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VARIABLE PITCH PROPULSION DRIVE MODEL

MODEL VRTULOVÉ POHONNÉ JEDNOTKY S VARIABILNÍM ÚHLEM NÁBĚHU

Abstract

The contribution deals with the mathematical model of the propeller drive unit with variable pitch. The introductory part of the article aims at a general mathematical description of the internal structure of the aircraft propulsion. The DC motor and propeller model are presented in next chapter. The last part presents the comparison between MatLab Simulink model and experimental laboratory stand of variable pitch drive unit. Variable pitch propeller drive is useful to minimize power consumption. The use of these units for the drones is only experimental in terms of optimization of energy consumption.

Abstrakt

V tomto článku je popsán matematický model vrtulové pohonné jednotky s variabilním úhlem náběhu vrtulových listů (VPPU). V úvodní části článku je popsán základní matematický model celé pohonné jednotky. V další části je popsán model motoru ve vazbě s vrtulí. V závěru článku je prezentován výstup simulací v MatLab Simulink v porovnání s výstupy s laboratorního standu. Význam VPPU je v možné úspoře energie letounu. Využití těchto jednotek pro pohon dronů za účelem snižování spotřeby energie je v současnosti jen na experimentální úrovni.

Keywords

Variable pitch, propulsion drive, UAV.

1 INTRODUCTION

An UAV propulsion unit is usually composed of propeller, DC motor and speed controller. Each propulsion system element must be designed for maximal efficiency in its field of operation.

The knowledge of propeller torque characteristics is necessary for calculation of DC motor parameters in order to create efficient propulsion in setpoint range of RPM. The propulsion parameters are based on shape of propeller airfoil and DC motor values. The correct combination of propeller and motor moment characteristics is critical in order to achieve efficient propulsion.

The way to create efficient propulsion in wide spread RPM is to use the variable pitch propeller drive (VPU). Thrust could be changed by the change of RPM and also by the change of pitch. Application of this VPU to the quadrotor or similar UAV is possible. Nevertheless, with necessity of light improvement of flight stability controller.

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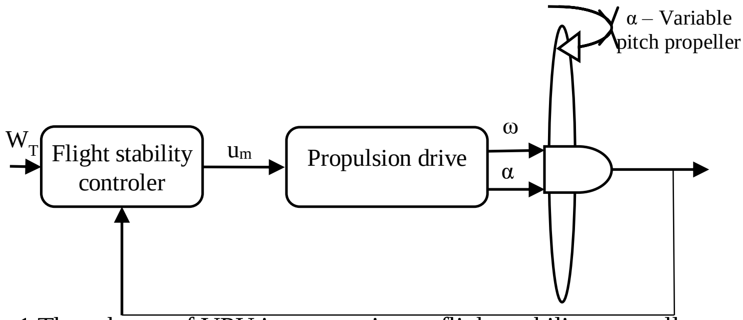

Fig. 1 The scheme of VPU in connection to flight stability controller.

The DC motor electric spare diagram is based on resistance R, inductance L and power source in series. This simplified connection is quiet accurate for DC motor simulation. The DC motor equation is

$$\frac{\partial\omega}{\partial t} = \frac{1}{J_M}\left[\left(u_m - \frac{\omega}{k_v}\right)\frac{1}{R} - i_0\right]\frac{1}{k_M} - \frac{1}{J_M}M_z \tag{1}$$

where:

R -	Resistance [Ω]
L -	Inductance [H]
ω -	Motor speed $[rad.s^{-1}]$
$\dot{\omega}$ -	Motor acceleration $[rad.s^{-2}]$
k_v -	Voltage constant $[rad.s^{-1}.V^{-1}]$
i -	Current [A]
i_0 -	Unloaded motor current [A]
M_M -	Motor torque [Nm]
M_Z -	Load torque [Nm]
k_M -	Current constant $[A.Nm^{-1}]$
J_M -	Motor inertia $[Kg.m^2]$

Motor current formula is

$$\frac{\partial i}{\partial t} = -\frac{Ri}{L} + \frac{u_m}{L} - \frac{\omega}{L.k_v} \tag{2}$$

Presented formulas was integrated together into the Simulink model on Fig. 2.

