fig. 2

This indicates that the impulse response could be obtained by determining the cross-correlation function between input and output for a test that used an input signal whose autocorrelation function was the delta function.

It is well known that a maximal-length pseudo-random binary sequence or *m*-sequence has an autocorrelation function near the delta function. (Fig. 2)

$$
\begin{aligned}
C_{11}(\tau) &= 1-[(z+1)/T] \quad \text{for } 0 \leqq \tau \leqq T/z\,, \\
&= -1/z \quad \text{for } T/z \leqq \tau \leqq (z-1)T/z\,, \text{ and} \\
&= -z+[(z+1)/T]\tau \quad \text{for } (z-1)T/z \leqq \tau \leqq T
\end{aligned}
$$

where $C_{11}(\tau)$ is the autocorrelation function, Δt the bit duration, z the number of bits, and T the period.

III. Design Consideration

Select the number of bits z. The autocorrelation function has a spike at 0, T, $2T$, $\cdots$ and a negative bits of $1/z$ between spikes. As the number of bits increases, the spike becomes sharper and the bias becomes smaller. Thus the autocorrelation function looks more like a series of delta functions as z increases. At the same time the power spectrum becomes flatter as z increases, while the absolute amplitude of the harmonics decreases as z increases. This is expected, since the same control power is distributed rather evenly over more harmonics for the longer sequences. This suggests that a compromise may be required in selecting a sequence for a particular application. Long sequences give the desired flat spectra, but the signal-to-noise ratio at each harmonic may be too low, otherwise the amplitude of *m*-sequehce should be increased but this is not expected because the disturbance of test signal will be high.

As in this case for the purpose of identification, z is selected equal to 127. Because it covers about two decades of frequency band, it is generally enough for the practical application.

IV. System Description

(a) Hardware.

The overall system block diagram is shown in Fig. 3. The m-sequence generator sends the m-sequence signal with maximum amplitude ± 5 V to the plant. The output of the plant analog signal is converted into the digital using the A/D converter and kept in the RAM. The CPU calculates the autocorrelation and cross-correlation functions and keeps the results in the RAM.

For the purpose of displaying the input and output of the plant as well as the autocorrelation and cross-correlation functions, an oscilloscope is used through the D/A converter. And for the purpose of recording a digital plotter is employed.

As for the m-sequence generator, two quad flip-flop chips are used to form a shift register and the $\overline{Q_1 \oplus Q_7}$ signal is feedback to the Q_1. (Fig. 4)

(b) Software.

The software is composed of the following:

(1) Monitor program.
(2) Input data program.
(3) Cross-correlation calculation program.
(4) Display program.
(5) Digital plotter program.

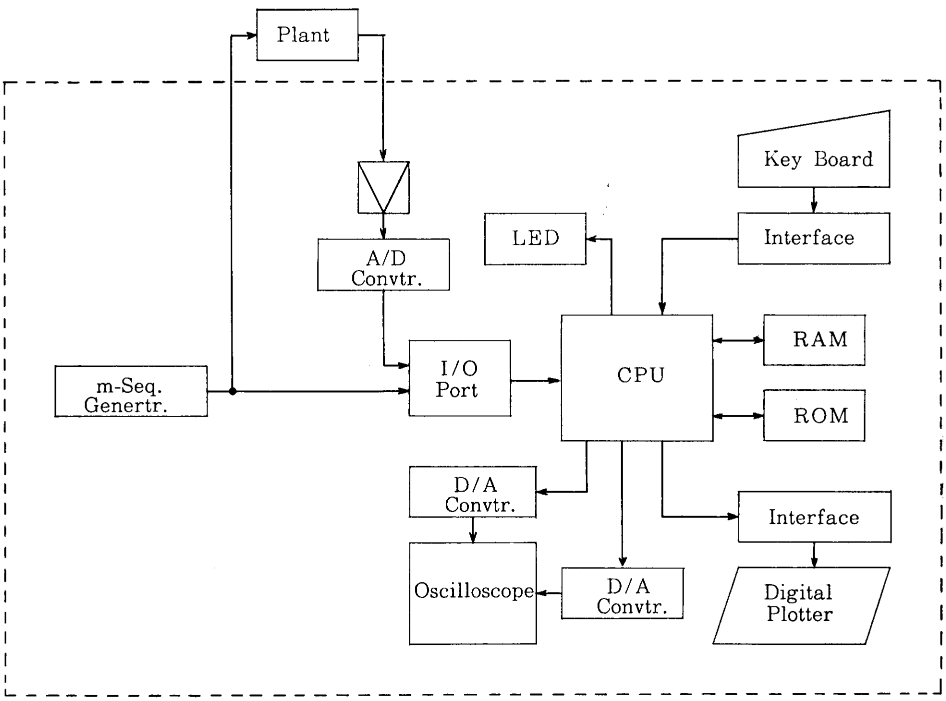

Fig. 3. Block Diagram of the System Configuration.

