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ADAPTIVE CONTROL APPROACH FOR PROGRAMMED PEENING AND CONTROLLED MASS FLOW OF STEEL SHOTS

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ABSTRACT

A shot peening process requires precise peening of the surface which has undergone a cyclic loading and developed fatigue and enhances surface characteristics. It should cover the desired surface for an adequate amount of time of peening. It is proposed to consider a DC drive for controlling the movement of feed screw thereby controlling the mass flow of the steel shots. An adaptive control algorithm is used for the precise speed/position control of the DC drive in the presence of uncertainties and simultaneously fulfill the requirement of programmed peening.

INTRODUCTION

Adaptive control techniques have proven their excellence in situations occurring in increasingly complex and sophisticated system. It can be implemented easily inexpensively now a day due to the availability of microprocessors. The adaptive control has proved its viability for controlling many systems like Aircraft Control, missile control, process control, electric drive, navigational course control of ships, metallurgical processes, satellite attitude control. Adaptive control may be applied efficiently in all such situations where conventional controller cannot maintain the performance at acceptable levels. There is therefore a need for a special class of control system, which can automatically compensate for these unforeseen variations in parameters and input signals (disturbances). In general the reason for such changes may be the following:-

1. Changes in the plant transfer function, either its order or in the value of some parameters due to variations in the environment, the size and properties of raw materials, the plant through put, the characteristics involving alterations in the co-efficients, and/ or wear and tear in some important components.
2. Stochastic disturbances.
3. The change in the nature in the input
4. Propagation of disturbances along the chain of unit processes
5. Nonlinear behaviour as in the case of complex chemical and bio-chemical reactions.
6. Appreciable dead time
7. Unknown parameters, as when a control system for a new process is commissioned.

ADAPTIVE CONTROL

All adaptive control techniques can be grouped in two categories 1. Direct adaptive control; and 2. Indirect adaptive control.

1. Direct Adaptive Control :

In this kind of control the controller parameters are adjusted so that the output coordinate of the system agrees with that of the reference model. Usually the value of mismatch between the control coordinates between the system and model is used to perform parameter adjustment. Sometimes it is required that the transfer function of the closed loop system and the reference model be identical. In this case their frequency characteristics are used. This kind of adaptive control is often referred to as model reference adaptive control (MRAC).

Fig.1 Shows the schematic block diagram of MRAC.

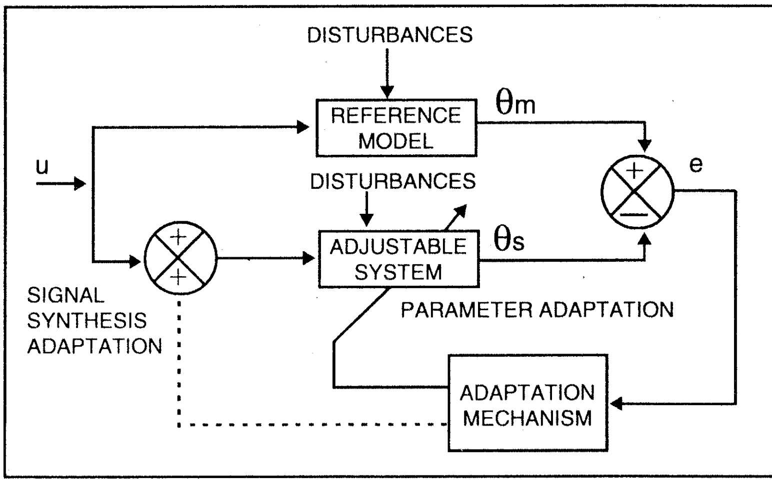


Fig. 1 Model Reference Adaptice Control scheme

It has been reported pertaining to MRAC that where the ideal reference model is not achievable due to system limitations the response of the reference system is substantially different from that of the actual system. The difference in performance is interpreted as system fault, and the adaptation of system gain occurs even when the system is in steady state. However fundamental problem associated with the MRAC technique is, to obtain a close loop response, the system zeroes must be cancelled by controller poles. Hence it cannot deal with systems with zero outside the stability region. It is also reported that the discrete time cancellation of zeroes by poles that correspond to oscillating continuous time function can lead to unacceptable inter sample behaviour. Hence this technique is not suitable for our present problem.

