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Adaptive Control of Two Mass Drive Systems Using ADALINE Speed Controller

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Abstract: ***An industrial two mass system is composed of a motor which is connected to the load machine through a shaft. Sometimes the shaft may be stiff, but in applications such as rolling mill drives, robotic arms, conveyor belt etc., the shaft is elastic. These elastic joints are susceptible to torsional vibrations that limit the performance of industrial drives. Due to this the motor speed may be different from the load speed. To solve this problem speed controllers are used which will adjust the load speed and the motor speed with that of the reference speed. Fuzzy logic controllers and PI controllers were used earlier. The limitation of these controllers is the lack of analytical tuning. In recent years, neural network have been applied for the control of two mass systems. ADALINE (Adaptive Linear Neuron) based speed controller with an efficient adaptation algorithm can be used to stabilize the two mass drive systems. The control signal to be applied to the two mass system is generated by the ADALINE controller which updates its weight value on demand. The design of modules can be done in Xilinx System Generator. System generator enables the use of MATLAB/Simulink for simulating the designed modules. It also enables the user to create user defined blocks. The modules that are designed in System Generator can be implemented in FPGA.***

Keywords: ADALINE, Two mass systems, Llinear activation function, Adaptation algorithm, Xilinx system generator, Matlab/Simulink.

1. Introduction

Industrial two mass systems should be efficient in the sense that they should give better performance without giving up stability. A two mass system is one in which motor and load are connected via a shaft. Depending upon applications the shaft may be elastic or inelastic. In applications such as robotic arms, conveyor belts etc., elastic shafts are connecting the two mass systems. These elastic shafts are liable to speed oscillations called torsional vibrations which decrease system reliability and product quality, and in some special cases, they can even lead to instability of the whole control structure. So here arises the necessity of damping torsional vibrations, and for that different control concepts have been developed.

The ordinary Proportional Integral (PI) and fuzzy logic controllers (FLC) are not much efficient in damping torsional vibrations. The main problem is with the difficulty in adjusting its parameters. One of the solutions to this problem is the use of Genetic gradient algorithms (GGAs). GGAs [2] are optimization algorithms that can be applied to obtain proper adjustment in PI and FL controllers but it doesn't ensure the speed adjustment at low speed ranges. Sliding mode controller (SMC) is another popular non linear controller which applies a discontinuous signal to modify the dynamics of a nonlinear system. Chattering phenomenon is the issue that affects the SMC's performance by degrading its reliability. In order to cope up with this situation another control structure called SMC with an integral function [3] was developed. Here the discontinuous function used by the SMCs are replaced by a continuous function i.e., calculated by the integral function incorporated along with the SMC. Adaptive SMC [4] systems based on neural network can also be used for this purpose. When the discontinuous function is replaced by continuous function the robustness of the system will be negatively affected.

The ordinary cascade structure of PI controller cannot damp the torsional vibrations effectively hence to improve the system performance a state variable will be selected and additional feedback loops will be constructed from those state variables. The introduction of additional feedback can be done to torque control loop or to speed control loop. Following this idea [5] control structures were constructed from all state variables such as shaft torque, motor and load speed and it ensures very good performance but the direct feedback is not possible. A major advancement noticed in industries was with the use of FPGAs for [6] implementing different control structures due to its re-configurable nature and low cost.

Artificial intelligence techniques were also developed to achieve a more accurate control. Recently Neural Network (NN) based control structures were developed that uses neural network estimators [7] which are more powerful in estimating parameters and measurement noises. However estimation errors are slightly increased in this method. By combining the properties of adaptive systems and neural network a simple structure called Adaptive Linear Neuron (ADALINE) is obtained.

This paper describes the adaptive control of two mass drive system using ADALINE speed controller. ADALINE is an adaptive linear system that reacts to changes in environment while it is functioning. It uses adaptation algorithm or Widrow Hoff's learning rule to adapt to the changes and calculates the control output with the help of a linear activation function. The output from the activation function is the control signal that is applied to the two mass systems to make the motor and load speeds alike. The design of the modules is done in Xilinx system generator and they are simulated by using Matlab/Simulink.

