Measurement Method and System for Navigation Signal and Online Diagnosis Method and System for Navigation Equipment

Yujun Bai[1, a], Ping Yang[2, b, *], Jing Liu[2, c], Jiaquan Ye[2, d], Zhengbo Yang[2, e] and Fei Liang[2, f]
[1]*East China Regional Air Traffic Management Bureau CAAC, Shanghai, 200335, China*
[2]*The Second Research Institute of CAAC, Chengdu 610041, China*

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Abstract: Due to the influence of the surrounding environment of airport's navigation equipment, the existing measurement technology cannot carry out fault diagnosis of navigation equipment according to the results of the measurement system of the navigation equipment, and the staff can only carry out artificial fault diagnosis according to their experience. However, the artificial diagnosis results may be inaccurate. This paper proposes a navigation signal measurement method and system, in order to eliminate or reduce the environmental factors interference to the measurement, so that the navigation equipment test system can measures the navigation signal more accurately, and obtains more accurate measurement results. Based on the measurement results, this paper also proposes an online diagnosis method and system for navigation equipment, which can realize the online diagnosis of navigation equipment and has a high accuracy.

1 INTRODUCTION

Civil aviation navigation equipment is very important to ensuring aviation flight safety, measuring the equipment is now highly regarded at home and abroad. International Civil Aviation Organization (ICAO), International Radio Consultative Committee (CCIR) and the International Special Committee on Radio Interference (CISPR) and other international organizations have developed and issued related documents of navigation equipment, that include inspection and maintenance methods of navigation equipment. The Civil Aviation Administration of China (CAAC) also has developed relevant measure procedures, requirements and flight inspection criterion of aviation equipment (S. Bo and W. Yong, 2011; E. Ma, J. Li, B. Liu and P. Wang, 2010).

When the airport navigation system works, the working condition and navigation accuracy of the navigation equipment are closely related to the fault of the navigation equipment itself and the surrounding environment, such as buildings, navigation equipment sites, radio interference and other factors. Navigation equipment uses space signals to guide aircraft, the characteristics of space signals are not only related to the navigation equipment itself, but also affected by the environment around the station (J. Chen, S. Zheng and J. Liu, 2011). When an object is located in the protected area of the site, it will reflect the signal of the navigation equipment and change the signal radiation environment. Under the influence of environmental factors around navigation equipment, navigation test equipment will produce measurement errors, leading to uncertainty measurement results.

During the measurement of navigation test equipment, due to the influence of personnel operation and surrounding environment, errors may be inconsistent during on-site calibration, so the errors caused by various factors need to be analysed (G. Li, H. Wei and S. Sun, 2011; B. Wang, P. Yang, J. Liu, et al, 2017). At present, the test equipment at home and abroad is regularly calibrated, and the possible errors are corrected by embedding self-test modules in the test equipment, but the influence caused by non-equipment factors in the test site is not considered.

For the measurement results of navigation test equipment, the future development trend is: fully considering the impact of the test site environment on the measurement results, correct the measurement

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results and comprehensive judge the fault of navigation equipment based on the corrected measurement results, and give relevant suggestions. At present, only foreign R&S companies have started to introduce fault diagnosis system, which can preliminarily analyse the fault reasons of navigation equipment, and mainly judge based on domestic experience.

2 A MEASUREMENT METHOD AND SYSTEM FOR NAVIGATION SIGNAL, AND AN ONLINE DIAGNOSIS METHOD AND SYSTEM FOR NAVIGATION EQUIPMENT

In order to solve the existing technical problems, when analysing the measurement results, it is necessary to fully consider the impact of factors of the navigation equipment itself, environmental factors and personnel operation on the measurement results, so that the measurement results can truly reflect the state of the navigation equipment during testing. The measurement uncertainty of navigation online test system needs to consider various factors such as the signal radiation of navigation equipment and the reflection of measurement equipment on the signal, and it needs to combine various methods such as electromagnetic signal simulation and experimental verification to obtain more accurate uncertainty factors.

In view of the defects in the existing technology, this paper proposes a navigation signal measurement method and system, in order to eliminate or reduce the interference of environmental factors on the measurement, so that the navigation equipment test system can be more accurate to measurement the navigation equipment signal, obtain more accurate measurement results. At the same time, this paper also proposes an online diagnosis method and system for navigation equipment. Based on the accurate measurement results obtained by the above navigation signal measurement method and system, the online diagnosis of navigation equipment can be realized with high accuracy.

