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Fault detection observer design using time and frequency domain specifications

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Abstract: This paper deals with a multi-objective fault detection observer design problem in time and frequency domain for time invariant systems. Firstly, to improve the abilities of designed observer, different design criteria are proposed, which are evaluated by some suitable performance indices in time and frequency domain. Details about the relationships among different criteria are analyzed for two cases when the fault appears and disappears. With selected residual evaluation function and threshold, a formula with an envelope in time domain to realize fast fault detection is proposed for some typical faults. The designed observer considers the trade-off between fast transients of the residual for specified faults and the traditional criterion H_-/H_∞ for general faults and disturbances. Compared with H_-/H_∞ frequency design method, the effectiveness of the proposed method is demonstrated by the numerical simulation with a vehicle lateral dynamics system.

Keywords: Fault detection, Frequency domains, Time domains, Multiple-criterion optimisation.

1. INTRODUCTION

As fault detection and isolation (FDI) becoming critically important in the more and more complex and integrated system such as aircrafts and petrochemical plants, a great deal of works about FDI has been done in the recently decades. And great progress has been made in searching for model based diagnosis techniques. Since the exact model of the plant is difficult to get, and various disturbances and noises will affect the the system, the robustness of the system becomes an important issue to consider. Different from the robustness in control theory, the FDI also has to be sensitive to the faults. Difficult to decouple the faults and disturbances Massoumnia et al. (1989), it is reasonable to consider the trade-off between the robustness to the model uncertainty, disturbances and the sensitivity to the faults to get a satisfactory performance of a FDI system Chen and Patton (1999); Ding (2008). It is also critical to be able to detect the possible faults as early as possible so that some solutions could be taken to prevent significant performance degradation or significant damages. Therefore, the objective of the fast fault detection should be considered in the FDI design.

Currently, mixed-norm FDI problems has received much attention, and a great deal of methods are proposed. Among them, the worst case, minimum influence of faults on residual and maximum effects from the disturbances, is investigated in many literature Ding (2008); Casavola et al. (2008); Hou and Patton (1996); Wang et al. (2007b); Bouattour et al. (2011); Liu et al. (2005); Rambeaux et al. (1999); Yang et al. (2013); Ding et al. (2000); Chen et al. (1996); Chen and Patton (1999); Wang et al. (2007a). Typically, for the worst-case of the influence of faults on residual, the smallest singular value (H_-) is considered as a suitable sensitivity measurement. And the biggest singular value (H_∞) is always considered as a suitable performance index to evaluate the maximum robustness of the FDI system. The mixed criterion H_-/H_∞ is typically designed for unknown faults and unknown disturbances case. Ding (2008); Casavola et al. (2008); Hou and Patton (1996); Wang et al. (2007b); Bouattour et al. (2011); Liu et al. (2005); Rambeaux et al. (1999); Yang et al. (2013); Ding et al. (2000); Chen et al. (1996); Chen and Patton (1999) propose to use the technique LMI (linear matrix inequality) and ILMI (iterative LMI) to solve this mixed-norm H_-/H_∞ optimization problem. In Wang et al. (2007a), pole assignment approach is utilized to transform the fault detection problem into an unconstrained optimization problem, which could be solved by a gradient based optimization method. The eigenvalues could be chosen to improve the rapidity of the residual responses. With the aid of nonsmooth optimization method, Yang et al. (2013) design a switched observer for multi model system. Without using Lyapunov variables, whose number grows quadratically when the system state size increases, the nonsmooth optimization method can calculate faster than the ILMI for the worst case design. To realize a faster fault detection, Yang et al. (2013) propose to increase the fast transients of the residual responses from fault by optimizing the eigenvalues of the transfer function from fault to residual.

