Abstract— This proof-of-concept study was done to research the advantages and disadvantages when combining spinning-mass gyroscopes with an electro-mechanical gyro stabilized camera gimbal mechanism on a small vertical take-off and landing (VTOL) rotorcraft and to show that a method like this has the potential of being used. As spinning-mass gyroscopes conserve angular momentum, they can be used to maintain system orientation and also to eliminate vibrations dispersing through the airframe. The experiment started by attaching a small gyro stabilized gimbal on a miniature VTOL rotorcraft and performing flight tests and logging the data about the base position angles in conjunction with the gimbal mechanisms output shafts position and ability to compensate these rotational movements. After that, 2 spinning-mass gyroscopes were taken from inside missile guidance units and implemented to the system by a special pivoting mechanism. The tests were performed again after upgrading the mechanism. Although the overall take-off weight of the platform increased, the video-image quality, which was the main evaluation method, was significantly improved.

I. INTRODUCTION

Fast developments in the field of small unmanned multi-rotor-configuration rotorcraft have begun to push aside conventional helicopters due to their simple mechanical build, relatively low cost and secure operation. Being simple to construct and build makes them also very lightweight compared to other VTOL machines. For this reason, multi rotor aerial vehicles are highly maneuverable and stable in non-windy conditions, but very prone to stronger wind gusts, which makes them oscillate and vibrate in a lot of occasions. This may affect the used instrument, especially video cameras with CMOS sensors.

For this reason, a study was performed to see, whether or not combining spinning-mass gyroscopes help to improve the overall performance of a the electro-mechanically gyrostabilized camera gimbal. Spinning mass gyroscopes conserve angular momentum (1) and add synthetic inertia to the system.

\[ L = I \cdot \omega \]  

By combining mechanical gyroscopes and a positioning gimbal by a specialized mechanism, which takes precession and the rotation of the spinning-mass gyroscopes axes into account, it is possible to eliminate the base motion (in this case VTOL rotocrafts airframe rotational movement (Fig.1)) from affecting the picture.

The obtained result would find many applications where improved gimbal precision and eliminated vibration are crucial like laser illumination, distance measuring, target surveillance and other similar application areas.

II. SYSTEM DESCRIPTION

A. Developed gyrostabilized mechanism

The objective of the study was to find a solution, which improves the performance of a 2-axis electromechanically gyro-stabilized camera gimbal [1] mounted on a Y6 configuration multi rotor VTOL rotorcraft (Fig. 1). The applicable small gimbal is not roll-stabilized although it can be used in Roll-Pitch configuragion if needed (Fig. 2).
At system startup, the optical switch detects its relative position to zero angle and seeks to according direction until the front is reached (Fig. 4, 5 and 6). At this point the incremental encoders readout is reset [6] and gimbal is ready for operation.

Now the IMU (SBG Systems IG-500A) detects the rotational movement of the base and outputs Euler angles $\eta = (\phi, \theta, \psi)$ [5] for yaw, pitch and roll to represent its spatial orientation. This information is processed in the main controller and output to motor controllers by I2C bus (Fig.7).

The amount needed to compensate for the base movements is calculated and with encoder feedback, the mechanism axes counter-rotate the required amount.
A. Adding spinning-mass gyroscopes

Spinning mass mounted on a gimbal on a base maintains its orientation based on the principles of angular momentum [3]. The higher the rotating speed and the mass of the spinning body, the higher the applied momentum is needed to deviate the gyroscopes angle of rotation. Coming up with a mechanism that allows to constantly maintain the angle of rotation to the 0-coordinate system or in other words removing the angular base motion [4] is one of the key tasks for this study.

Precession of the spinning axis occurs when a force is affecting the spinning mass [3]. Although, if the angular speed and/or mass of the spinning wheel is high enough, the axis will hold its position and no deviation occurs.

![Spinning mass from a missile guidance system](image)

The mechanical test platform uses two modified spinning-mass gyroscopes (Fig. 8) on 2 DOF-gimbals, so that their rotational axes cross. This mechanism itself is mounted on a separate gimbal, which can pivot in all 3 rotational axes in relation to the base. The electro-mechanically gyrostabilized servo mechanism is mounted underneath the pivoting point so that the center of mass is slightly on the lower side thus making gravitation level the system when there is no sideways acceleration occurring. In other cases, the mechanical gyroscopes resist the input force that is caused by accelerating and decelerating the aircraft.

This implementation adds a fourth coordinate system between the base and the gimbal output (Fig. 9). Coordinate system 1 is now solely the rotorcraft (base), 1A is the spinning-mass mechanical gyrosystems frame and also the IMU, and coordinate system 2 remains the servo-driven output.

![Coordinate systems: 0 - ground, 1 - base, 1A, 2 – gimbal output](image)

Because the coordinate system 1A can rotate along with the spinning-mass mechanism, an additional feedback unit is needed on the pan axis to sum up in the final mechanical output of the gimbal. For this application an absolute encoder is needed (Fig. 10), because incremental encoder would also need indexing, which is impossible in this case.

The gyroscopes used in this experiment were removed from a missile guidance system and during testing they were powered up using compressed air.

![Block diagram of system processes after implementing spinning-mass gyroscopes](image)
B. Multirotor test platform

The base for testing the gyro stabilized mechanism was a custom Y6-configuration multirotor VTOL platform (Fig. 11 & 12). This allowed the gimbal to be mounted in front of the aircraft so that the spinning-mass mechanical gyroscopes system pivoting point is at the same level with aircrafts rotational center (Fig. 13).

Fig. 11. Multirotor VTOL rotorcraft platform with gyrostabilized gimbal

Fig. 12. Multirotor VTOL rotorcraft in test hangar

C. Results

The aircraft has a standalone flight controller which can also be used to log flight data. When this information was compared with the according data from the gimbal mechanisms IMU unit, it was seen that spinning-mass mechanical gyroscopes greatly reduced the amount of compensation amplitude that was necessary for the camera gimbals output shaft to remain level. Most of the base movements were canceled by the spinning-mass gyrosystem. Another advantage is seen when comparing the pre and after results of a CMOS block camera image. There was no rolling shutter artifact seen in the image, when the mechanical gyroscopes are used. CMOS sensors are known to be very prone to vibrations and sudden sharp movements.

III. FUTURE DEVELOPMENTS

The proof-of-concept with this system was achieved. Future plans include gathering all the necessary data to develop the methodology and procedures to calculate exact parameters for the spinning-mass gyroscopes. Another important task is to construct customised driving motors for gyroscopes that allow constant and long operation. Finding the correct balance between the spinning masses and their angular velocities allows getting optimum overall mass and saves energy.

IV. CONCLUSION

The objective of this study was to find a method to take advantage of synthetic inertia provided by spinning-mass gyroscopes to help in stabilizing a electro-mechanically gyrostabilized camera gimbal. The results were satisfying and the most significant part is the fact that there is no need to void the biggest advantage of multi rotor aircraft, which is being very lightweight and agile, by adding additional mass to the frame of the vehicle to cope in gusty weather conditions. Instead it is possible to modify the gimbal suspension type and use it in conjunction with spinning-mass gyroscopes to keep the gimbal level plus eliminate almost all vibrations. The fact that the gimbal is moving independently from the crafts frame allows to use smaller and lighter servomotors which are used to direct the used instrument to the desired position. This somewhat also compensates the mass of the mechanical gyroscopes. Additional research needs to be done.

REFERENCES