Taking the Localizer beacon (belongs to the Instrument Landing System, ILS) as an example, the Localizer signal is composed of 90Hz, 150Hz and 1020Hz modulated signals. When analysing the measurement results of the Localizer signal, it is necessary to analyse the frequency, amplitude and phase of 90Hz, 150Hz and 1020Hz signals, and the Morse code decoded by the 1020Hz signal.

2.1 A Method for Measuring Navigation Signals

When spectrum analysing the navigation signals, there are errors usually in the frequency, amplitude and phase, the all-phase FFT (Fast Fourier Transformation) spectrum analysis can eliminate or greatly reduce these errors, so as to improve the analysis accuracy. FFT panoramic spectrum can be acquired by performing FFT of different lengths or two successive segments on the navigation signals transmitted by the navigation equipment, so as to get accurate phase by correction. All-phase FFT spectrum analysis mainly includes two parts: all-phase data pre-processing and FFT (M. Nowaczyk, G. Sek, J. Misiewicz, et al, 2000).

When the number of FFT calculation points is N, the length of data to be processed should be (2N-1).According to the superposition principle of linear time-invariant system, the superposition of the response values generated by all input sequences should be equal to the response values generated by the superposition of all input sequences and the excitation of the system. Using this property, the data sequences with input system length of (2N-1) are periodic extended, summed and truncated by the all-phase data pre-processing, and all the segments of length N containing input sample point x (n) are considered. For example, when N=3, the flow chart is shown in Fig. 1.

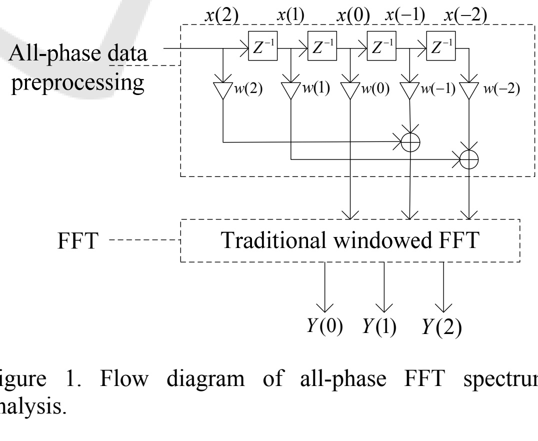

Figure 1. Flow diagram of all-phase FFT spectrum analysis.

This method has phase ergodicity because it considers all the data segmentation cases, thus weakening the amplitude jump of waveform head and tail, and improving the signal performance. The whole process of all-phase FFT can be completed through the data pre-processed with all phase and the traditional windowed FFT calculation, and the phase of 90Hz/150Hz/1020Hz signals can be accurately obtained from the phase spectrum of all-phase FFT.

DFT (Discrete Fourier Transformation) is used to calculate the part to be refined to obtain the frequency spectrum with extremely high precision, and then the frequency and amplitude are corrected, which has the advantages of good adaptability and high precision (G. H. Hostetter, 1980).

First, the integral of the continuous Fourier transform changed into three steps: sum the discretization in time domain and the truncation in time domain of finite length, are transformed into the special Fourier transform form of time discretization and frequency continuity, as follows:

$$X(f)=\sum_{n=0}^{N-1}x(n)\exp\left(-j2\pi n\frac{f}{f_s}\right)$$

$$n=0,1,...N-1 \tag{1}$$

Where, $x(n)=A_0\cos(2\pi f_0^{-1}n/N+\theta_0)$ is a single harmonic signal sequence, whose frequency, amplitude and initial phase is respectively refer to f_0, A_0 and θ_0, $f_0^{-1}=f_0/\Delta f$ is the normalized frequencies according to frequency resolution $\Delta f=f_s/N$. N is the number of FFT points, and N is the sampling frequency.