The traditional method for improving the transients of the responses utilizes suitable frequency domain specifications to realize the corresponding constraints in time domain. This paper considers the transients of the residual in time domain directly, and the designed fault detection observer will not only consider the mixed criterion H_-/H_∞ for general faults and disturbances, but also have fast transients of the residual for some specified faults, such as steps, ramps or other typical fault signal. With selected evaluation function and threshold, the rapidity of the fault detection will only depends on transients of the residual responses. After the analyses of the relationship among the different factors of fault detection in the case when the fault appears and disappears, a procedure to generate an appropriate setting for the envelopes in time domain is proposed. With the aid of the Sdotool in Matlab, the criteria in time and frequency domain could be solved to design a multi-objectives fault detection observer. Numerical simulations are used to illustrate the effectiveness of the results.

The paper is organized as follows. First, Section 2 formulates the problem of multi-objective fault detection observer design in time and frequency domain. Different performance indexes are proposed to evaluate different design objectives, either in time or frequency domain. Then, in Section 3, the proposed multi-objective problem is solved with a vehicle lateral dynamics system by the tool of Sdotool in Matlab. Finally, the conclusion is given in Section 4.

2. PROBLEM FORMULATION

2.1 Residual generation

The linear time invariant (LTI) system with faults and disturbances is described by

$$\Sigma_0 \begin{cases} \dot{x}(t) = Ax(t) + Bu(t) + B_f f(t) + B_d d(t), \\ y(t) = Cx(t) + Du(t) + D_f f(t) + D_d d(t), \end{cases} \tag{1}$$

where $x(t) \in R^n$ is the system state vector, $y(t) \in R^m$ represents the output measurement vector, $f(t) \in R^{n_f}$ denotes the fault vector, which can be the process faults, sensor faults, or actuator faults. $d(t) \in R^{n_d}$ is the unknown input vector, including disturbance, modeling error, process and measurement noise or uninterested fault. $u(t) \in R^{n_u}$ is the control input vector. The matrices A, B, C, D, B_f, D_f, B_d, D_d are constant with appropriate dimensions. Without loss of generality, the following assumptions are used:

- (A, C) is detectable.
- $f(t)$ and $d(t)$ are L_2 norm bounded.

For the generation of the residual, we propose a full-order observer for LTI model in the following from Chen and Patton (1999):

$$\Sigma_1 \begin{cases} \dot{\hat{x}}(t) = A\hat{x}(t) + Bu(t) + L(y(t) - \hat{y}(t)), \\ \hat{y}(t) = C\hat{x}(t) + Du(t), \\ r(t) = Q[y(t) - \hat{y}(t)]. \end{cases} \tag{2}$$

where $\hat{x}(t) \in R^n$ and $\hat{y}(t) \in R^m$ are the system's state and output estimations, $r(t) \in R^{n_r}$ is the corresponding residual vector, $L \in R^{n \times n_r}$ is the observer gain to design, and $Q \in R^{n_r \times m}$ is the residual weighting matrix, which could be static or dynamic as a $Q(s)$.

Connecting the observer $\sum_1$ in (2) with the system $\sum_0$ in (1) together, and considering the state estimation error $e(t) = x(t) - \hat{x}(t)$, we can get the residual error dynamic equations:

$$\Sigma_2 \begin{cases} \dot{e}(t) = (A - LC)e(t) + (B_f - LD_f)f(t) \\ \qquad\quad + (B_d - LD_d)d(t), \\ r(t) = QCe(t) + QD_f f(t) + QD_d d(t). \end{cases} \tag{3}$$

The corresponding residual responses from faults and disturbances are:

$$\begin{aligned} r(s) =& Q\{D_f + C^i(sI - A + LC)^{-1}(B_f - LD_f)\}f(s) \\ &+ Q\{D_d + C^i(sI - A + LC)^{-1}(B_d - LD_d)\}d(s) \\ =& G_{rf}(s, L, Q)f(s) + G_{rd}(s, L, Q)d(s) \end{aligned} \tag{4}$$

Obviously, the dynamics of the residuals rely on the transfer function from faults and disturbances to the residual, so the multi-objective design of fault detection observer (design the observer gain L and the residual weighting matrix Q) contains the following objectives:

i) The residual error dynamics equations (3) with the observer gain L should be stable (design L),
ii) Maximize the effects of faults on the residual (design L and Q),
iii) Minimize the effects of disturbances on the residual (design L and Q),
iv) Faster to detect the fault without false alarm(design L, Q and threshold).