2. Methodology

Speed oscillations are limiting the performance of two mass drive systems. Adaptive linear neuron (ADALINE) is a structure with simple design process. ADALINE is having a framework similar to that of an adaptive linear combiner. Along with adaptive linear combiner it contain adaptation algorithm to adjust with the non linearity and an activation function to process the output. The basic block diagram of ADALINE based speed controller is shown in Figure 1. It contains ADALINE speed controller and the two mass systems.

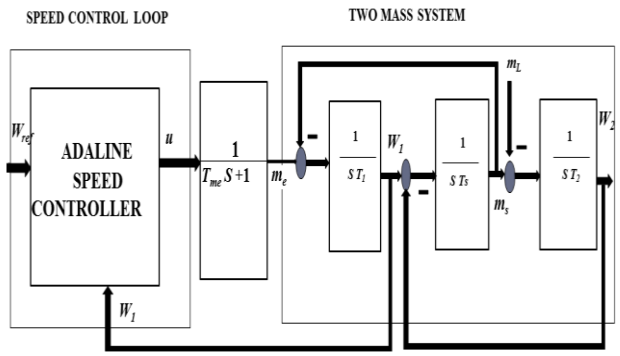

Figure 1: Basic block diagram of ADALINE based speed controller.

The vibrations in elastic shaft connecting the motor and the load machine, leads to speed oscillations. Thus these oscillations in speed make the load speed different from motor speed. To damp this oscillations the motor speed W_1 is fed back to the ADALINE speed controller and also the reference speed W_{ref} is given as input to it. ADALINE speed controller will generate a control signal which is given to the torque control loop which will shape the electromagnetic torque of the motor thereby controlling the two mass systems.

2.1 Two mass systems

Two machines connected by a shaft can be referred to as a two mass system. The Figure 2 shows a two mass system containing a driver and a load connected via elastic shaft. Depending upon the applications the two masses can be motors. Elastic shafts are subjected to speed oscillations called torsional vibrations which are undesirable. For analysis the two mass drive system can be mathematically modeled as shown in Figure 3. Usually such drives are analyzed as a system with two masses where the first mass represents the moment of inertia of the drive and the second mass represents the moment of inertia of the load.

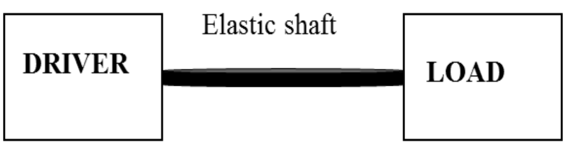

Figure 2: Two mass system.

In the figure T_1 (t) and T_2(t) represents the motor and the load. W_1(t), W_2(t), m_e(t), m_L(t), m_S(t)represents the motor speed, load speed, electromagnetic torque of motor, torque of load and the shaft torque respectively. The motor and load are modeled as integral elements 1=s T_1 and 1=s T_2. Where T_1 and T_2 are the time constants of motor and load respectively. The shaft modeled as 1=sTs, where Ts is the time constant of shaft. The outside torque control loop is used to control the electromagnetic torque m_e(t) of the motor. Applying the stability or equilibrium condition the forces acting along an axis should be balanced.

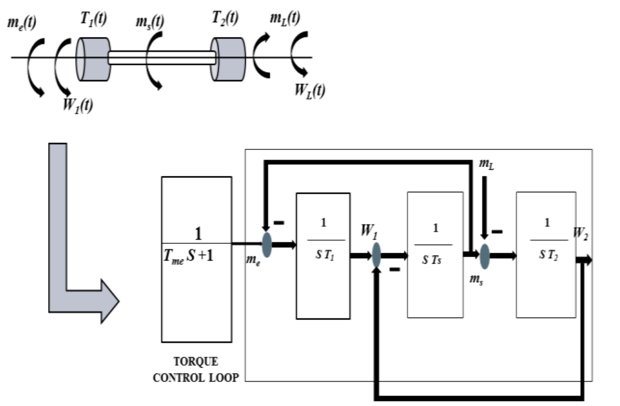

Figure 3: Mathematical modeling of two mass systems.

