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Evaluation method for the resonance frequency of the multi-copter UA by measurement of rotor and body frequencies

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Foreword

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Introduction

This standard defines the correlation between the excitation frequency caused by rotor rotation and the resonance frequency of the main body in the design of the multi-copter UA, and suggests the evaluation method to define the design requirements of the multi-copter UA to prevent damage due to resonance.

Typical applications for evaluation of resonance of UA are ;

a) measuring the natural frequency of UA ;

b) measuring the thrust forces and rotor rotating frequency ;

c) determining the modal properties of UA(natural frequency, damping and mode shape) ;

d) checking the resonance between main body and rotor rotating frequency ;

e) evaluation of the effect on UA after resonant frequency analysis.

Evaluation method for the resonance frequency of the multi-copter UA by measurement of rotor and body frequencies

1 Scope

This standard provides a method for evaluating the resonance vibration frequency of multi-copter UA only. The frequency of the rotor means the frequency within the operating frequency range, and the frequency of the main body means the global mode frequency. This standard specifies a method to avoid design of UA that the resonance occurs generated by the coincidence of the natural frequency of the UA body and the rotational frequency of the rotor.

This standard relates to multi-copter UA weighing less than 150kg.

2 Normative references

ISO 21384-2:2019, *Unmanned aircraft systems – Part 2 : Product systems*

ISO 21384-3:2019, *Unmanned aircraft systems — Part 3: Operational procedures*

ISO 21384-4:2019, *Unmanned aircraft systems – Part 4 : Vocabulary*

ISO 21895:2020, *Categorization and classification of civil unmanned aircraft systems*

ISO 7626-2:2015, *Mechanical vibration and shock — Experimental determination of mechanical mobility — Part 2: Measurements using single-point translation excitation with an attached vibration exciter*

ISO 7626-5:2019, *Mechanical vibration and shock — Experimental determination of mechanical mobility — Part 5: Measurements using impact excitation with an exciter which is not attached to the structure*

IEC 60068-2-6:2007, *Environmental testing – Part 2 : Tests Fc*

IEC 60068-2-64:2008, *Environmental testing – Part 2 : Tests Fh*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
operating frequency range
Rotation frequency of the rotor for the UA to overcome gravity and to fly after take-off

3.2
natural frequency
When an elastic object vibrates without external influence, the shape of the vibration is called natural vibration, and the frequency corresponding to natural vibration that is generated when an elastic object vibrates without external influence. The natural frequency is determined by the nature of the shape, mass distribution, and elasticity of the object.

3.3
resonant frequency
Oscillation of a system at its natural or unforced resonance. Resonance occurs when a system is able to store and easily transfer energy between different storage modes, such as Kinetic energy or potential energy as you would find with a simple pendulum.

3.4
frequency response function
Frequency response function is a relationship between the input and the output of a system.

3.5
FFT
Fast Fourier Transform(FFT) is an algorithm that computes the discrete Fourier transform(DFT) of a sequence. Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa.

4 Test method

4.1 Concept of test method

In the case of small size UA, impact hammering method is simple, it has good cost-effectiveness and is often used to measure the natural frequency of small structures. In the case of a large size, if an impact hammer is used, the energy transfer is small and accurate measurement may not be possible. In such a case, the natural frequency and natural mode can be measured using an exciter. Which method to use depends on the size, shape, and material of the UA, so it is determined by previous experience. It is also able to measure by hammering for large UA.

4.1.1 Hammering method

Figure 1 and Figure 2 show the concept of the test device of natural frequency and natural mode shape measurement. A typical method for measuring the natural frequency is to measure it after being suspended in the air using a wire or to measure it by placing it on a sponge. At this time, in order not to affect the natural frequency of the wire's stiffness, it is enough to have the minimum strength that can hang UA. The sponge should also be soft, if possible, in order not to affect the natural frequency. A previous analysis shall be done so as to determine the natural frequencies, which should be far away high enough in order not to affect the natural frequencies of the UA (estimated previously). And since the stiffness of the blade is very small compared to the stiffness of the frame, the direction of the blade is not so important in small UA. However, it is better placing the blades in such that direction of them is perpendicular to each arm.

