International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:7, No:7, 2013

Design of QFT-Based Self-Tuning Deadbeat Controller

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***Abstract*—**This paper presents a design method of self-tuning Quantitative Feedback Theory (QFT) by using improved deadbeat control algorithm. QFT is a technique to achieve robust control with pre-defined specifications whereas deadbeat is an algorithm that could bring the output to steady state with minimum step size. Nevertheless, usually there are large peaks in the deadbeat response. By integrating QFT specifications into deadbeat algorithm, the large peaks could be tolerated. On the other hand, emerging QFT with adaptive element will produce a robust controller with wider coverage of uncertainty. By combining QFT-based deadbeat algorithm and adaptive element, superior controller that is called self-tuning QFT-based deadbeat controller could be achieved. The output response that is fast, robust and adaptive is expected. Using a grain dryer plant model as a pilot case-study, the performance of the proposed method has been evaluated and analyzed. Grain drying process is very complex with highly nonlinear behaviour, long delay, affected by environmental changes and affected by disturbances. Performance comparisons have been performed between the proposed self-tuning QFT-based deadbeat, standard QFT and standard dead-beat controllers. The efficiency of the self-tuning QFT-based dead-beat controller has been proven from the tests results in terms of controller's parameters are updated online, less percentage of overshoot and settling time especially when there are variations in the plant.

***Keywords*—**Deadbeat control, quantitative feedback theory (QFT), robust control, self-tuning control.

I. Introduction

ADAPTIVE QFT has been an interesting topic among researchers in recent years due to the high demand in simultaneous robust and adaptive specifications. These two control techniques have their own capability. Adaptive control has the capability to cover wider uncertainty range for plant with no sudden change occurred [1], meanwhile QFT is a technique to achieve robust control based on predefined specifications, but for a certain uncertainty range. By marrying both techniques, the advantages of both controllers which are adaptive, robust and wider coverage of uncertainty can be achieved.

Adaptive QFT proposed by Ahn and Dinh (2009) for force controller is based on gradient decent and back propagation algorithm [2]. The results were very convincing however the process is very slow and inefficient due to the algorithm chosen. There is possibility that the algorithm may get stuck in local minima resulting in sub-optimal solutions in gradient decent method. Adaptive QFT developed using RLS and pole-placement algorithm has been proposed by Mansor et. al. (2011). Test results showed that adaptive QFT produced faster response in case of larger uncertainty range and at the same time the human's skill dependence on loop shaping was removed and the controller design was made online [3]. Several useful literature reviews related to the success of adaptive QFT design and applications can be found from [4], [5], [6].

In this research, deadbeat control algorithm has been proposed in order to achieve adaptive or self-tuning QFT. Deadbeat is known for its capability to settle the output at a very minimum step size, or producing very fast response. The problem of deadbeat controller due to problem with physical realization and incomplete pole-zero cancellation can be avoided with the advent of Digital Signal Processing (DSP) systems [7]. Deadbeat controller has been successfully implemented on type 1, second order system. It was proven from the test result that, as the order increased, the settling time is also increased. The chosen case-study, grain dryer plant model is categorized as third order system and longer settling time is expected. Therefore the challenges in this study are to reduce the settling time of the overall grain dryer control system as well as achieving the predefined specifications. The proposed self-tuning QFT-based deadbeat controller is designed to produce fast response and yet more robust system for a grain dryer plant model.

The main control objective of the grain dryer control system is to reduce the grain moisture content from 17% to 14% w.b for safe and longer storage life of grain [8].

II. Methodology

A. Standard QFT Design Procedure

Conveyor-belt type grain dryer plant model has been chosen as the case study [5].

$$P(s) = K\frac{1+T_Z s}{(1+2\zeta T_W s+(T_W s)^2)(1+T_{P_3} s)}e^{-T_d s} \tag{1}$$

where $K = 0.17788$; $T_w = 0.32426$; $\zeta = 0.17533$; $Tp_3 = 32.076$; $T_d = 27.027$; $T_z = 0.47177$.