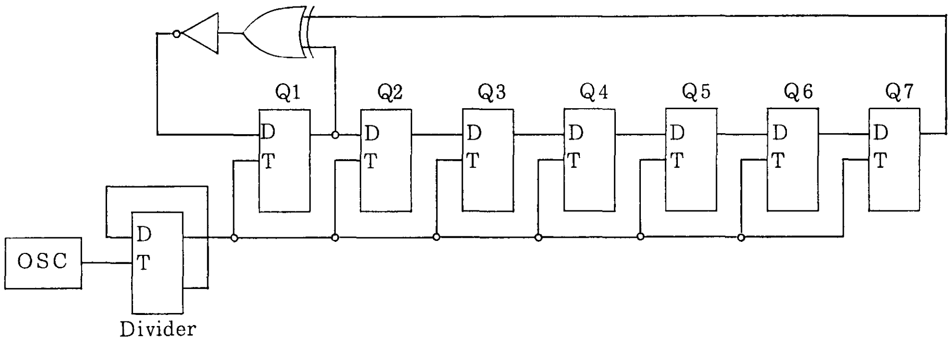

Fig. 4. *m*-Sequence Generator.

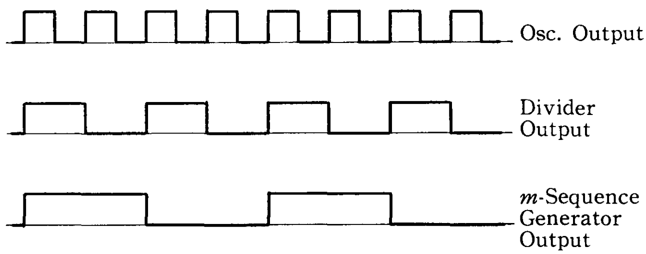

Fig. 5

The explanation of these programs is as follows:

(1) Input data program.

For the sake of accuracy of digital integration, the input data are sampled twice during one bit duration; that is, the sampling frequency is equal to 4 times of the highest frequency. The timing diagram is shown in Fig. 5.

The output of oscilloscope is sent to the 1/2 divider, the output of which is then sent to the shift register, and the sampling time is always kept at 1/4 and 3/4 bit time duration.

The output level of the *m*-sequence generator which is 1 or 0 is written into the RAM of addresses 1400 H through 14 FDH by way of port C of the *I/O* port. At the same time the plant output signals are written into the RAM of addresses 1500 H through 15 FDH from port A of the *I/O* port. Furthermore, the data in addresses 1500 H to 15 FDH are copied repeatedly in addresses 15 FEH through 16 FBH; (H here indicates the hexadecimal expression.) this is only for the convenience of programming. A counter is provided in the *I/O* port to count up the number of input data. In this case that is 254.

(2) Cross-correlation calculation program.

Since the calculation of cross-correlation function

$$C_{12}(\tau)=\frac{1}{T}\int_{-T/2}^{T/2} I(t)O(t+\tau)dt$$

includes the multiplication of $I(t)$ and $O(t)$, it takes a long time for execution. In the digital form

$$C_{12}(m)=\frac{1}{2z}\sum_{n=0}^{2z-1} I(n)O(n+m)$$

where the summation takes from 0 to $2z-1$ because the sampling is made twice for every bit time duration Δt. The calculation can be much simplified by noticing that $I(n)$ is equal to $+5$ or -5 volts.

$$C_{12}(m)=\frac{1}{2z}\,|I(n)|\sum_{n=0}^{2z-1} \mathrm{Sign}\,[I(n)]O(n+m)$$

That is, the calculation of cross-correlation is reduced to the addition and subtraction. Fig. 6 depicts the flowchart of the program. When input data $I(n)$ are

