Research on Civil Aircraft Flight Test of Power Supply Quality Analysis

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Abstract. In the process of civil aircraft airworthiness, analyzing power quality is the key to verify whether the power supply system meets the requirements of the clause. This paper makes deep research on the domestic and foreign power supply quality standard files and detailed introduces the characteristics of the power supply quality standard files. Then, comparative and analysis give suggestions which tally with power supply quality test requirements. Finally, define the special power supply quality test method for the practical engineering specifically, and power supply quality test characteristic in civil aircraft flight test, to provide guidance help for the future civil aircraft models.

1. Introduction

Because of the installation and use of a large number of electronic equipment, the pulse load and nonlinear load in the electrical equipment have a serious impact on the aircraft power system and the power supply quality, so the [1] of the power supply quality is put forward. At present, the standard documents of aircraft power quality analysis have been issued at home and abroad. However, in the field of civil aircraft power quality test flight, there is no standard to stipulate the correct and unified test requirements, and the parameters of aircraft power quality characteristics are difficult to measure correctly. Besides, the aircraft power quality testing equipment must meet the standard requirements in hardware and data processing software to ensure the correct and unified measurement results.

2. Characteristics of domestic and foreign standard compilation

At present, the mainstream standard documents for aircraft power quality analysis include the MIL-STD-704 series standard issued by the U.S. Naval Aviation Development Center, ISO1540 series standard formed after many discussions between power suppliers and aircraft companies in developed countries with aviation technology, and TOCT 19750B standard from Russia. MIL-STD-704 "Aircraft Power Supply Characteristics and Application" issued in 1959 is the first international standard for aircraft power supply characteristics. And ISO1540 is the lowest technical index in the international power supply characteristic standard, the most kinds of power supply standard, mainly in the balance of technical indicators and economic and applicability and
other aspects. The original reference standard of Russian standard TOCT 19750B is also MIL-STD-704, which refines and relaxes some parameters, making the standard more operable, such as distortion coefficient, current distortion, etc. Based on MIL-STD-704 and ISO1540, the corresponding GJB181A series standards, GJB5558-2006 test standards, and ISO12384-2010 test standards have been issued in China (the test standards are based on the original standard documents to clarify the accuracy of the test equipment and other requirements, as well as the measurement method of power quality characteristics indicators). ISO12384 is the first international aviation standard compiled in China, and it is an important "milestone" in the standardization of our aviation industry [2].

3. Analysis of power quality test requirements

Aircraft power quality analysis and test system consist of two parts: test acquisition hardware equipment and data processing software, which have a great impact on the accuracy of the test system. To satisfy the reliability of power quality data analysis, it is necessary to make specific requirements on allowable error, sampling frequency, and sampling time. In this regard, GJB5558-2006 and ISO12344-2010 test standards have put forward different test requirements [3][4].

3.1. Allowable error requirements for testing

In the GJB5558-2006 and ISO12344-2010 test standards, the error of characteristic parameters is defined as the absolute accuracy of the indicated value of the measured result, which includes both the measurement error of hardware and the calculation error of software. Except for the steady-state DC current parameters, the error requirements of each characteristic parameter in the two test standard documents are basically the same. Steady-state DC current in GJB5558-2006 requires that the absolute error of the measured indicated value be within ±1% of the rated steady-state DC current, while in ISO12344-2010, it mainly takes into account the larger limit range of the steady-state DC, which improves the requirement of the steady-state DC error, which requires that the absolute error of the measured indicated value be within ±0.8% of the rated steady-state DC current. Because the current market equipment can meet the needs of ±0.8%, it is recommended to ISO12384 error requirements as the standard. Specific error requirements of power quality index parameters are shown as follows:

A) Steady-state characteristic data error requirements : (1) the absolute error of the measured values of the steady-state AC and DC voltages should be within the range of ±0.5% of the rated steady-state voltage; (2) The absolute error of the measured value of the DC component of the AC voltage should be within the range of ±10% of the DC component; (3) the absolute error of the measured steady-state AC current should be within the range of ±1% of the rated steady-state AC current; (4) the absolute error of the measured steady-state DC current should be within the range of ±0.8% of the rated steady-state DC current; (5) The absolute error of the measured value of the steady-state frequency should be within ±0.1% of the highest frequency; (6) the absolute error measured within the range of 110°~130° should be within the range of ±0.2°; (7) The absolute error of the measured value of the distortion spectrum amplitude should be within 5% of the envelope limit.