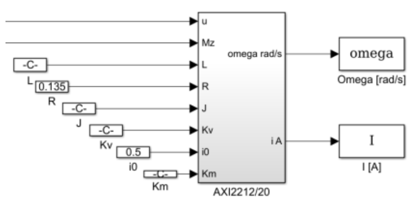

Fig. 2 DC motor Axi2212/20 simulation model.

Variable pitch propeller simulation is well described in [1], [2]. The useful formula for calculation of propeller torque based on knowledge of propeller parameters is

$$M_z = \rho c R_P^4 \omega^2 \left(\frac{C_{D0} + C_{Di}\alpha^2}{4} - \frac{C_{L\alpha}\alpha\omega}{3R_p} \right) \tag{3}$$

where:

C_{D0}, C_{Di} - Drag coefficients (parasitic, lift-inducted) [-]

$C_{L\alpha}$ - Lift coefficient [-]

R_p - Propeller radius

α - Propeller pitch angle [rad]

ρ - Air density

c - Propeller cord

All parameters could be calculated by software published in [2]. Simulation VPU model is on Fig. 3.

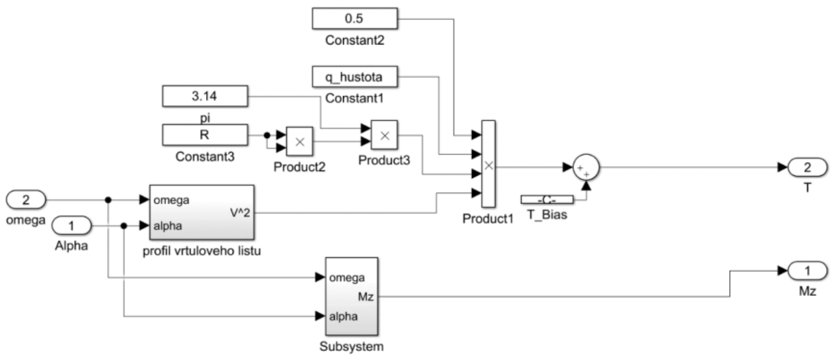

Fig. 3 Variable pitch propeller model.

The airfoil parameters and detailed propeller blade simulation is described in [4], [5], [6]. Thrust T and torque M_z depends on pitch angle α and propeller speed ω. Other parameters such as air density could be modified in order to increase accuracy of the simulation.

Combination of previous formulas (1), (2), (3) is in equation (4). The pitch actuator is also included. The detailed explanation of all blocks could be found in [4].

$$J\dot{\omega} = \left[\left(u_m - \frac{\omega}{K_v} \right) \frac{1}{R} - i_0 \right] \frac{1}{K_M} - \rho c s^4 \, \omega^2 \left(\frac{C_{D0} + C_{Di}\alpha^2}{4} - \frac{C_{L\alpha}\alpha\omega}{3s} \right) \tag{4}$$

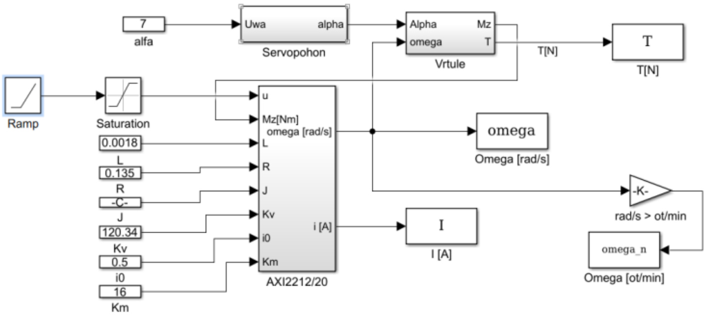

Fig. 4 The VPU simulation model.

The beginning step response of simulation model is shown in Fig.5. The thrust is produced in two different ways. First is the step of motor RPM with steady pitch angle. Second is the step of pitch angle with constant RPM.