2. Indirect Adaptive Control:

In this type of adaptive control the object is to control the system so that its behaviour has the given properties. The control can be thought of composed of two loops inner loop and outer loop. The inner loop consists of the process in a ordinary linear feedback controller. The parameters of the controller are adjusted by the second namely the outer loop and is composed of a recursive parameter estimator. This kind of control is known as Self Tuning Control (STC). Fig.3 shows the block diagram of self tuning control. In essence the self tuning control is composed of two parts, system identification and control calculations. Different combinations of various identification techniques and various control strategies will result in different kind of self tuning controllers. Due to its simplicity and implementability a self tuning controller is proposed to be used in speed feedback of a DC drive in shot peening process. Some commonly used identification methods and control strategies are discussed below:

SYSTEM MODEL AND IDENTIFICATION METHODS:

Many types of discrete mathematical models are used in adaptive control techniques.

i. ARMA ii. ARMAX and iii. LR (Linear Regression).

i. ARMA is used as a model for stochastic signals and has no control input.

ii. With ARMAX, the prediction error $\varepsilon(t) = y(t) - y(t) = \xi(t)$ is no longer uncorrelated. Hence Principal property of RLS that the estimates are unbiased no longer holds. Therefore to overcome the difficulty with correlated residuals RELS identification should be used. RELS gives unbiased estimates but is not as robust as RLS one of its short coming is convergence cannot be proved for all cases. Secondly it increases the computational burden. And hence it may create problem in real time implementation. Therefore due to its suitability and reasonable simplicity LR model may be used for the present simulation studies.

iii. The system model (LR) is assumed to be of form

$$A(Z^{-1})\, y\,(t) = z^{-k}\, B(z^{-1})\, u\, \xi(t) + (1) \qquad \ldots\ldots\ldots\ldots(1)$$

and block diagram is shown in Fig.2. Where A and B are polynomials in Z^{-1} (backward shift operator) Defined as

$$\left.\begin{array}{l} A(Z^{-1}) = a_0 + a_1 z^{-1} + \ldots\ldots + a_{n_a}\, z^{-n_a} \\ A(Z^{-1}) = b_0 + b_1 z^{-1} + \ldots\ldots + b_{n_b}\, z^{-n_b} \end{array}\right\} \qquad \ldots\ldots\ldots\ldots(1)$$

n_a and n_b are the orders of the polynomials A and B respectively (n_a □ n_b) k represents the system time delay in sample intervals. Variables y and u are system output and input. $\xi(t)$ is an uncorrelated random sequence of zero mean which disturbs the system.

For the self tuning controller only the most important part of the system dynamics need to be considered therefore simplification of mathematical order is of special importance in self tuning control. The commonly used order for A (z^{-1}) and B (z^{-1}) in self tuning controller is three. But as in the shot peening process DC drive is considered for controlling the quantity of shots for peening through screw feed. In the present case system model order can be taken as two.

Thereby the model representation in our case assumes the following form:

$$(a_0+a_1 z^{-1} + a_2 z^{-2})\, y(t) = z^{-k} (b_0+b_1 z^{-1})\, u(t) + \xi(t) \quad \text{.............(3)}$$