B) Transient characteristic error requirements : (1) The absolute error of the measured values of AC and DC voltages should be within the range of ±1.0% of the maximum limit of the specified transient AC voltage; (2) The absolute error of the measured value of AC and DC current should be within the range of ±2.0% of the maximum limit of the specified transient AC voltage.
3.2. Sampling frequency

The increase of sampling frequency has a great effect on the accuracy of test results. The accuracy of test results can be improved only by the sampling frequency, and the effect is limited. Excessively high sampling frequency will also increase the cost and complexity of the testing equipment, and the further increase of sampling frequency after reaching a certain value will have no significant effect on reducing errors [5]. In both Gib5558-2006 and ISO12344-2010 test standards, the sampling frequency requirements for power quality analysis are put forward based on the constant frequency aircraft of 400Hz. The main difference between the two is the sampling frequency requirement when calculating the distortion spectrum and distortion coefficient of AC and DC. In Gib5558-2006, the sampling frequency of distortion is required to be 1MHz, while in ISO12344-2010, the sampling frequency of distortion is required to be 200kHz. In actual engineering, compared with military aircraft, the power supply system of civil aircraft is mainly harmonic interference, so the requirement for distortion analysis is relatively low. The transverse axis of the distortion spectrum encoder in the corresponding ISO1540 standard is only 33kHz, and the sampling frequency of 200kHz can also satisfy the distortion spectrum analysis. Therefore, it is recommended to refer to the ISO12384-2010 test standard, which requires a lower sampling frequency. Besides, when the aircraft is a frequency conversion power supply system, the appropriate sampling frequency can be selected according to the ratio between the maximum frequency of frequency conversion and 400Hz. The sampling frequency requirements in ISO12384 standard are shown in Table 1 below:

Table 1. Frequency requirements for sampling parameters of 400hz constant frequency aircraft

| Type of power supply | Index parameters                                                                 | sampling frequency |
|----------------------|----------------------------------------------------------------------------------|--------------------|
| communion            | Steady state voltage, voltage unbalance, voltage modulation amplitude, voltage phase difference, voltage peak coefficient, AC voltage dc component, steady state frequency | 72kHz              |
|                      | Transient voltage                                                               | 80kHz              |
|                      | Distortion coefficient, distortion spectrum and harmonic content                  | 200kHz             |
|                      | Steady-state voltage, voltage pulsation                                          | 20kHz              |
|                      | Transient voltage                                                               | 80kHz              |
|                      | Distortion coefficient, distortion spectrum                                      | 200kHz             |
| direct current        | Steady state voltage, voltage unbalance, voltage modulation amplitude, voltage phase difference, voltage peak coefficient, AC voltage dc component, steady state frequency | 72kHz              |
|                      | Transient voltage                                                               | 80kHz              |
|                      | Distortion coefficient, distortion spectrum and harmonic content                  | 200kHz             |
|                      | Steady-state voltage, voltage pulsation                                          | 20kHz              |
|                      | Transient voltage                                                               | 80kHz              |
|                      | Distortion coefficient, distortion spectrum                                      | 200kHz             |

3.3. Sampling time

In the test method, different sampling times should be specified for different test parameters. The selection of sampling time has a great influence on the measurement results [5]. There is no substantial difference between GJB5558-2006 and ISO12344-2010 in the requirement of sampling time for each index parameter. However, considering the uniformity of the overall test requirements and criteria, it is recommended to refer to the ISO12384-2010 test standard. The sampling time requirements are as follows:(1) The sampling time of AC/DC normal transient is
greater than 0.25s. (2) Steady-state AC voltage, voltage modulation amplitude, AC distortion spectrum, DC component, steady-state frequency, power factor sampling time is less than 1s. (3) Steady DC voltage, total harmonic content, wave peak coefficient, and DC voltage pulsation are greater than 1s.

4. Application of power quality test method

4.1. Overview of power quality indicators and criteria
In domestic and foreign mainstream standard documents, the specification of the power quality characteristic index is all different. Power quality index is divided into AC steady state index, DC steady state index, AC transient index, DC transient index, power and power factor and power conversion time. Because the test flight of the power supply system of civil aircraft is to examine the power quality of the aircraft in the normal working mode, and the abnormal state indicators such as under frequency, over frequency, over voltage, and under voltage limit are mainly analyzed and calculated by adjusting the generator drive platform and load box simulation in the ground laboratory.