One point we should notice is that the last objective not only depends on the dynamics of the residuals, but also depends on the selection of the evaluation function and threshold. Design the observer (L and Q) and the threshold will give a faster fault detection. This paper just focuses on the problem that if the evaluation and threshold are selected, how to produce a suitable residual to realize the objective of fast fault detection.

2.2 Criteria for evaluation

Considering the robustness to the disturbances or the unknown signals of the residual, the criterion H_∞ is used in this paper,

$$\|H\|_\infty = \sup_{\omega \in \Phi} \bar{\sigma}(G(j\omega)) \tag{5}$$

where $\bar{\sigma}(G(j\omega))$ denotes the maximum singular value of matrix $G(j\omega)$, and Φ is the evaluated frequency range, which could be infinite or finite.

For the problem of fault detection observer design for unkown faults and disturbances, we are more interested in the "worst-case" of the fault detection, so we use H_- index to evaluate the minimum sensitivity of faults to the residual.

Definition 1. The index H_- of a transfer function $G(s)$ is defined by

$$\|G(s)\|_- = \inf_{\omega \in \Phi} \underline{\sigma}(G(j\omega)) \tag{6}$$

where $\underline{\sigma}(G(j\omega))$ denoting the minimum singular value of matrix $G(j\omega)$, and Φ is the evaluated frequency range, which can be either infinite or finite.

For the problem of fault detection, the rapidity to detect fault is an important criterion to design the observer. One factor to affect the time to detect fault is the threshold selection. Nevertheless, the threshold is normally dependent on the disturbances but not the faults. This paper will consider to improve the rapidity of the fault detection by residual generation with selected threshold to detect faults faster. The adaptive residual threshold evaluation is introduced in Frank and Ding (1997), which depends upon the nature of the system uncertainties and varies with the system disturbances. The time windowed root mean square (RMS):

$$J_{RMS} = \|r\|_{rms} := \left(\frac{1}{T} \int_{t}^{t+T} r^T(\tau)\, r(\tau)\, d\tau \right)^{\frac{1}{2}} \tag{7}$$

where T is the finite time window.

In the absence of any faults, the threshold should be bigger than $\|r\|_{rms}$:

$$J_{th} = \sup_{f=0} \|r(t)\|$$

Under fault-free condition, we have the following relationships:

$$\begin{aligned} J_{th} &= \|r(t)\|_{RMS,\ f=0} = \|G_{rd} d(t)\|_{RMS} \\ &\leqslant \|G_{rd}\|_\infty \| d(t)\|_{RMS} \leqslant \|G_{rd}\|_\infty \cdot \max(\|d(t)\|_{RMS}) \end{aligned}$$

To detect the fault, the logic decision unit we consider could be:

$$\begin{cases} J_{RMS} > J_{th} & \text{alarm} \\ J_{RMS} \leq J_{th} & \text{no alarm} \end{cases}$$