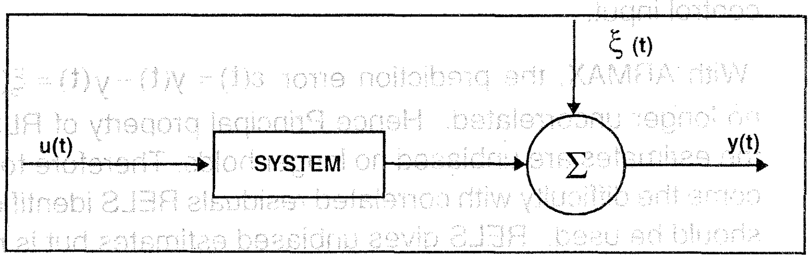


Fig. 2 A block diagram of LR Model

Another method called Recursive Maximum Likelihood method (RML) has very nice asymptotic properties and it provides accurate parameter estimates. But due to large computational problem this method is not suitable for real time control.

DESCRIPTION OF RLS ALGORITHM

The RLS identification is mainly used to treat LR model (Eqn.2) It is convenient to initialize the RLS algorithm by suitable choice of the P(0). Typically it is taken to be diagonal matrix αI , where a large value of (10^4, say) implies little confidence in θ (0) and gives rapid initial changes in θ (t). Small values of α (0.1) implies that θ (0) and gives rapid initial changes in θ (t). Small values of α (0.1) implies that (0) is reasonable estimate of θ and θ (t) changes only slowly. Hence [K] tends to 0 and θ (t) tends to constant vector θ. This behaviour is acceptable if the true parameter were in fact constant but in practice we would want the algorithm to track slowly varying parameters (so that the self tuner stays in tune). Therefore the RLS algorithm has to be modified. To achieve this, best way is using forgetting factor β, $0 < \beta \leq 1$. More weightage is given to recent data instead of giving equal weightage to the error. So [P] and [K] do not tend to zero.

ASL $\underline{\Delta}$ 1/(1-β) indicates number of important previous samples contributing to θ (t). Typical values of β are in range of 0.95 (Fast variation to 0.999 (1) slow). The corresponding ASL are 20 to 1000.

BLOW UP

When the algorithm is started up and estimates are poor the regulator makes large excursions until estimates improve and so P9t) becomes very small, especially in near deterministic system. So there will be little or no information about the dynamics during long periods of near steady state of plants. But as P(t) is constantly scaled by a factor < 1, P(t) will grow exponentially and may become very large. The regulator is now very sensitive to any disturbance or numerical error and frequently a random input or a set point change will lead to a temporarily unstable system or complete instability.

ENHANCEMENT OF PARAMETER TRACKING

In RLS identification algorithm

Parameter vector $\hat{\theta}^{T}(t) = a_1, ..., an_a, ... b_0, b_1 .... b_{nb}$ ....(4)

Vector containing measured data

$X^T(t) = [-y(t-1), ...-y(t-n_a), u(t-k),.......,u(t-k-n_b)]$ ....(5)

Model $y(t) = \hat{\theta}^{T}(t)\, x(t) + \xi(t)$ ....(6)

Let y(t) be an estimate of y(t) based on □ (t) and x(t), then

$$y(t) = \hat{\theta}^T(t)\, x(t) \qquad \text{.........................(7)}$$

$$\varepsilon(t) = y(t) - \hat{y}(t) \qquad \text{.........................(8)}$$

θ is chosen in such a way that the criterion

$$J = \sum_{t=1}^{m} \varepsilon^2(t) \text{ is minimized} \qquad \text{.........................(9)}$$

Giving $\hat{\theta} = [X^T X]^{-1} x^T Y$ ....(10)

The algorithm requires following steps to estimate parameter recursively.

$$\hat{\theta} = \hat{\theta}(t-1) + K(t)\,[y(t) - \hat{\theta}^T(t-1)\, x(t)] \qquad \text{.........................(11)}$$

$$K(t) = \frac{P(t-1)x(t)}{[1 + x^T(t)P(t-1)x(t)]} \qquad \text{.........................(12)}$$

$$P(t) = [1 - K^T(t)\, x(t)]\, P(t-1)] \qquad \text{.........................(13)}$$

Proportional to error covariance matrix.