At present, the main AC steady-state characteristic indexes suitable for the analysis of civil aircraft flight test include steady-state AC voltage, voltage imbalance, voltage modulation amplitude, voltage phase difference, AC voltage distortion coefficient, harmonic content, AC voltage distortion spectrum, voltage wave peak coefficient, AC voltage DC component, steady-state frequency. The steady-state characteristics of DC include steady-state DC voltage, DC voltage distortion coefficient, DC voltage distortion spectrum, and DC voltage pulsation amplitude. The transient characteristics of AC parameters are AC transient voltage. The indicators of DC transient characteristics are DC transient voltage.

In the actual civil aircraft flight test, the data analysis of power quality includes the output end of power generation (main generator, auxiliary generator, emergency generator, variable voltage rectifier) and the input end of the load. The power quality criterion of power output comes from the design document of aircraft power generation equipment, and the power quality criterion of load input comes from ISO1540, MIL-STD-704, and other standard documents.

4.2. Application of complex power quality index test method
In practice, some power quality parameters such as voltage amplitude modulation, voltage phase difference, ac distortion, ac dc voltage distortion, the power conversion time, due to the complexity of test methods, so you need to detailed definition of the concrete calculation method, choose the appropriate test plan, in order to model.

4.2.1. Voltage modulation amplitude
Voltage modulation is caused by the change of prime mover speed, the working characteristics of the voltage regulator, and the working characteristics of the load. To limit potential unintended effects of voltage modulation on the steady-state voltage range, ISO12344-2010 states that "voltage modulation amplitude is the difference between the maximum voltage peak and the minimum voltage occurring in any 1 s during steady-state operation", while "AC peak voltage" is defined as "the maximum AC voltage in a period". Therefore, the test of "voltage modulation amplitude" is to calculate the difference between the maximum value and the minimum value of the phase voltage
peak value in each week during the collection period, and then make a comparison to find the maximum value as the voltage modulation. Also, the value closest to the wave peak was obtained by the parabolic fitting method [6], and then all the forward wave peaks within 1s were connected to form the forward modulated voltage waveform, as shown in Fig. 1. Then Fourier transform was carried out to obtain the modulated voltage spectrum of the forward cycle, as shown in Fig. 2.

\[ \theta = \frac{t_0}{T_0} \times 360^\circ \]

In the formula:
\( \theta \) —— voltage phase difference, unit degree;
\( t_0 \) —— the time interval between the adjacent positive phase zero-crossing points of the two-phase voltage fundamental in seconds;

4.2.2. Voltage phase difference

Voltage phase difference refers to the difference of electrical angle between the adjacent intersection points of any two-phase voltage fundamental wave from negative to the positive direction. Because the fundamental voltage is a pure sine wave and is linear near zero-crossing point, the time interval between the positive phase zero-crossing points of the two-phase voltage fundamental wave can be obtained by the linear fitting method, and then divided by the fundamental voltage period, the phase difference between each forward cycle can be obtained. Finally, the average value of the phase difference between all positive phase waves in the integer voltage cycle time of less than and closest to 1 s is taken, that is, the voltage phase difference. The formula is as follows:

Figure 1. Example of a waveform of a forward modulation voltage

Figure 2. Modulated voltage spectrum example
Tθ —— fundamental phase voltage period in seconds.

4.2.3. AC distortion
According to the definition in ISO12384-2010, the AC distortion coefficient is the ratio of AC distortion to the square root value of the voltage fundamental component. In the test, the AC distortion, that is, the square root value of the AC waveform voltage other than the fundamental wave is first calculated. The formula is as follows:

$$F_d(\%) = 100 \times \frac{\sqrt{U^2 - U_f^2}}{U_f}$$

In the formula:
Fd —— AC voltage distortion coefficient;
U—— AC steady-state voltage in volts;
Uf—— fundamental component square root value, the unit is volt.
The ac distortion spectrum is defined as the ac distortion is represented by the amplitude quantization of each frequency component. The distortion spectrum includes the components generated by amplitude modulation and frequency modulation, as well as the harmonic and anharmonic components generated in the waveform. The measurement of distortion spectrum is to collect the instantaneous value of steady AC distortion waveform according to the specified sampling frequency, and the time corresponding to steady AC voltage is taken. The amplitude of each frequency component is calculated by discrete Fourier transform algorithm (FFT) as AC distortion spectrum [7], as shown in figure 3. In spectrum analysis, a large number of data points participate in discrete Fourier transform operation, which makes the running time of the program longer. Therefore, in data processing, we consider classifying the frequency of the measured signal according to the frequency band, which can reduce the amount of data needed for analysis [1].