In order to improve the fast transients of the residual from faults, Yang et al. (2013) proposed to optimize the eigenvalues of the transfer function from fault to residual. In a low order systems (e.p. secend order system), the constraints of the eigenvalues are appropriate to increase the rapidity of the responses. However, in some cases, especially for a high order systems, optimizing the eigenvalues can not give a good transients of the residual. Normally, a high order transfer function could be separated as some different low order transfer functions:

$$G_{rf}(s) = \sum_{i=1}^{n} g_i(s) = \sum_{i=1}^{n} \frac{a_i(s)}{b_i(s)}$$

where $b_i(s)$ is a first order or second order transfer function, the real part of whose eigenvalues is represented as λ_i ($\lambda_i < 0$ when $G_{rf}(s)$ is stable). We assume that

$$\max_{i=1,\ldots n} (\lambda_{\rm i}) = \lambda_{\rm j}$$

In general, the eigenvalues, which has the maximum real part, will determine the major transients of the residual. However, if the weights in a_j is much smaller than the weights in $a_i (i \neq j)$, the dynamics of the responses will not mainly depend on the part of $g_j(s)$. In other words, the λ_j can not be used to evaluate the transients of the residual response of the fault exactly. In this case, to develop the transients of the responses, we not only should consider

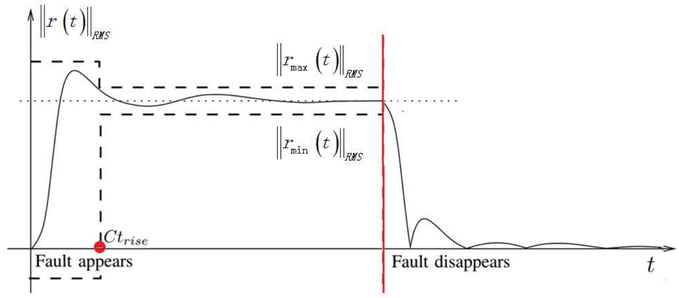

Fig. 1. Shape-constraints of the fault $f(t)$ response on the evaluated residual ($\|r\|_{RMS}$)

the effects of the eigenvalues, but also should consider the the weights of the different eigenvalues. In this case, the criterion of eigenvalue is too complicated to do the design.

Fortunately, with some formulations, we could consider the dynamics of the response in time domain directly. In traditional frequency design method for time invariant systems, the criteria in time domain such as overshoot, rise or settling time can not be addressed directly. Alternatively, an idea of direct approach to handle the time-domain constraints applies the residual $r(t)$ to specified fault (fixed reference inputs) such as impulses, steps or other inputs, and then the observer should be designed to let the residual $r(t)$ follow up the given behavior. With this design method, the given behavior could be used to design for different faults. In this paper, we will focus on the case that the fault $f(t)$ is a step signal.

The time responses of the residual $r(t)$ from a fault $f(t)$ signal with the observer gain L and residual weighting matrix Q satisfies the envelope constraints

$$\begin{gathered} r_{i,\ min}(t) \leqslant r_i(l,\ q,\ t) \leqslant r_{i,\ max}(t), \\ \forall t \geqslant 0,\ i \in I := \{1, \ldots, n_r\} \end{gathered} \tag{8}$$

As shown in Fig. 1, normally, the low envelope $r_{i,\ min}(t)$ in (8) is a constraint to produce a suitable residual for fast fault detection. Therefore, the residual should react as fast as possible when fault appears. It means that the constraint of the rise time Ct_{rise} should be as small as possible, which may be result in a large overshoot. The constraint of the upper envelop $r_{i,\ max}(t)$ will restrict the large overshoot, thus it will affect the effects of minimizing the Ct_{rise}.

To evaluate the effects of fast fault detection, the time (t_{detect}) when the observer begins to detect fault could be defined as

$$\{t_{detect}\, | \|r(t_{detect})\|_{rms} \geqslant J_{th}, \|r(t_{detect} - \xi)\|_{rms} < J_{th}\}$$

where ξ is a tiny positive value.

However, as shown in Fig. 1, a phenomenon appears when the fault disappears. After the fault disappears, the residual is still nonzero if the transients of the residual is not good. In this case, the fault detection observer will give alarms even when there is no fault. To eliminate this kind of false alarms, we propose to add the constraint of the upper envelop $r_{i,\ max}(t)$ into the time domain constraints

(8). The details how to design this constraint will be introduced in the next part.