2.2 Adaptive linear neuron element (ADALINE)

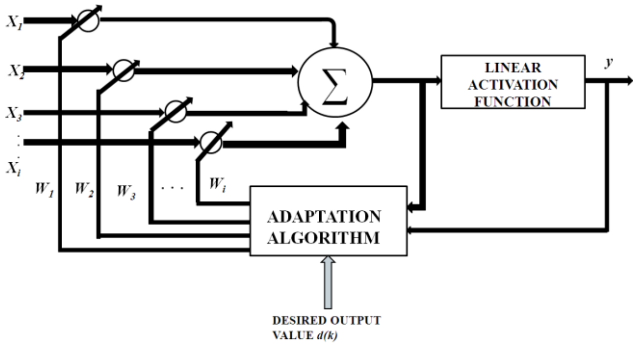

Figure 4: Structure of ADALINE speed controller.

Adaptive linear neuron (ADALINE) is a single neuron structure developed by Bernard Widrow in 1959. It contain multiple nodes, each node takes multiple input process and produce a single output. The structure of ADALINE is shown in Figure 4. The inputs are multiplied by the weights calculated by adaptation algorithm and then the output is processed by the linear activation function. As the activation function is linear the output will be equivalent to linear combination of the inputs. The whole structure of ADALINE speed controller is shown in Figure 5. The main sections present in the structure of ADALINE are:

- Input vector processing block.
- Adaptive linear combiner.
- Adaptation algorithm.
- Linear activation function.

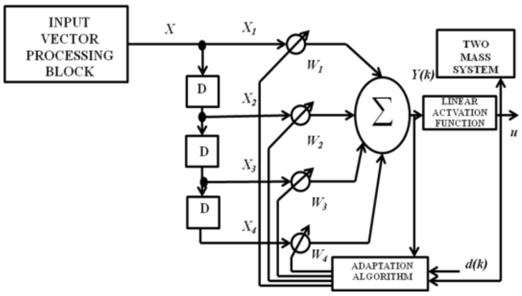

Figure 5: The whole structure of ADALINE speed controller.

The Figure 6 shows the input vector processing block which is used to process the input X. The input given to this block is the motor speed W_1 and the error signal which is obtained by reducing the motor speed form the reference speed i.e., Error signal e = $W_{ref} - W_1$.

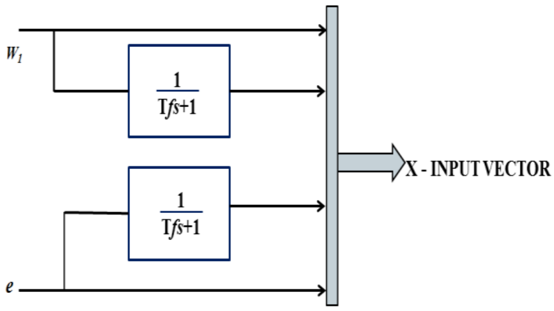

Figure 6: Input vector processing block

Transfer function of the input low pass filter (LPF) is given by 1/Tfs+1, where Tfs represents the filter time constant. A 4:1 multiplexer (MUX) is used to select the inputs. The four inputs given are Wref directly to MUX and via a LPF, similarly the error signal is also given directly and via LPF. The input LPF is used in the input to filter out the noises that might be present in the input.

The output from the input vector processing block is given to adaptive linear combiner section. The output from the input vector processing block is delayed several times to obtain the inputs to the ADALINE speed controller. Figure 6 shows how it can be done. It is having a simple structure that can be easily analyzed. The inputs X_1, X_2, X_3, X_4 are multiplied by the weights W_1, W_2, W_3, W_4 and the output is calculated as shown in Figure 5. The error signal is calculated by reducing the desired value form the output. The adaptation algorithm works in such a way to reduce the output.

The adaptation algorithm is given by,

$$W_{k+1} = W_k - \alpha \sum_{i=1}^{N}\left(X_i W_i - d(k) X_i(k)\right) \quad (1)$$

Where W_{k+1} and W_k represents the weights in kth and k=1th iteration. α is the learning coefficient. The learning can be done in such a way that the error should be reduced with the help of Adaptation algorithm. Adaptation algorithm is an iterative algorithm which is developed from the back propagation algorithm. This algorithm relies upon the minimal disturbance principle. It will adapt to reduce the output error for the current training pattern.