In the normal RLS algorithm (as discussed above) a criterion J is considered that weights every error equally. If the system is time varying this criterion gives an estimate of the average behaviour during $1 \leq t \leq m$. As the time increases the number of measurements become very large and contribution of each individual measurement to the parameter estimation tends to zero.

Therefore another criterion J is considered in which old values are discounted by an exponential weighting scheme which places heavier emphasis on the more recent data. As a result the parameter tracking capability is greatly increased;

$$J = \sum_{i=1}^{m} \beta^{m-1} e^2(i) \quad 0 < \beta < 1 \qquad \text{.........................(14)}$$

Hence the later errors are given more weight than earlier ones. Accordingly

$$P(t) = \frac{[1 - K^T(t)x(t)]P\ (t-1)}{\beta} \qquad \text{.........................(15)}$$

PARAMETER TRACKING WITH VARIABLE FORGETTING FACTOR (VFF)

The basic idea involved in all self tuning controllers was a use of RLS algorithm with constant forgetting factor. Then β in the range of 0 and 1 was suggested to avoid the blow up problem. When the system is continuously in the steady state, the large value of β gives good results. But it does not show desired performance during the transient conditions. Secondly, as the error covariance matrix P(t), is being continuously scaled by a factor < 1 (β). This matrix may grow exponentially, resulting in the unreasonable controller output, when the system is in steady state. In order to avoid such difficulties, several solutions emerged in the literature but in our proposed STR we have used Lozano Leal, R. et al method of introducing VFF into the RLS identification algorithm. This is known as Data Normalisation Technique with non-vanishing gain matrices and constant trace. The algorithm chooses β (t) such that trace P(t) = Trace P_O. Hence the P matrix is calculated as:

$$P(t) = \frac{1}{\beta(t)}[P(t-1) - \frac{P(t-1)x(t-1)x^T(t-1)P\ (t-1)}{1 + x^T(t-1)P(t-1)x(t-1)}]$$

$$0 < \beta \leq 1,\ P_O = P_O^T > 0 \qquad \text{.........................(16)}$$

It can be shown that trace P(t) = trace P_O at all time t, when β (t) is chosen to satisfy

$$\beta(t) = 1 - \frac{1}{tr\ P_0}\frac{x^T(t-1)P^2\ (t-1)x(t-1)}{1 + x^T(t-1)P(t-1)x(t-1)} \qquad \text{.........................(17)}$$

The modification done in the recursive least square algorithm to estimate the controller parameter of the self tuning controller can be explained as below:

1. Cost function to be minimized:

$$I = E[\phi^2 (t+k)] \quad \text{.........................(18)}$$

Where $\phi(t+k) = Py(t+k) + Qu(t) - R\omega(t)$ ....(19)

2. The Parameter vector

$$\hat{\theta} = [h_O, h_1, g_O, g_1, e_O, e_1]$$

$$\hat{\theta}(t) = \hat{\theta}(k-1) + K(t)[\phi(t) - \hat{\theta}(t-1)\, x(t)] \quad \text{.........................(20)}$$

where, $$K(t) = \frac{P(t-1)x(t-1)}{1 + x^T(t)P(t-1)x(t)} \quad \text{.........................(21)}$$

$$P(t) = \frac{[1 - K^T(t)x(t)]\, P(t-1)}{\beta(t)} \quad \text{.........................(22)}$$

Here $\beta(t)$ is a variable forgetting factor determined by Eqns. (17) and (18) Controller output is given by;

$$u(t) = \frac{-[g_O\, y(t) + g_1\, y(t-1) + e_O\, w(t) + e_1\, w(t-1) + h_1\, u(t-1)]}{h_O} \quad \text{..(23)}$$

SIMULATION STUDIES WITH DC DRIVES FOR PROGRAMMED PEENING AND MASS FLOW CONTROL OF SHOTS USING SCREWFEED:

