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# Application of Adaptive Minimum-variance Control Technique for Cyclic Production Machine

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***Abstract*— In this paper, we consider the control problem of cyclic production machine. There are many mechanical parts produced by cyclic production machine. For example, springs are usually made of long stock wire which is fed into cyclic forming machine. A spring forming machine can force wire into a coiled shape during the cyclic motion, but the length of the produced spring in each cycle is varying according to the internal stress of wire, mechanical uncertainty of the forming machine etc. To improve the accuracy of free length of spring produced by forming machine, we propose an adaptive minimum-variance control strategy for cyclic production system and successfully applied to commercial spring forming machine.**



***Keywords*— *cyclic production machine; deviation of products quality ; adaptive minimum variance control; spring forming machine***

## I. Introduction

In many production process, the quality of products is varying depending on the variation of materials, uncertainty of production machine, unknown disturbances and so on.

For this kind of problem, by formulating the variation of the products quality as the output of system with stochastic disturbance, the stochastic control strategies like minimum-variance control are successfully applied to the continuous production system.

Especially, in process industry, the adaptive control technique are very useful because the characteristics of the system may vary during the operation [1][2].

In contrast, in the cyclic production process, the control system is usually designed to achieve the desired performance during each production cycle, because the quality of products depend on the physical process in the cycle time.

This kind of control is effective to reduce the quality of each product in each production cycle. However, the variation of the cyclic production process is not considered.

For this problem, the authors have proposed a new idea to design the control system for cyclic production system.

In the proposed control system, the variation of the product for successive production cycles is modeled by the output of discrete time system with stochastic disturbance [3].

In this case, the variation of the product for each production cycle can be reduced by applying appropriate stochastic control strategy.

In our research, we propose an adaptive minimum-variance control strategy for cyclic production system considering the characteristics variation of production machine and auto-tuning function for start-up of the spring forming machine.

The application of adaptive control system to the spring forming machine have been proposed in the literature.

However, it is not considered the variation of mechanical characteristics of forming machine for each production cycle [4].

In this paper, to improve the accuracy of free length of spring produced by forming machine, we propose an adaptive minimum-variance control system based on the cyclic dynamics of the forming machine. The model structure is determined considering the variation of mechanical characteristics for each production cycle. The experimental results using commercial spring forming machine show the effectiveness of the proposed control algorithm compared with the previous embedded control algorithm.

## II. Mechanism of Spring Forming Machine

A spring is made by forming steel wire between some outer dies and a pitch tool, which give geometrically orthogonal forces to the wire as shown in Fig.1.

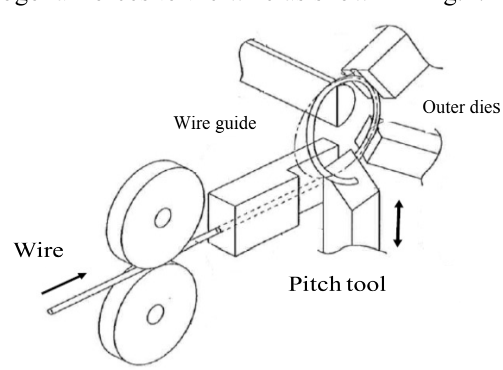


Fig. 1 Mechanism of spring forming machine

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In Fig.1, the steel wire is fed into the wire guide by feed wheels. By forcing to press the wire to the outer dies, the wire bends and forms the ring like shape with desired diameter while the pitch tool controls the length of spring.

To control the free length of the spring in each production cycle, we decide to adjust the extrude position of the pitch tool for each cycle as the input.

## III. Caracteristics of Fluctuation in Spring Production and its Modeling

The aim of spring forming machine is to produce springs of a guaranteed quality with minimum production cycle.

First, we consider the characteristics of the deviation in spring production

For example, typical result for one fabrication condition (Table 1) is presented.

Table 1 Fabrication condition

| | |
|---|---|
| Free length[mm] | 40.8 |
| Wire diameter[mm] | 1.6 |
| Outside diameter[mm] | 14.9 |
| Production speed[spm] | 120 |

In this table, the production speed [spm] means the number of spring produced in 1 minute.

Figure 2 shows the variation of free length of the manufactured spring under the above fabrication condition.

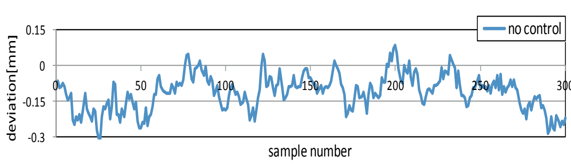


Fig. 2 Typical variation of free length of the manufactured spring

The deviation of spring length in Fig. 2 may be caused by some disturbances or uncertainties in forming machine, and can be regarded as random error.

In this case, we investigate that the sequence of the free length of the spring can be predicted by linear time-series model of the signal or not. If it can be modeled by such type of model, the stochastic control theory is applicable. In order to check this condition, we describe the characteristic of the time-series by AR (Auto-Regressive) model described by the following equation.

$$y_k = \sum_{i=1}^{n} a_i y_{k-i} + v_k \qquad (1)$$

Where, $y_k$ denotes measured data at sampling instant $k$ and $v_k$ is the white noise with average 0 and variance $\sigma^2$. The model

The above processes are executed in each production cycle. That is, the spring forming process can be modeled by the discrete time process synchronized

order $n$ corresponds the number of past data $y_1, \cdots, y_n$ which affect the current measurement and $a_i$ is its coefficient.

To determine the order and parameters of the AR model, we adopt some information criteria. For example, the criteria called AIC (Akaike's Information Criteria) is used.

$$AIC = -2\log L(\tilde{\theta}) + 2(n+1) \qquad (2)$$

Where, $L(\theta)$ is the likelihood defined by using the parameter $\theta$ and data number $N$ as follows.

The procedure to determine the best model can be easily performed by using "System Identification Toolbox" in MATLAB [4].

For this data, AIC gives the model (AR5) with the order 5 and the parameters $a_1$=-0.2969, $a_2$=-0.5453, $a_3$=0.09458, $a_4$=-0.1436, $a_5$=0.04322.

Figure 3 shows the comparison between the observed data and the output of the AR model determined by AIC.

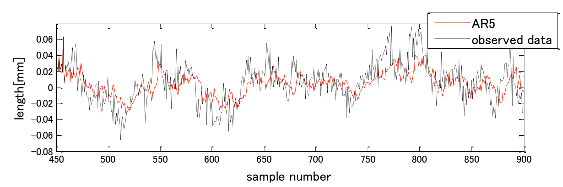


Fig. 3 Observed data and the output of model AR5.

From this figure, we can conclude that the future value of the deviation can be predicted by this model. Moreover, all models obtained by other data under different fabrication condition with same or different information criterion have the optimal order $n \geq 1$. This means that the production machine has some kind of cyclic dynamics.

## IV. Control Input and System Model for Controller Design

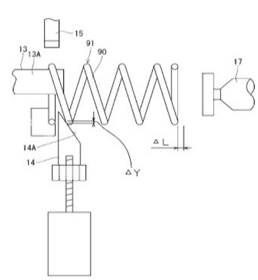


Fig.4 Mechanism of pitch forming tool

In the previous section, we can confirm that the output sequence of the system can be predicted by linear model. This satisfies the necessary condition for stochastic control system. To construct the controller for spring forming machine, we need