Linear activation function is a neural transfer function. It calculates a layer's output from its net input. The output will be equal to the sum of the product of inputs multiplied by weights.

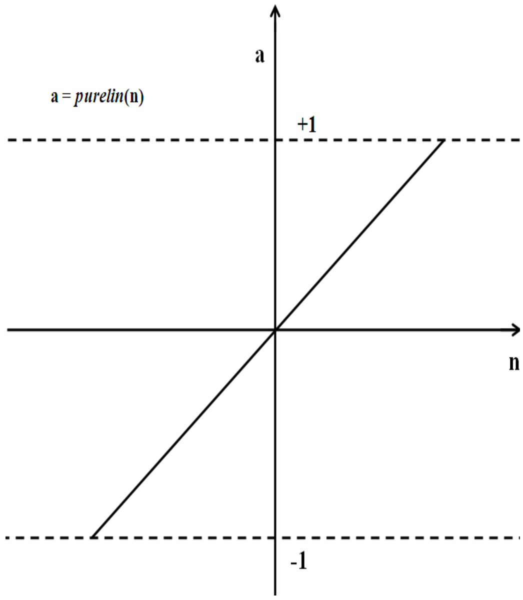

Figure 7: Linear activation function

The entire procedure is given as:

Step 1: First the weights are initialised to some random values.

Step 2: Multiply the inputs with weights to obtain the output y(k).

Step 3: Calculate the error signal,

e = W_{ref} - W_1 (2)

Step 4: Apply the Adaptation algorithm to calculate the weights. Adapt to reduce the output error for the current training pattern. For training the value of the α, the learning coefficient is adjusted to obtain the desired control signal.

The ADALINE module designed in Xilinx system generator is shown in Figure 8.

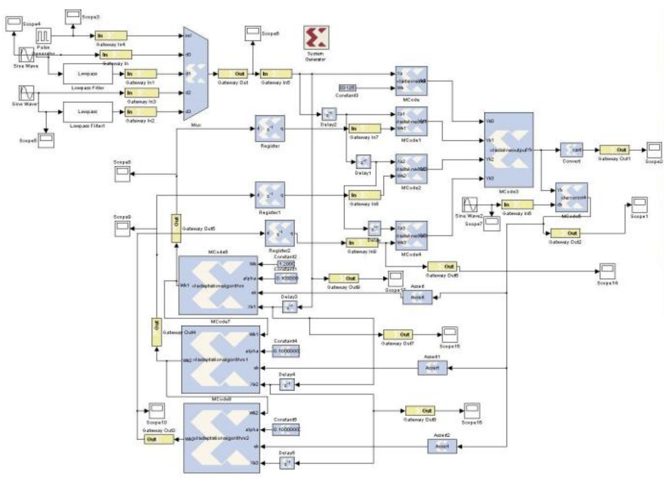

Figure 8: ADALINE speed controller in Xilinx system generator.

3. Results and Discussion

The design of the modules is done in Xilinx System generator that is available in Xilinx design suite 12.1 and system generator allows the user to simulate the designed blocks in MATLAB/Simulink R2010a. The motor speed W1 was set to 50 and the Wref is set to 60 which gives an error of 10.

3.1 Simulation result of two mass system

The two mass system is designed in MATLAB/Simulink R2010a. The output of the model is observed in a wave scope. The design was done assuming the values of motor and load time constants as T1=T2=203ms and the shaft time constant is assumed to be Ts=2.6ms. Thus the motor speed is obtained as shown in figure 9 and the load speed with speed oscillations due to the presence of elastic shaft is shown in Figure 10.