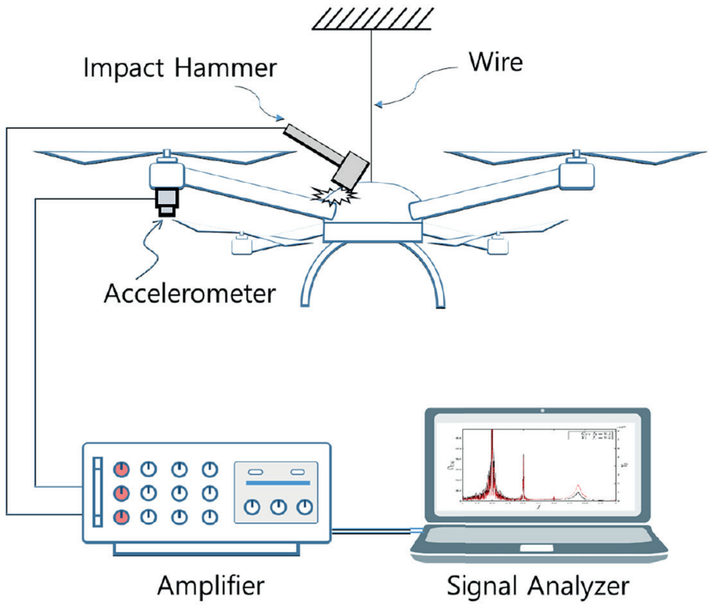

Figure 1 — Schematic diagram of measuring natural frequency using a wire(small size UA)

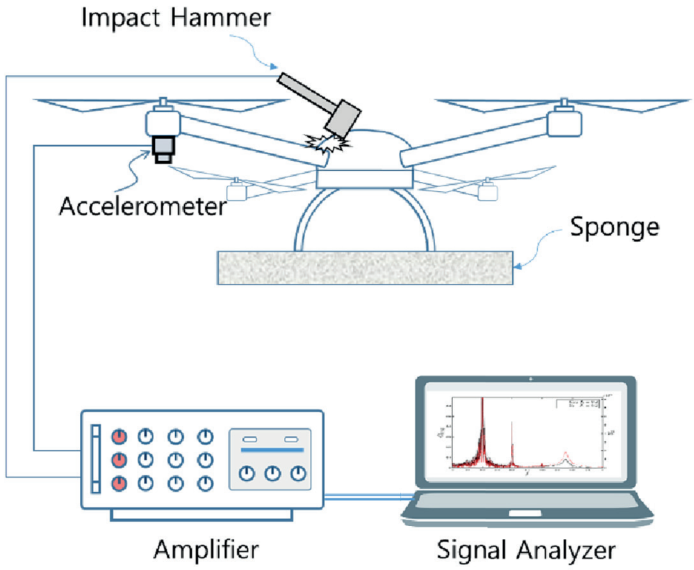

Figure 2 — Schematic diagram of measuring natural frequency using a sponge(small size UA)

4.1.2 Excitation table method

When the size of UA is large, it is good to measure it by getting it on the vibrator. Resonance frequency of UA using vibrator shall be measured according to IEC 60068-2-6 or IEC 60068-2-64. Figure 3 shows the measurement on the vibrator. In this test, the natural frequency and natural mode shape of the UA are measured. In order to measure the natural frequency of UA, it is necessary to attach and measure the accelerometer while moving it in several places, and it is more efficient to use a 3-axis accelerometer.