As in the shot peening process the rotation of screwfeed controls the feeding of shots by controlling the rotation of the DC drive i.e. start, stop and reversal and even the position of the shaft. In this way programmed peening can be achieved by using a variety of shots for selected duration depending upon the reference signal. DC drive is considered to be equipped with a dual converter and a discrete PI controller in the forward path (current loop) and the proposed STR controller speed/position loop. It is also assumed that the firing circuit is linear i.e., gain A is constant. After some preliminary runs were made to find reasonable values for proportional and integral gains and integral time constants the best values of the constants were used in our simulation. The test system is considered of second order having speed and current as output vectors. These linear differential equations were solved by fourth order Runge-Kutta method using a step length of 1 ms. Sample rate of 100 ms has been selected for self tuning controller employed in the outer speed loop. The details of the DC motor are as below:

Base Voltage = 220 Volt, Base power 2 HP, Current = 7.53 IIAmp, Speed 1050 rpm, R_a = 6.44 ohm, L_a = 0.145 henry, J = 0.3192 Kg-m², K_b = 1.939 volt/rad/sec, B = 0.0799 Nw-m/rad/sec, K_T = 1.939 Nw/Amp, Ta = 22 ms. Tm = 546 ms.

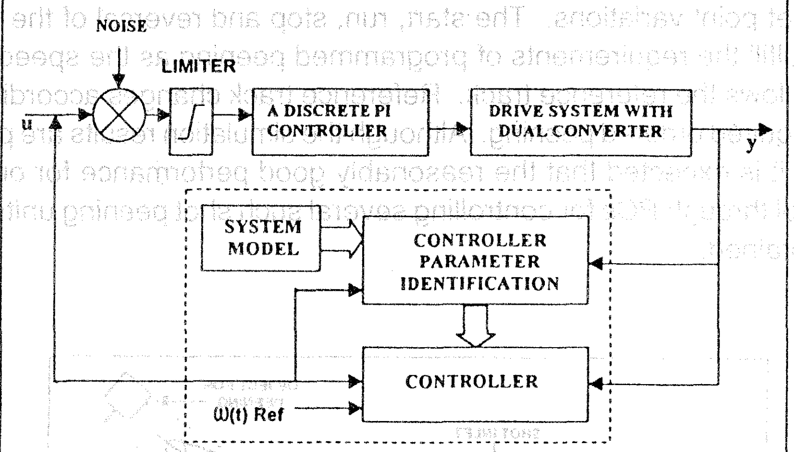


Fig.3. Block diagram of the proposed self-tuning controller and the drive.

RESULTS AND DISCUSSION

Frequent start, run, stop and reversal are required in our present application of programmed peening and show flow control. It is assumed that a number of screws are used in applying different shots (different materials and sizes) as required for the surfaces to be peened. In our simulation study rectangular reference signal rising from zero to rated speed and then decreasing to zero and rising to rated speed in reverse direction after a pause has been chosen. It means during the period of set running and pause shots from the different screws will be used for shot peening. Fig.4(a) shows the drive output with respect to the reference and output follows the reference. Fig.4(b) shows the behaviour of the VFF with respect to time and is as desired and changes to lower value during transient condition of the drive. The results are promising.

CONCLUSION

A novel scheme for programmed peening and shot flow control through application of self tuning controller has been suggested. Self tuning controller incorporating variable forgetting factor in the RLS identification has been used and blow of the gain matrix has been avoided. Performance index of the control algorithm incorporates input, output and set point variations. The start, run, stop and reversal of the drive can fulfill the requirements of programmed peening as the speed output follows the reference track. Reference track changes according to the required ordered peening. Although the simulation results are promising, it is expected that the reasonably good performance for on line control through PCs for controlling several such shot peening units can be obtained.