This research is funded by International Islamic University Malaysia (IIUM) under the grant no. EDW B11-235-0713.

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A. QFT-Based Controller Design

QFT-based controller is designed based on pre-defined specifications which are to achieve gain margin ≥ 12 dB and phase margin ≥ 50° [9]. A variation of ± 5% multiplicative nonparametric uncertainty (due to linearization, parameter variation and delay in the process) has been considered in the controller design.

- Robust stability margin

$$\left|\frac{L(j\omega)}{1+L(j\omega)}\right| \leq 1.2 \qquad (2)$$

- Robust output disturbance rejection

$$\left|\frac{Y(j\omega)}{D(j\omega)}\right| < 0.07\left|\frac{j\omega^3+64(j\omega)^2+748(j\omega)+2400}{(j\omega)^2+14.4(j\omega)+169}\right|,$$

$$\omega < 10\,rad/s \qquad (3)$$

- Robust input disturbance rejection

$$\left|\frac{Y(j\omega)}{V(j\omega)}\right| < 0.01,\ \omega < 50\,rad/s \qquad (4)$$

The QFT design procedure involves three basic steps [10].

1. Computation of QFT bounds
2. Design of controller (and possibly pre-filter)
3. Analysis of the design

B. Figures Deadbeat Controller Design

All the discrete transfer function of the controlled system is given as follows [11]:

$$G(z^{-1}) = \frac{B(z^{-1})}{A((z^{-1})} = \frac{b_1z^{-1}+b_2z^{-2}+b_3z^{-3}}{1+a_1z^{-1}+a_2z^{-2}+a_3z^{-3}} \qquad (5)$$

where *a* and *b* are the process parameters.

For a third order controlled system, the control law of deadbeat controller is given by [11]:

$$u_k = r_0w_k - q_0y_k - q_1y_{k-1} - q_2y_{k-2} - p_1u_{k-1} - p_2u_{k-2} \qquad (6)$$

where *u* is the controller output, *w* is the reference value, *y* is the process output and *k* is the step number. The constants values of r_0, q_0, q_1, q_2, p_1 and p_2 are calculated from the identification initial plant parameter estimation.

C. QFT-Based Deadbeat Controller Design

The design steps for the proposed online QFT-based self-tuning controller can be summarized as the following:

i. Zero level tracking error is the requirement of the controller after a change to the controller output in a finite number of control steps.
ii. Algebraic method (deadbeat) with integrated QFT specifications is used to find the optimal values of the controller.
iii. By using step (i) at each running step of the system operation, a new set of the controller's parameters is given, only if condition in step (ii) satisfied. The controller will be updated for the next step of time.

III. Results and Discussions

Tests have been conducted in Matlab & Simulink environment. Three different controllers have been tested on the same grain dryer plant model, with the same working conditions. In order to show the effectiveness of the proposed controller, three different types of tests have been conducted; reduction of moisture content from 17% to 14% w.b., adaptation test, and uncertainty test.

In the first test, the grain dryer control system is required to reduce the moisture content of grain from 17% to 14% w.b. As can be seen in Fig. 1, all three controllers are able to reduce to moisture content effectively. Standard adaptive deadbeat controller produces the fastest response as the algorithm of deadbeat controller is to achieve zero level tracking error in minimal steps towards any changes. However, there are large peaks in the first step due to fast stabilization of the process output. This is the main disadvantage of deadbeat controller. When deadbeat is integrated with QFT specifications, the QFT-based deadbeat controller produces better response that has smaller overshoot, slower but yet faster settling time than the standard QFT controller. From this test, it can be seen that the emerging of QFT specifications into deadbeat algorithm reduced the large peaks in the output response.

In the second test, repetitive step signals have been applied to the grain dryer plant in order to determine the adaptive capability of the controllers. The responses in Fig. 2 show the adaptive capability of adaptive/self-tuning controllers using both standard deadbeat and QFT-based deadbeat algorithms. The learning mechanism improves as the number of sampling events increases and result in better quality of response. However, the performance of QFT-based controller is consistent throughout the test, because it is an offline controller. This test shows the capability of robust QFT-based controller to be adaptive to any changes occurred in the plant.