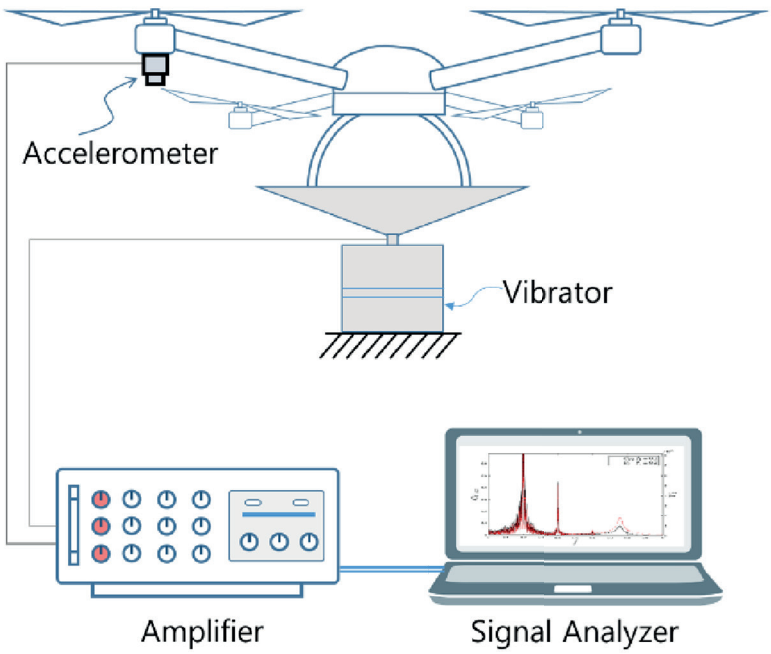

Figure 3 — Schematic diagram of the natural frequency measuring device(large size)

4.2 Concept for an operation frequency

Figure 4 shows the schematic diagram of the rotor speed and thrust force measuring device. The purpose of this test is to measure the thrust force caused by the rotational speed of the UA rotor. The small size of UA is difficult to measure with a tachometer because the motor rotates at high speed, so it is recommended to measure it using a microphone. On the other hand, it is better to measure the larger size UA using a tachometer.

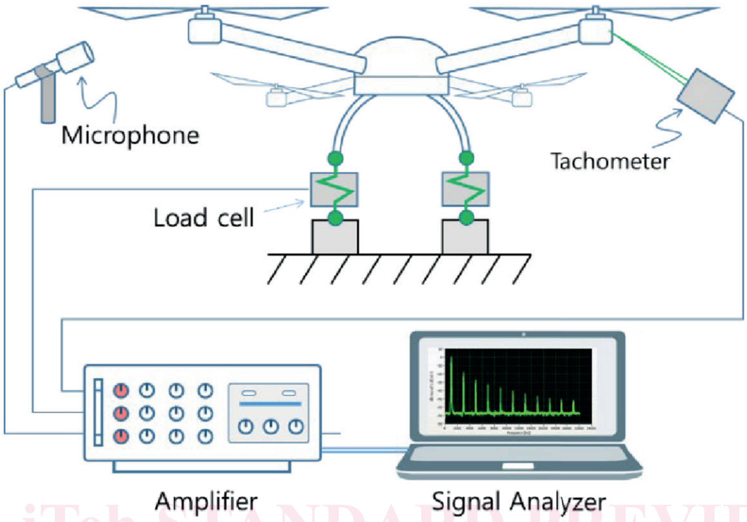

Figure 4 — Schematic diagram of the rotor speed and thrust force measuring device

5 Measurement of natural frequency and operation frequency

5.1 Natural frequency

Because the rotor that generates the thrust force of the UA is located at the end of an arm, it can be modelled to a form with a fixed cantilever and a concentrated mass at the end. The natural frequency of a multi-copter UA is governed by the following equation (1) of four main design factors. The main design factors related to natural frequency are the young's modulus of cantilever arm, the 2'nd moment of inertia, the mass of cantilever arm and the length of cantilever arm. This formula will give a good idea to change the design parameter of the natural frequency when design changes to avoid resonance.

Equation of the natural frequency of cantilever arm is ;

$$f_n = \frac{1}{2\pi}\sqrt{\frac{3EI_n}{Ml^3}} \qquad 1$$

Where

f_n is the natural frequency of I_n direction ;

E is the young's modulus of cantilever arm;

I_n is the 2'nd moment of inertia(maximum I_1 , *minimum* I_2);

M is the mass of cantilever arm;

l is the length of cantilever arm.