TEST STRATEGIES FOR COMMUNICATION CHANNELS OF AIR TRAFFIC CONTROL SYSTEMS

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Abstract

Communication is one of the most important domains of air traffic control system from flight safety point of view. The most fundamental and difficult problem is providing reliability and fault tolerance of such systems.

Paper investigates reliability of repairable voice communication channels (air/ground and ground/ground) of air traffic control systems with periodical sessions of communications.

Three different test strategies is described:

1. Communication channel does not have built-in-test equipment.
2. Communication channel has built-in-test equipment with diagnosis procedures during communication sessions.
3. Communication channel has periodical test in the pauses between communication sessions.

Marcovian models are studded and communication channel availability is examined for each of above mentioned test strategies.

Some numerical examples of real communication systems are presented.

Key words: test, communication channel, air traffic control

1. Introduction

Communication is one of the most important domains of air traffic control system (ATC) from flight safety point of view. The most fundamental and difficult problem is providing reliability and fault tolerance of such systems.

Today the redundancy is the main method of reliability improvement of ATC communication channels (CC). The reliability of the redundant systems in the present time is quite well investigated, however, concerning the controller channels this task has a specific aspects, which are caused by the used method of the CC failure fixation and test strategy of the technical condition of ground-based communication radio aids.

This paper investigates reliability of repairable voice communication channels (air/ground and ground/ground) of air traffic control systems with periodical sessions of communications for different test strategies.

2. Notation

ATC	Air Traffic Control
CC	Communication Channel

MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
λ	Failure Rate
μ	Repair Rate
A	Availability
h_i	Probability of being in state H_i
T_k	Periodicity of test operations with parameter of Poisson flow $\omega=1/T_k$
t_k	Time of test operations
τ	Parameter of exponential distribution of t_k
t_{f1}	Time of failure fixation by human operator
$\nu_1=1/t_{f1}$	Parameter of exponential distribution of t_{f1}
t_{f2}	Time of failure fixation by automatic test system
$\nu_2=1/t_{f2}$	Parameter of exponential distribution of t_{f2}
T_c	Periodicity of communication demands with parameter of Poisson flow $\varphi=1/T_c$
t_c	Time of communication session
$\psi=1/t_c$	Parameter of exponential distribution of t_c
t_n	Mean time of test interruption in the case of communication session begins
$\nu_3=1/t_n$	Parameter of exponential distribution of t_n
t_R	Time of repeat demand on communication in the channel with failure
η	Parameter of exponential distribution of t_R

3. Reliability of communication channel with different test strategies

3.1. Strategy 1. Communication channel does not have built-in-test equipment

In the case when the test equipment is absence the CC failure is detected by controller during the process of operation.

In this case the process of the CC failure detection is possible to clarify by the time diagram (Fig.1). Communication channel with completely good set of the equipment starts functioning in the moment of time t_0. After some operation time T_0 in the moment of time t_1 the failure of the main set of the on-ground communication radio aids happens. However, due to the absence of the automatic test system the fixation of the failure does not happen. After some time T_c in the moment t_2 controller obtains the requirement on communication, for example, in the form of any request from the aircraft. Controller does not know about the malfunction of the operation of the communication channel. He transmits the answer on the request to the aircraft. In this case the crew does not receive the answer and after some time T_R makes the repetitive request. The delivery of the repetitive request in moment t_3 is the information about the malfunction of CC for the controller. In such case controller goes over to the operation with the reserve on-ground communication equipment in this way fixing the failure of the main set of the equipment. The similar process repeats in case the refuse of the reserve radio station too.

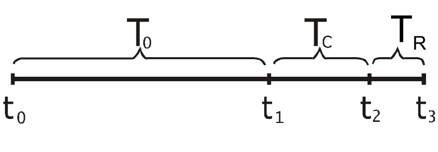

Figure 1. Time diagram of failure detection

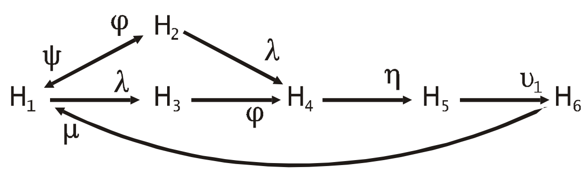

Figure 2. State transition diagram for test strategy 1.

The behavior of the examined system is described by the state transition diagram (Fig.2), where: H_1 – completely good state of the CC equipment; H_2 – communication session in CC; H_3 – failure of the main CC system; H_4 – communication session in the CC with failure of the main on-ground communication radio aid; H_5 – repeat demand on communication in CC with failure of equipment; H_6 – detection of the failure state of the main on-ground communication radio aid, switch over to the reserve one.