Then, refine a specified frequency interval $[f_1,f_2]$, set the refinement multiple as D, and the frequency resolution after refinement is

$$\Delta f^{'}=\Delta f/D \tag{2}$$

Thus, it can be known that the refined computational frequency sequence is

$$\left\{f_1,f_1+\Delta f^{'},f_1+2\Delta f^{'},...,f_2\right\} \tag{3}$$

Finally, formula (1) is used to obtain the amplitude spectrum and phase spectrum of the frequency sequence to be calculated. The frequency value corresponding to the maximum point of the searching amplitude in each refined spectral line is the estimated frequency of the harmonic signal. The estimated frequency is searched for frequencies close to 90Hz/150Hz/1020Hz, and the corresponding amplitude is obtained by combining with the phase spectrum of all-phase FFT.

The all-phase FFT spectrum analysis method is used to analyze the spectrum of the navigation signal transmitted by the navigation equipment and obtain the panoramic spectrum. The phases of 90Hz, 150Hz and 1020Hz signals are determined according to the panoramic spectrum. The DFT spectrum analysis method is used to analyze the local part of the panoramic spectrum and refine the spectrum. The amplitudes of 90Hz/150Hz/1020Hz signals were determined according to the refined spectrum. Navigation signals were measured according to the phase and amplitude values of 90Hz/150Hz/1020Hz signals, and the measurement results were obtained.

The measurement results include: 90Hz/150Hz modulation depth, difference between their modulation depth, their DDM (Difference in Depth of Modulation) value, SDM (Sum of the Depths of Modulation) value, and the Morse code decoded from the 1020Hz signal. The all-phase FFT spectrum analysis method is adopted to analyze the spectrum of the navigation signal transmitted by the navigation equipment and obtain the panoramic spectrum, including: the all-phase data preprocessing method is adopted to preprocess the navigation signal transmitted by the navigation equipment. The windowed FFT is applied to the preprocessed data to obtain the panoramic spectrum.

2.2 A System for Measuring Navigation Signals

According to the above navigation signal measurement methods, this paper proposes a navigation signal measurement system, which mainly includes: the all-phase FFT module, which is used to analyse the spectrum of the navigation signal transmitted by the navigation equipment by using the all-phase FFT spectrum analysis method, to obtain the panoramic spectrum. The signal phase determination module is used to determine the phase of 90Hz/150Hz/1020Hz signals according to the panoramic spectrum. The DFT module is used to analyse the local part of the panoramic spectrum by using the DFT spectrum analysis method and obtain the refined spectrum. The signal amplitude determination module is used to determine the amplitude of 90Hz, 150Hz and 1020Hz signals according to the refined spectrum. The signal measurement module is used to measure the navigation signal according to the phase and amplitude values of 90Hz/50Hz/1020Hz signals and obtain the measurement results.

Among them, the all-phase FFT module includes: all- phase pre-processing unit, which is used to pre-processing the navigation signal transmitted by the navigation equipment by using the all-phase data pre-processing method. The windowed FFT unit is used for windowed FFT after pre-processed data, to obtain panoramic spectrum.

2.3 An Online Diagnosis Method for Navigation Equipment

Analysing the impact of changed space of navigation signal on the measurement results, which is caused by the surrounding environment, according to the model of navigation equipment, uses the Method of Moment (MoM) to draw navigation signal direction, combines with the conditions of the navigation equipment's surrounding terrain or obstacles, uses the Physical Optics (PO) method to simulate draw a theoretical course structure, and comparing it with the true course structure that is draw with the measurement result by the proposed navigation equipment online measuring system, if their structure has similar trend, it shows that the changed space navigation signal caused by the environment around the navigation station will affect the measurement results. If their structural trends are not similar, it is considered that the navigation equipment is broken.

When analysing the interference effect of active radiation near the navigation equipment stations on ILS/VOR's space signal measurement, the electromagnetic propagation theory can be combined with navigation equipment models, active radiation near navigation station, to draw a theory of course structure, and then compare it with the true course structure that is draw with the measurement result, if the trend of their structure are similar, it shows that the active radiation near the navigation station will affect the measurement results. If their structural trends are not similar, it is considered that the navigation equipment is broken.

Finally, the equipment status diagnosis can be established to provide reference for the preventive and corrective maintenance of navigation equipment, based on the above results. Combined with the active or passive interference around the navigation equipment station, this paper analyses whether the measured data (e.g. DDM) measured in and around the airport runway is similar to the structural trend of the simulated course structure or not. If not, the fault of the navigation equipment can be determined.