When the fault disappears, it is also important for the observer to detect that there is no fault. In this way, we define the time $t_{disappear}$ of the observer detect that the fault disappears:

$$\{t_{disappear} \mid \; \|r(t_{disappear})\|_{rms} \leqslant J_{th}, \quad \|r(t_{disappear} - \xi)\|_{rms} >_{th} \}$$

In other words, to improve the rapidity of the fault detection without false alarm when fault disappears, we should focus on the time t_{detect} and $t_{disappear}$ together. Therefore, in the following discussion, minimizing t_{detect} and $t_{disappear}$ becomes an important criterion to design the observer. In fact, considering to a step fault signal, the dynamics of the residual from the fault when fault appears and disappears (without disturbances) are upside down, which means that the trends of t_{detect} and $t_{disappear}$ are same when the dynamics of the residual changes. Therefore, these two criteria could be considered as one criterion.

2.3 Transformation for calculation

Applying the criteria H_∞ and H_- into the residual model (4), the problem of fault detection observer design can be formulated as follows:

i) $A - LC$ is asymptotically stable;

ii) $\max\limits_{L,Q} \| G_{rf} \|_- = \max\limits_{L,Q} \inf\limits_{\omega\in[\omega_1,\omega_2]} \underline{\sigma}(G_{rf})$,

$$= \max_{L,Q} \inf_{\omega\in[\omega_1,\omega_2]} \underline{\sigma}(QD_f + QC(sI - A + LC)^{-1} \times (B_f - LD_f)),$$

iii) $\min\limits_{L,Q} \| G_{rd} \|_\infty = \min\limits_{L,Q} \sup\limits_{\omega\in[\omega_1,\omega_2]} \bar{\sigma}(G_{rd})$

$$= \min_{L,Q} \sup_{\omega\in[\omega_1,\omega_2]} \bar{\sigma}(QD_d + QC(sI - A + LC)^{-1} \times (B_d - LD_d)),$$

iv)

$$\underset{\gamma,l,q}{\text{minimize}} \;\; \gamma$$

$$\text{subject to} \begin{cases} r_i(l,\; q,\; t) - r_{i,\;max}(t) - \gamma \leqslant 0 \\ r_{i,\;min}(t) - r_i(l,\; q,\; t) - \gamma \leqslant 0 \end{cases}, \quad (9)$$

Remark 2. To transform the above multi-objective optimization problem to be an easily solved formulation, the traditional frequency design method always combines the $\max\limits_{L,Q} \| G_{rf} \|_-$ and $\min\limits_{L,Q} \| G_{rd} \|_\infty$ together to be

$$\min_{L,Q} \frac{\| G_{rd} \|_\infty}{\| G_{rf} \|_-} \quad (10)$$

2.4 Quantitative analysis for the criteria

One critical problem is how to set the the upper and lower envelopes ($r_{i,\;max}(t)$ and $r_{i,\;min}(t)$) to produce a satisfied residual to detect fault. From a practical point of view, the residual should be designed to detect the fault faster and without any false alarms when fault disappears. Therefore, under these objectives, it is straight-forward to propose the specifications like rise time, peak time, settling time, overshoot, damping, threshold. In this paper, we consider to design the residual for any deterministic fault of practical interest such as ramps, step, sinusoid, etc with selected threshold. The relationship among the different criteria and different objectives are shown in Fig. 2.