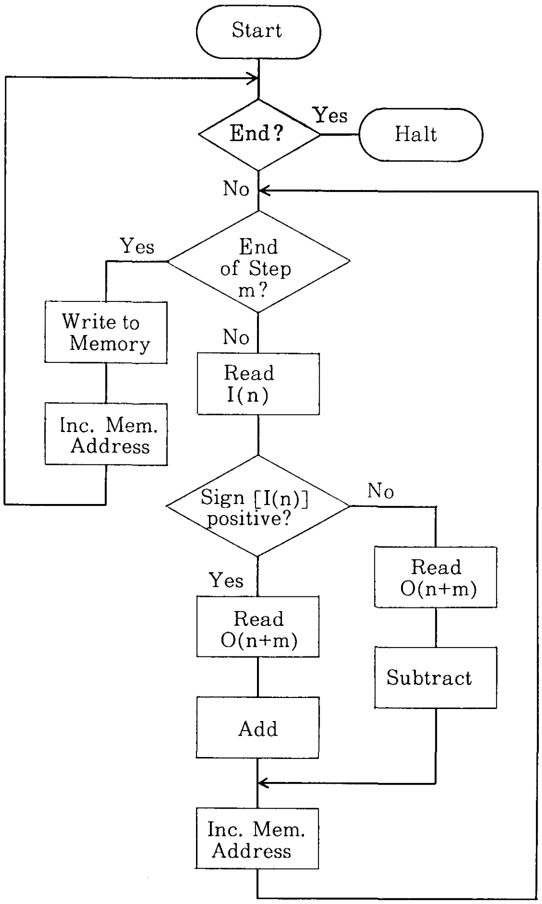

Fig. 6

positive, output data $O(n+m)$ are added to the sum. When input data $I(n)$ are negative, output $O(n+m)$ are subtracted from the sum. For this aim, the data beginning from 1400 H are first read out, and then the data beginning from 1500 H $+m$ are read out. Depending on whether the input data at addresses 14 xxH are 1 or 0, the output data 15 xxH$+m$ are added to or subtracted from the sum. Since m varies from 0 to 253, for the sake of convenience, the output data are kept in the memory 1500 H through 15 FDH and repeated at addresses 15 FEH to 16 FBH. This makes the algorithm much simpler. The result of each step m is kept in address 1700 H$+m$ of the memory.

(3) Display program.

For the purpose of displaying the input, output, autocorrelation and cross-correlation functions, two D/A converters are used connected to the x- and y-axis input of the oscilloscope, respectively. When the x-axis D/A converter's input varies from 00 H to FDH, the y-axis D/A converter reads out the data from address 1700 H of the RAM. This process is repeated automatically. Thus the stable waveforms can be seen on the screen.

(4) Digital plotter program.

For the purpose of accurately recording the curve a digital plotter is employed, for which this program is developed.

V. Experiments

As the test plant an active network is used as shown in Fig. 7. The transfer function of the plant is

$$W(s)=\frac{-1}{Ts+1}$$

where $T=R_2C=10\times10^3\times2\times10^{-6}=20$ ms, $R_2/R_1=1$. The theoretical impulse should be

$$X(t)=\frac{-1}{T}e^{-t/T}$$

The experimental result is shown in Fig. 8. The result is quite accurate except that at the beginning instant there is a short-time diverse from the theoretical one; this is due to the fact that the autocorrelation function is not an ideal delta function but a triangular spike.

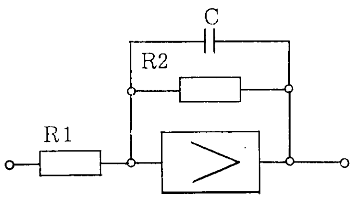

Fig. 7

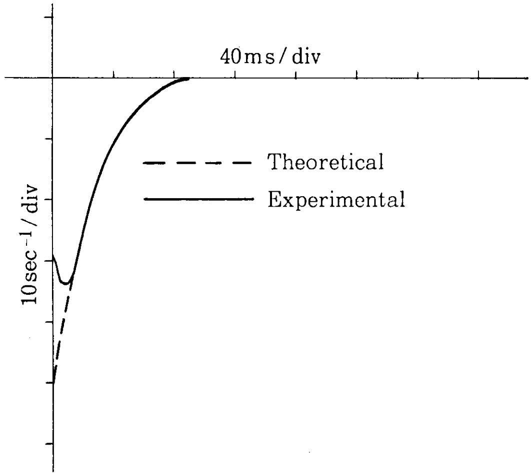

Fig. 8

VI. Conclusion

Using this microprocessor based instrument we successfully measured the impulse response. It is easy to use and convenient to move to the field and gives the result immediately. At the same time we can check whether the output is saturated or not. If saturation happens, then we can adjust the input signal so that we can avoid the uncorrect result due to the saturation.

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