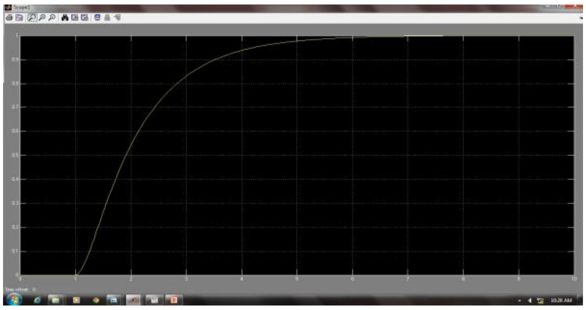

Figure 9: Motor speed

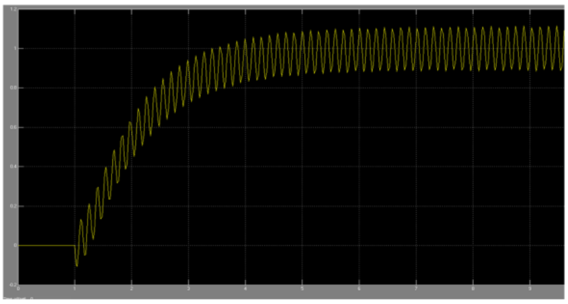

Figure 10: Load speed with speed oscillations.

3.2 Simulation result of ADALINE

The ADALINE modules output is calculated by designing the ADALINE structure in XILINX System generator and simulating it in MATLAB/Simulink R2010a. The output which is a linear combination of inputs and weight for weight 1.2 and learning coefficient 0.1 for which the required speed of 60 obtained is shown in Figure 11. Figure 12 given below shows the weight values adapted after applying adaptation algorithm.

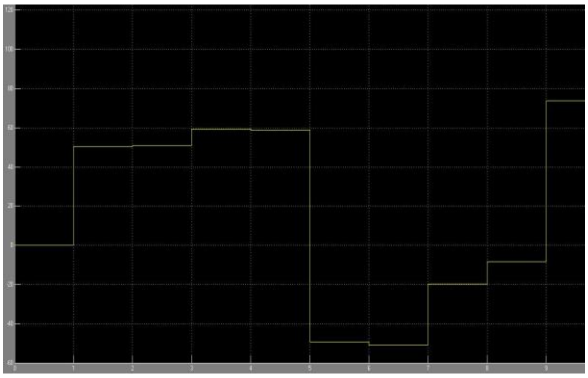

Figure 11: Output from ADALINE for weight 1.2 and learning coefficient 0.1.

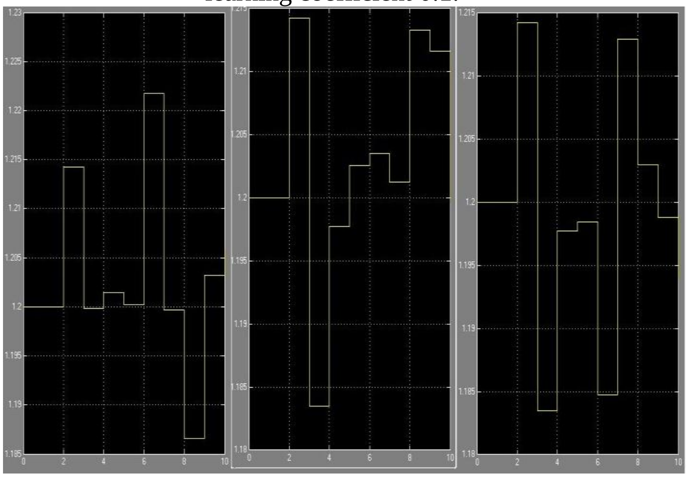

Figure 12: Weight values adapted after applying adaptation algorithm

4. Conclusion

Adaptive control of two mass drive system using ADALINE speed controller is designed for the speed control of two mass systems that experience speed oscillations due to the presence of elastic shaft connecting motor and load. Adaptive linear neuron (ADALINE) speed controller is having a simple structure with reduced number of parameters in the design process. It contains multiple inputs which are multiplied by the weights that are calculated from the adaptation algorithm. The learning procedure of ADALINE starts by initializing the weight value to a random value and then calculating the ADALINE output from which the error signal is calculated. The learning is done in such a way that the error should be reduced by adjusting the value of learning coefficient.

The two mass drive system has been modelled in Simulink where the motor, load and shaft are modelled as integral elements. The control signals generated by the ADALINE speed controller have to be fed to the two mass drive systems. The modules are designed in Xilinx System Generator are simulated in MATLAB/Simulink R2010a. The work of designing the ADALINE can be extended to systems other than two mass systems. Also Adaptive linear neuron (ADALINE) speed controller is having a linear activation function. Changing the Linear activation function with a more appropriate activation function can also be done which is having the ability to consider the non linearity at the output.

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