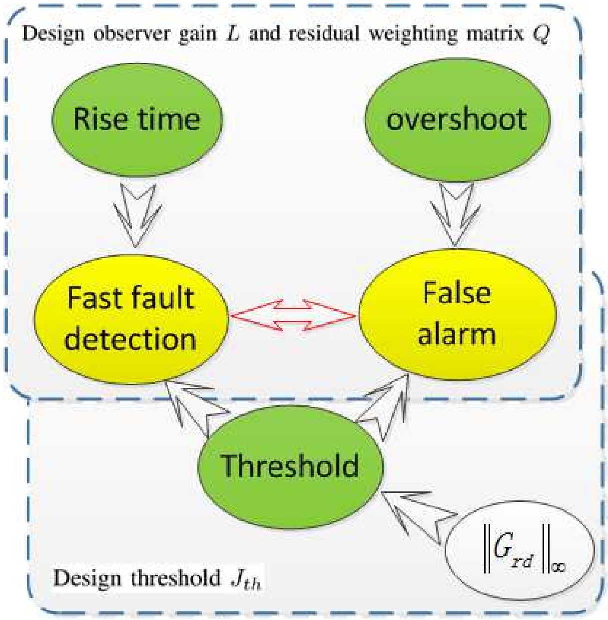

Fig. 2. Relationships among different criteria

Remark 3. The relationship between the fast fault detection and short rise time. It is reasonable to design the observer to make the residual react fast when the fault appears or disappears. In the field of fault detection, a smaller fault detection time t_{detect} is more interesting for the design. Only with the constraints of small rise time, there could be an oscillation in the residual, which will cause a series of peaks and troughs in the residual. The fault will be detected when the evaluated residual $\|r(t)\|$ is bigger than the threshold J_{th}. However, the first trough may be smaller than the threshold J_{th}, and the time interval between the first jump and first tough is two small for the observer to react for the alarm. Thus, besides the minimization of the rise time, there should be a constraint to bring down the oscillation of the residual.

Remark 4. The effects of the high overshoot on the rate of false alarm when fault disappears. A small rise time may cause a high overshoot. A disadvantage of the high overshoot will reveal when the fault disappears, which will result in false alarm. As shown in Fig. 1, a higher overshoot means that there will be a more violent oscillation after the fault disappears. If peak of the oscillating evaluated residual (after fault disappears) is bigger than the threshold, there will be a fault alarm even the fault disappears. Therefore, in the ideal case, to eliminate this kind of false alarms, there should be no overshoot for the residual response in time domain. One point we should notice is that it will be allowed to design the residual with some overshoots with a higher threshold. The selection of threshold gives other freedoms to optimize the transients of the residual, which will be discussed in anther paper.

Remark 5. The effects of the finite time window T in (7). A big finite time window will not increase the fault detection time t_{detect}, but will delay the time $t_{disappear}$.

It will also decrease the effects of the fast transients of the residual. To illustrate the effects of the design with constraints in time domain, the finite time window T will be small in the design.

2.5 Two types of cases

$D_f = 0$ In the case of $D_f = 0$ in (1), the fault should be an actuator fault. And the corresponding transfer function from the fault to the residual G_{rf} will be strictly proper. Considering that if the fault is kind of step signal, the corresponding responses of the fault $f(t)$ on the residual $r(t)$ at $t = 0$ will be zero. In this case, when we design the envelope for the residual in time domain (8), just following the analysis in the previous part is enough to get a suitable response of the residual in time domain.

$D_f \neq 0$ Different from the case of $D_f = 0$, when $D_f \neq 0$ in (1), the transfer function G_{rf} is biproper, which will result in a nonzero initial responses in $r(t)$ from the fault $f(t)$. And the corresponding value is dependent on the parameters D_f of the system. Without suitable design, the nonzero initial value in the response will cause a trend downward in a short time interval. This kind of phenomenon will delay the time to detect the fault (increasing t_{detect}) and cause false alarm when fault disappears. In order to utilize the nonzero initial value of the response, a constraint of the minimum value for the residual after the residual begins to decrease. In some cases, with this kind of design, we even can realize a zero time fault detection without false alarms when the fault disappears.

3. NUMERICAL EXAMPLE

To compare the proposed method with the traditional frequency method, there are two types of criteria to optimize:

- The H_-/H_∞ frequency design method:

$$\begin{aligned} \underset{L,Q}{\text{minimize}} \quad & \frac{\|G_{rd}\|_\infty}{\|G_{rf}\|_-} \\ \text{subject to} \quad & \text{system is stable} \end{aligned} \tag{11}$$

This frequency design method focuses on the unknown faults and disturbances.