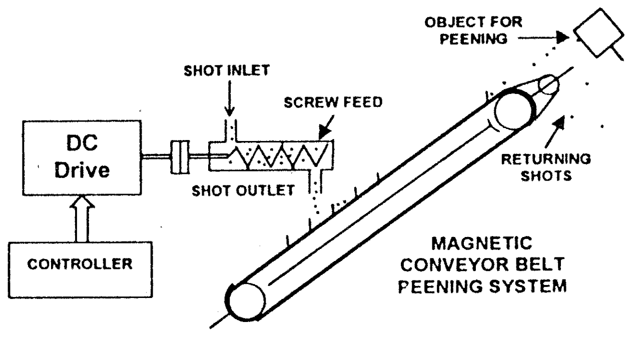


Fig.5. Proposed system of peening.

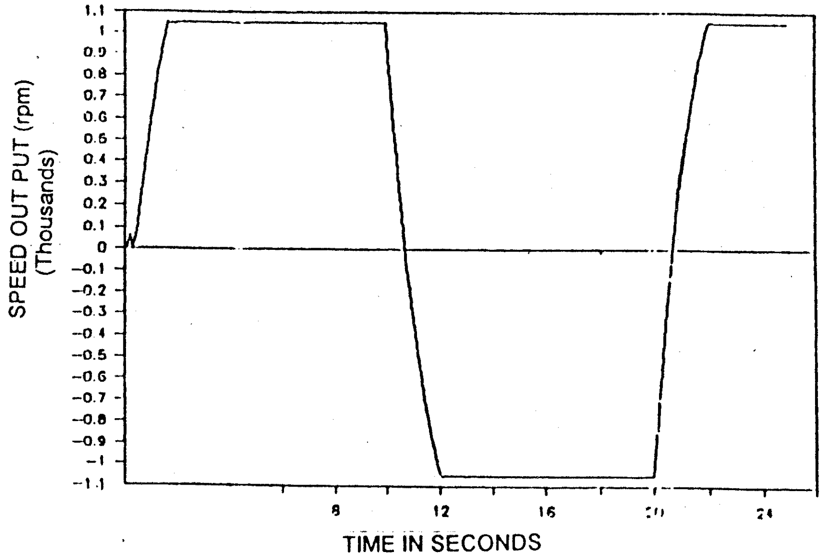
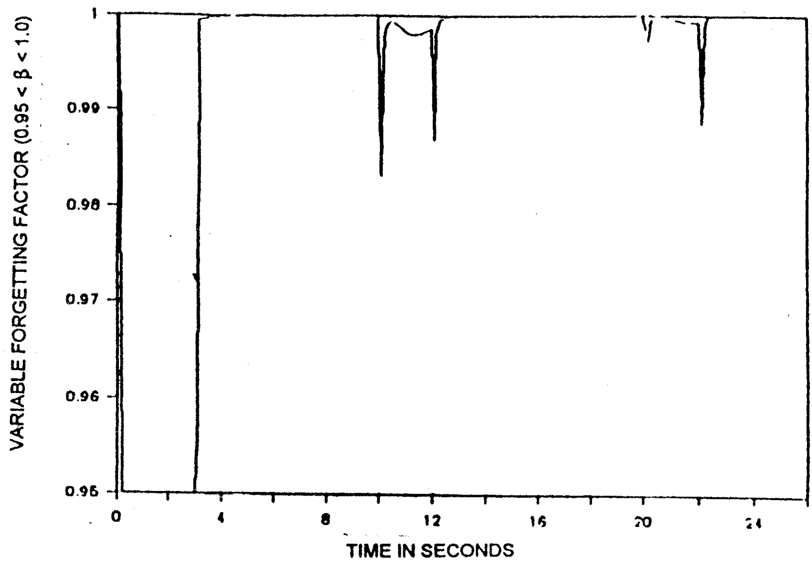


Fig. 4.(a)



4.(b)

Fig.4. (a) Performance of the drive, and (b) Behaviour of Variable Forgetting Factor (VFF).

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