The third test reveals the superiority of the proposed self-tuning QFT-based deadbeat controller where the plant experiences maximum 20% parameter variation/uncertainty at k=300s. The new parameters values are:

K = 0.187; T_w = 0.340; ζ = 0.184; Tp_3 = 33.680; T_d = 27.027; T_z = 0.495.

When applying a controller using standard deadbeat or standard QFT-based algorithms alone, the response produced consists of several unwanted peaks (deadbeat) or very long settling time with high overshoot (QFT). However, when both of the algorithms are incorporated together, self-tuning QFT-based deadbeat controller could achieve more desirable response. The proposed system is able to attenuate the disturbance in the form of parameter variation effectively. The performance of all three controllers is summarized in Table I.

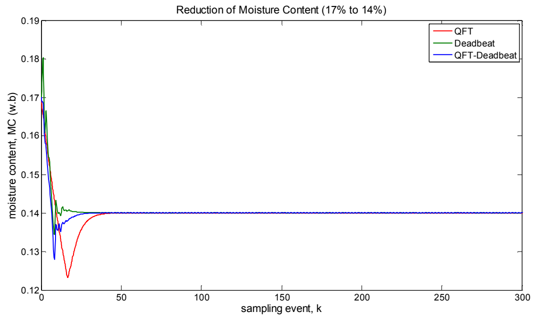

Fig. 1 Comparative responses of grain dryer control systems for reduction of moisture content (17% to 14% w.b)

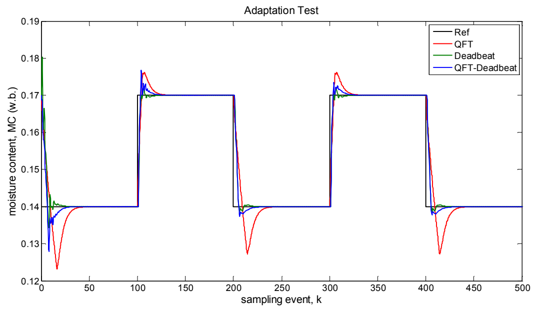

Fig. 2 Comparative responses of grain dryer control systems for repetitive step signals

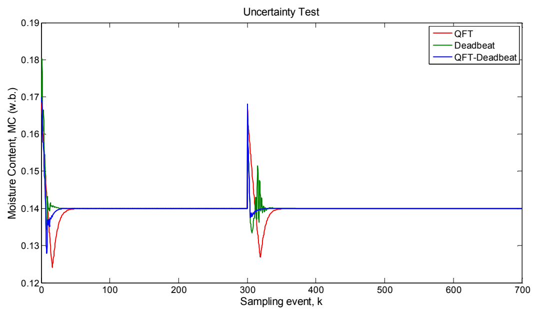

Fig. 3 Comparative responses of grain dryer control systems for uncertainty test

IV. Conclusions

A design method of robust and adaptive QFT-based deadbeat controller has been presented. Compared to the standard deadbeat and QFT-based benchmarked controllers, the integration between robust QFT-based controller and self-tuning deadbeat algorithm has improved the grain dryer control system's performance. Using grain dryer plant model as a pilot plant, the superiority of the proposed controller has been proven where settling time and maximum overshoot have been improved; especially when there is parameter variations occurred in the plant. The proposed controller also has the online capability where the controller can adapt to any changes occurred to the plant.

TABLE I
Summary of Performance of QFT, Deadbeat, and QFT-Based Deadbeat Controllers for Uncertainty Test

	QFT	Self-tuning Deadbeat	Self-tuning QFT-based deadbeat
Settling time, k	50	25	20
Percentage of overshoot (%)	10.7	3	1.43
Steady state error	0	0	0
Spiky response?	no	yes	no

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