- The time and frequency domain design:

The complex criteria just consider the time domain constraints for the specified faults, H_- for general faults and H_∞ for the disturbances. As introduced in the previous part, the criteria in time domain and frequency domain should be consider are:

$$\begin{aligned} \underset{L,Q}{\text{minimize}} \quad & \frac{\|G_{rd}\|_\infty}{\|G_{rf}\|_-} \\ \text{subject to} \quad & r_{i,\ min}(t) \leqslant r_i(L,\ Q,\ t) \leqslant r_{i,\ max}(t) \\ & \qquad \text{for all } \underline{t} \leqslant t \leqslant \bar{t} \\ & \text{system is stable} \end{aligned} \tag{12}$$

A solver named Sdotool in Matlab could be used to tune the observer (observer gain L and residual weighting matrix Q) to satisfy time and frequency domain design requirements. Here, we use the custom objective module to minimize $\|G_{rd}\|_\infty / \|G_{rf}\|_-$ and use the module of step response envelope to satisfy the criterion in time domain.

3.1 Fault detection observer design for comparison

To illustrate the effectiveness of the introduced method to design an observer in time and frequency domain, here is an example from Ding (2008). The simulation is implemented using Matlab Sdotool Toolbox and Simulink. The benchmark is about a simplified vehicle lateral dynamic system.

$$\begin{bmatrix} \dot{\beta} \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} \dfrac{Y_1}{mv} & \dfrac{Y_2}{mv^2} \\ \dfrac{Y_3}{I_z} & \dfrac{Y_4}{I_z v} \end{bmatrix} \begin{bmatrix} \beta \\ \dot{\psi} \end{bmatrix} + \begin{bmatrix} \dfrac{C_{\alpha V}}{mv} \\ \dfrac{l_V C_{\alpha V}}{I_z} \end{bmatrix} \delta - \begin{bmatrix} \dfrac{g}{v} \\ 0 \end{bmatrix} d$$

$$a_y = \begin{bmatrix} \dfrac{Y_1}{m} & \dfrac{Y_4}{mv} \end{bmatrix} \begin{bmatrix} \beta \\ \dot{\psi} \end{bmatrix} + \frac{C_{\alpha V}}{m} * \delta - g * d$$

with $Y_1 = -(C_{\alpha V} + C_{\alpha H})$, $Y_2 = l_H C_{\alpha H} - l_V C_{\alpha V} - mv^2$, $Y_3 = l_H C_{\alpha H} - l_V C_{\alpha V}$ and $Y_4 = -(l_V^2 C_{\alpha V} + l_H^2 C_{\alpha H})$, where β is the sideslip angle, ψ denotes the yaw rate, a_y is the lateral acceleration, δ is the relative steering wheel angle, d means the disturbance (road bank angle), and v represents the speed of the vehicle. In following simulation, an additive fault f_A in steering angle measurement (in the control input δ) will be considered.

The reference velocity is $v = 7m/s$. In this example, because there is only one output $m = 1$, the dimension of the residual is also 1. The residual weighting matrix Q is a scalar. In the simulation, the fault signal is simulated as a pulse of unit amplitude that occurs from 2 to 6 seconds and is zero elsewhere. The disturbances considered in the example is a triangle wave with period $T = 1$ from 0 to 2.

With the H_-/H_∞ frequency design method (11) , we can get

$$L_1 = [0.1381, 0.0.1003]^T; \|G_{rd}\|_\infty / \|G_{rf}\|_- = 0.1392$$

Because of one dimension of the residual, there is no effect of the residual weighting matrix Q on the criteria H_-/H_∞. In order to do the comparison with time and frequency domain design method, the value of Q_1 is set as 0.0052 to make the steady value of the response in the residual of the fault signal to be 1.