2.4 An Online Diagnosis System for Navigation Equipment

The online diagnosis system of navigation equipment includes: navigation signal measurement module, which is used to measure the navigation signal transmitted by the navigation equipment with the navigation signal measurement method provided in this paper, to eliminate or reduce the interference of environmental factors on the measurement, and obtain the measurement results. The actual navigation structure drawing module is used to draw the actual navigation structure according to the measurement results. The simulation navigation structure drawing module is used to draw the theoretical simulation navigation structure according to the model of the navigation equipment. The navigation structure comparison module is used to judge whether the structure trend of the actual navigation structure and the simulated navigation structure is similar or not. Navigation fault determination module is used to judge the failure of navigation equipment.

3 SPECIFIC IMPLEMENTATION MODE

The navigation signal measurement method provided in this paper includes the following steps:
Step 1: the all-phase FFT spectrum analysis method is adopted to analyse the spectrum of the navigation signal transmitted by the navigation equipment, and obtain the panoramic spectrum.
Step 2: determine the phase of 90Hz/150Hz/ 1020Hz signals according to the panoramic spectrum.
Step 3: the Discrete Fourier Transform spectrum analysis method is adopted to analyse the local spectrum of the panoramic spectrum, and obtain the refined spectrum.
Step 4: determine the amplitude of 90Hz, 150Hz and 1020Hz signals according to the refined spectrum.
Step 5: measure and obtain the navigation signal according to the phase and amplitude values of 90Hz, 150Hz and 1020Hz signals.

The measured results include the modulation value of 90Hz and 150 Hz signal, and their DDM and SDM value, and Morse code.

In this paper, the navigation signal measurement method adopts the combination of all-phase FFT spectrum analysis method and DFT spectrum analysis method for spectrum analysing, eliminates or substantially reduces the interference of environmental factors on navigation signals, and obtains accurate measurement results. Based on the above navigation signal measurement method, this paper proposes an online diagnosis method for navigation equipment, which includes the followings:

Step 1: measuring the navigation signal transmitted by the navigation equipment with the navigation signal measurement method provided in this paper, so as to eliminate or reduce the interference of environmental factors on the measurement, and obtaining the measurement results.

Step 2: drawing the actual navigation structure diagram according to the measurement results.

Step 3: drawing the theoretical simulated navigation structure diagram according to the model of the navigation equipment, including: according to the model of the navigation equipment, drawing the direction diagram of the navigation signal using the moment method. According to the terrain and obstacles around the navigation equipment, and the direction diagram of the navigation signal, drawing the theoretical simulated navigation structure diagram with the physical optical method. According to the model of navigation equipment and the active radiation situation near the navigation station, a theoretical simulated navigation structure diagram is drawn based on the electromagnetic propagation theory.

Step 4: judging whether the structure trend of the actual navigation structure diagram and the simulated navigation structure diagram is similar. Determining the factors that cause interference to the propagation of navigation signals according to the drawing method adopted to draw the simulated navigation structure diagram. If they are not similar, it shows that the navigation device has a fault.

Combining with the active or passive interference around the navigation equipment station, the paper analyses whether the measured data measured in and around the airport runway is similar to the simulated course structure's trend. If not, the fault of the navigation equipment can be determined.

4 CONCLUSIONS

In this paper, a navigation signal measurement method is proposed, which combines the all-phase FFT spectrum analysis method and DFT spectrum analysis method for spectrum analysing, to eliminate or substantially reduce the interference of environmental factors on navigation signals, and then obtain accurate measurement results.

In addition, this paper proposes an online diagnosis method for navigation equipment. Firstly, the navigation signal measurement method is used to measure the navigation signal transmitted by the navigation equipment, to eliminate or reduce the interference of environmental factors on the measurement, and obtain the measurement results. Afterwards, draw the actual navigation structure chart according to the measurement results. Thirdly, draw the theoretical simulation navigation structure diagram, according to the model of the navigation equipment. Finally, determine whether the structure trend of the actual navigation structure chart is similar to that of the simulated navigation structure chart, if they are not close, the navigation device is judged to be faulty.

In this paper, based on the navigation signal measurement method and its accurate measurement results, drawing the actual navigation structure diagram and comparing it with the theoretical navigation structure diagram, the online diagnosis of navigation equipment can be realized according to the comparison results, with high accuracy. Analysing the influence of passive and active interference on navigation equipment, this paper provides more accurate judgment basis for the analysis of measurement results. Through the calibration error, relatively certain measurement results are obtained.

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