Solving the Kolmogorov equation system describing the operation of the examined channel it is possible to define A_1 availability of the controller channel with the first test strategy

$$A_1=(1+a_1)/(1+a_1+a_2), \quad (1)$$

where: $a_1=\lambda[\gamma_1(1+\beta)+1/\varphi]$, $a_2=\beta$

$\gamma_1=1/\mu+1/\eta+1/\nu_1$, $\beta=\varphi/(\lambda+\psi)$

Comparing the equation (1) with the equation for the A_0 availability of the ideal system (immediate failure detection, immediate switchover, non-failure switch) [Barloy, 1965], it is possible to get certain that $A_1=A_0$ with non-limited increase of the intensity of communication φ and the reduction of the failure detection time ($\nu_1\to\infty$).

It is possible to evaluate the deterioration of the reliability in the real ATC communication channel in comparison with the ideal one with the help of reliability deterioration coefficient $V_1=(1-A_1)/(1-A_0)$. The function of influence of average time between communication session T_c and average switch time t_{f1} for ATC communication channel are submitted on Fig. 3 (line 1- for t_{f1}= 2 minute and line 2- for t_{f1}= 10 seconds).

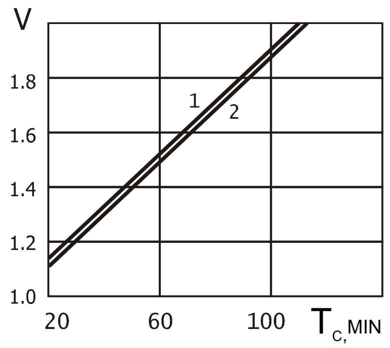

Figure 3. Deterioration of the reliability in the real ATC communication channel with test strategy 1

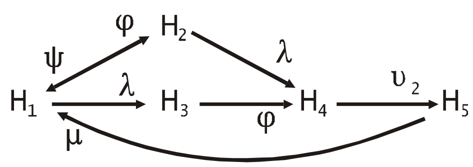

Figure 4. State transition diagram for test strategy 2

3.2. Strategy 2. Communication channel has built-in-test equipment with diagnosis procedures during communication sessions

At present many of the ground-based airport radio centers have built-in test equipment, which carry out test in the period of the communication sessions. The behavior of the examined system with the mentioned test strategy is possible to describe by the graph of states submitted on Fig 4, where the entered earlier symbols of states are saved. The availability A_2 of the controller channel with the second test strategy may be defined by solution of the Kolmogorov equation system, which is describing the mentioned graph:

$$A_2=(1+a_1)/(1+a_1+a_2),$$

$$a_1=\lambda[\gamma_2(1+\beta)+1/\varphi], \quad a_2=\beta, \quad \beta=\varphi/(\lambda+\psi), \quad \gamma_2=1/\mu+1/\nu_2.$$

The analysis of the reliability deterioration coefficient $V_2=(1-A_2)/(1-A_0)$ shows the dependency similar to the one submitted on Fig. 3.

3.3. Strategy 3. Communication channel has a periodical test in the pauses between communication sessions

In this case process of CC operation could be described by the following states: H_1 – good condition of CC equipment, absence of the communication session and test operations; H_2 – test in the channel without communication session; H_3 – communication session; H_4 – demand on communication in the test period; H_5 – failure of CC equipment in the pause of communication; H_6 – test of system with failure; H_7 – demand on communication in the channel with failure of equipment; H_8 – failure fact fixation by automatic test system or by human operator. On Fig. 5 there is a state transition diagram of the examined system.

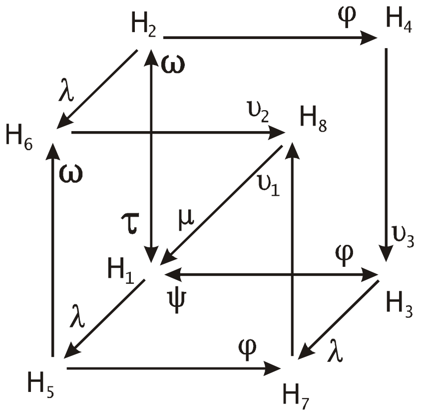

Figure 5. State transition diagram for test strategy 3.