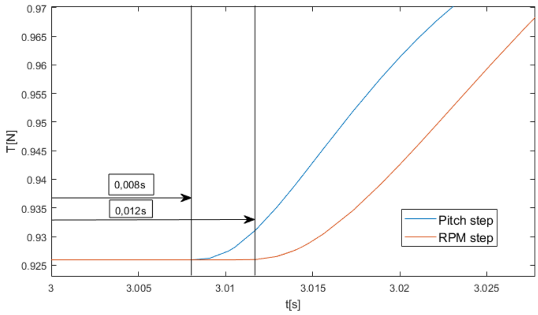

Fig. 5 Detailed look on time delay of two different approaches of thrust production.

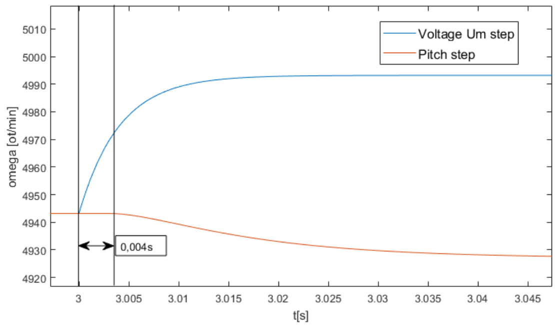

Fig. 6 Step response of VPU.

The time delay of pitch angle actuator is about 4μs as is shown on Fig. 6.

The simulation model was validated on laboratory stand of VPU (see Fig. 7 and [5]). The laboratory model is composed of AXI 2212/20 BLDC motor with Jeti Advanced 18 pro speed controller, variable pitch propeller actuated by digital servo and heart of system is ATMega2580 microcontroller. Measured values are electrical voltage and current, speed of BLDC motor and thrust force is obtained by strain gauge with propriety amplifier.

The setup of simulation is on Fig. 4. Comparing results on Fig. 8 the simulation fits the real laboratory model while the inaccuracy is lower than 5%.

Fig. 7 Laboratory stand of VPU.

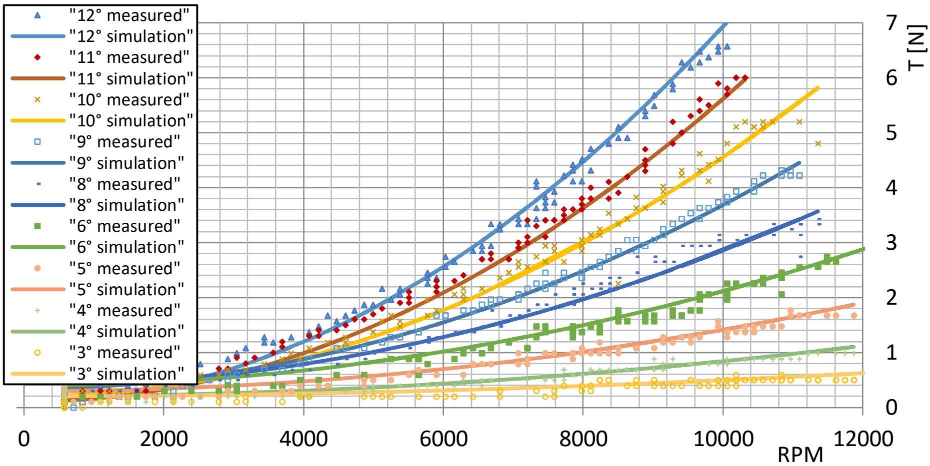

Fig. 8 Simulink model verification for pitch α = 3° ÷ 12°.

3 CONCLUSIONS

The results achieved on the real laboratory model during validation and verification of simulation model are presented in this article.

In the aerospace industry, the propeller drive unit with variable pitch angle is necessary to minimize power consumption in different flight regimes. Aircraft VPU requirements are different while rolling, take-off, landing, steady flight, etc. In reduced scale, such VPU´s could be found on the aerobatic 3D flying models, where fast response is required, but also the immediate possibility of creating negative thrust. The usage of these units for the drones is only experimental and extraordinary in terms of optimization of energy consumption. In terms of optimization.

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