As shown in Fig. 3, because of the big initial value of the response from fault, the designed observer L_1 and Q_1 can detect fault as soon as the fault arise ($t_{detect} = 0$). However, when the fault disappears at $6th$ second, the evaluated residual from $6th$ second to $7.05th$ second is still bigger than the threshold J_{th}, which means that there are false alarms when the fault disappears.

In order to improve the transients of the residual for specified fault (step signal), the second observer will consider the effects of short rise time, overshoot and simultaneously minimize the complex criterion $\|G_{rd}\|_\infty / \|G_{rf}\|_-$ as (12):

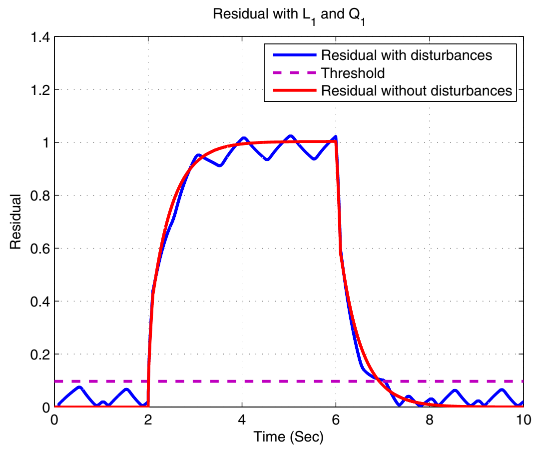

Fig. 3. Simulation with H_-/H_∞ design

$$L_2 = [0.1407, 0.8534]^T,$$
$$Q_2 = 0.014,$$
$$\|G_{rd}\|_\infty \,/\, \|G_{rf}\|_- = 0.1392$$

where the residual weighting matrix Q_2 is designed to make the steady value of the residual response from fault be 1. With the same value of criterion $\|G_{rd}\|_\infty \,/\, \|G_{rf}\|_-$ for the general case, we can find that the constraint of fast transients for typical fault does not decrease the ability of fault detection in the worst case.

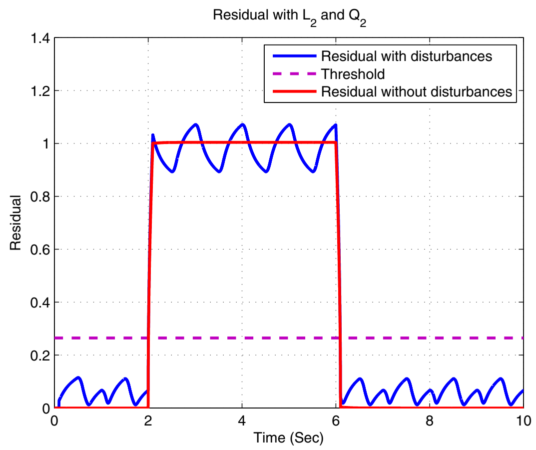

Fig. 4. Simulation with fast reaction design

The effects of the design are showed in the Fig. 4. The dynamics of the residual with L_1 and Q_1 are much better than the residual with L_1 and Q_1. Comparing the evaluated residual with the selected threshold, the residual with L_2 and Q_2 can detect the fault as soon as the fault appears, and the corresponding $t_{disappear}$ is nearly zero.

4. CONCLUSIONS

In this paper, we deal with a multi-objective observer design problem for fault detection in time and frequency domain. The relationships among different criteria are analyzed for two cases when the fault appears and disappears. With selected residual evaluation function and threshold, the context proposes how to format an envelope in time domain to improve the fast transients of the residual for some specified faults. The observer is designed with multi objectives of fast transients of the residual for specified faults and the traditional criterion H_-/H_∞ for general faults and disturbances. The effectiveness of the proposed method is compared with H_-/H_∞ frequency design method by the numerical simulation with a vehicle lateral dynamics system.

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