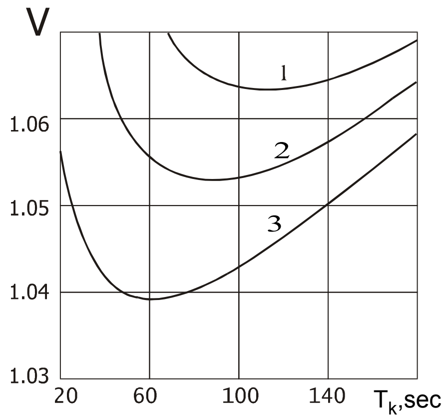

Figure 6. Function $V(T_k)$ for T_0=3000 h (1), T_0=2000 h (2), T_0=1000 h (3)

The availability A_3 of the examined CC is defined by equation:

$$A_3=\sum_{i=1}^{3} h_i$$

Forming and solving the Kolmogorov equation system describing the graph of the states it is possible to define probabilities h_i, i=1,…8, and the availability A_3:

$$A_3=(1+a_2)/(1+a_1+a_2),$$

where

$$a_1 = \omega/(\lambda+\varphi+\tau)[\lambda(1/\mu+1/\nu_2)+\varphi/\nu_3+\lambda\varphi/(\lambda+\psi)(1/\mu+1/\nu_1)]+\lambda/(\omega+\varphi)[1+\omega(1/\mu+1/\nu_2)+ \varphi(1/\mu+1/\nu_1)+\varphi/(\lambda+\psi)(1+ \lambda/\nu_1),$$

$$a_2=(\lambda+\varphi)^{-1}[\omega(\lambda+\varphi+\psi)/(\lambda+\varphi+\tau)+\varphi)$$

The reliability deterioration of the real CC may be evaluated by the coefficient $V_3=(1-A_3)/(1-A_0)$. The analysis of the $V_3(\omega)$ shows that it is a unimodal function with the extremes in ω_{opt} point.

The expression for the definition of $T_{k\ opt} =1/\omega_{opt}$ is possible to find out from the condition $dA_3/d\omega=0$. In general case the expression for the definition $T_{k\ opt}$ has quite a cumbersome look, but, for the practical crucial case of the highly reliable systems ($\lambda<<\mu$) with the short time of the failure fixation ($\mu<<\nu_1$, $\mu<<\nu_2$) the following approximate expression is justified for the definition of the optimal test periodicity:

$$T_{k\ opt}^{-1}=\nu_3\varphi^{-1}\{\lambda+[(\lambda-\varphi^2/\nu_3)^2+\lambda\varphi\tau/\nu_3]^{1/2}\}-\varphi$$

Example. Let's examine the CC availability of the ATC system in the airport area. The channel radio stations are operating in the day night operation regime. The sessions of communication are carried out in the random moments of time. The failures of the radio stations could be fixed by the objective technical test aids executing the periodical test, or subjectively according to the controller's evaluation. On Fig.6 there are $V(T_k)$ dependencies for various MTBF T_0 and typical average meanings of the characteristics of the ATC communication channel.

On Fig. 7-8 there are functions $T_{k\ opt}(T_0)$ for the various T_c periodicity of communication session and time of test interruption t_n .

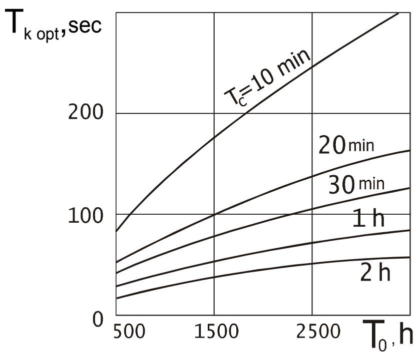

Figure 7. Functions $T_{k\ opt}\,(T_0,T_c)$

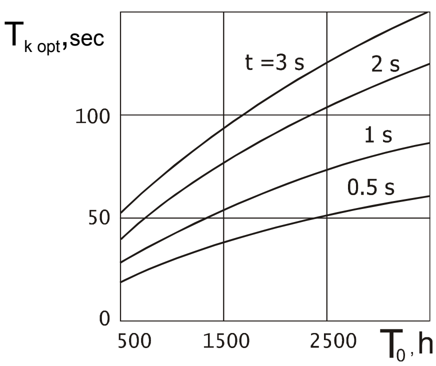

Figure 8. Functions $T_{k\ opt}\,(T_0,\ t_n)$

4. Conclusion

1. In the ATC communication channel availability for the third test strategy is more than decimal better as compared with the first and second ones.

2. The availability of the in case of the third test strategy is unimodal function of test period.

3. The optimal test period in the third test strategy increases with the increase of MTBF, the duration of test and time of its interruption. It is reduced with the increase of the intensity of communication and staying practically invariant to the MTTR, duration of the communication session and failure fixation time.

References

[1] B.E.Barloy, F.Proshan, L.C.Hunter (1965). Mathematical Theory of Reliability, John Wiley & Sons.