![Figure 3. Example of AC distortion spectrum](image)

4.2.4. AC voltage DC component
DC component is an important index to evaluate AC voltage waveform, ±0.1 V, in MIL-STD-704、GJB5558-2006、ISO12384-2010 It's not that big, But it has an important impact on the system. The DC component of AC voltage is the average value of the instantaneous voltage of positive and negative half wave. Since the maximum instantaneous voltage at steady state ±178.18 V(±118×1.51), The AC voltage DC component is smaller, ±0.10 V, only Test equipment with high resolution is required to detect. There are generally two ways to ensure accuracy, First, an A/D
analog converter with higher bits. Improved test resolution, this will increase the complexity and cost of the equipment; The second is to filter out the fundamental wave and then test. The second method of testing is generally recommended, Because the fundamental doesn’t contain DC, Positive and negative semicircular symmetry, Filter the fundamental wave does not affect the test results. while the remaining AC distortion voltage after filtering the fundamental is only 5% of the fundamental (normally), Therefore, the requirement of test resolution can be greatly reduced. The DC component formula is shown in (3):

\[ U_{Adc} = \frac{\sum_{j=1}^{n} u_j}{n} \]  

(3)

In the formula:
U_{Adc}—— AC voltage DC component in volts;
u_j—— the instantaneous value of of the sampling point in volts;
j—— sampling sequence, i=1,2,3,..., n;
The total sampling times of the corresponding time of integer voltage Zhou Bo during the period of n—— less than and closest to 1 s.

4.2.5 Power conversion time
In the normal working state, when the power supply mode is switched, the bus bar voltage will have a short power drop, as shown in Figure 4. The power conversion time shall be the time when the transient voltage changes between zero and the normal operating limit of the low voltage. That is, the time is calculated from the voltage below the normal operating limit until the voltage increases from zero to above the normal operating limit. The transient voltage is defined as the square root of the voltage of half a cycle in GJB55558 and is defined as the square root of the voltage

![Figure 4](image)

Figure 4. Example of waveform interrupt during power conversion

5. Power quality test characteristics in civil aircraft test flight
A) As can be seen from Table 1, the ISO12384 test standard has different sampling rate requirements for different power quality characteristic indicators. However, considering that in actual engineering, the test parameters of the added flight test may be changed in the progress of
the work, so if the test equipment can meet the conditions, the test equipment requirements can be raised in accordance with the highest sampling frequency of AC and DC parameters in the ISO12384 test standard. In this way, when the test parameters of subsequent flight test are changed, the purchased test equipment can still meet the sampling frequency requirements for power quality analysis of test parameters, and it is also more conducive to the analysis of some power quality characteristic index parameters with low sampling frequency requirements.

B) In the subject of compliance of power system test flight, the main assessment is the power quality of the aircraft under the normal working mode, while the abnormal state indicators such as under frequency, over frequency, overvoltage, and under-voltage limit are mainly stimulated by adjusting the generator drive platform and load box in the ground laboratory, and then analyzed and calculated. Therefore, in the test flight of the power supply system, the abnormal state indexes such as under frequency and overvoltage which need to be calculated in the standard documents can be removed.

C) In terms of power and power factor, after the test flight of the power system, it is necessary to analyze the total power and average power factor of the whole flight process rather than the test site. However, the sampling rate of original parameters is high, and the amount of data for calculating the total power and the average power factor is huge afterward, which causes a great burden on the software and hardware of power quality analysis. To meet the requirements for the analysis of total power and average power factor during the whole process of the aircraft in the later stage, the acquisition module shall not only collect the original voltage and current parameters but also have the ability to collect the total power and average power factor during the whole process and store them in the storage module.

6. Conclusion
In this paper, the characteristics of the compilation of standard documents at home and abroad are introduced at first, and then the ISO12344-2010 and GJB5558-2006 are compared and analyzed in three dimensions of error requirement, sampling frequency, and sampling time. It is concluded that ISO12344-2010 test requirements are more suitable for power quality analysis of civil aircraft test flights. At the same time, the power quality characteristic index and the source of the criterion for civil aircraft test flight analysis are summarized. Finally, through investigation and combined with professional knowledge, the test methods of some special power quality indicators are defined in detail, as well as the test characteristics of power quality in civil aircraft test flight, so that it can be used in civil aircraft test flight and it has a certain guiding significance for engineering application.

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