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Advanced Robotics System Design
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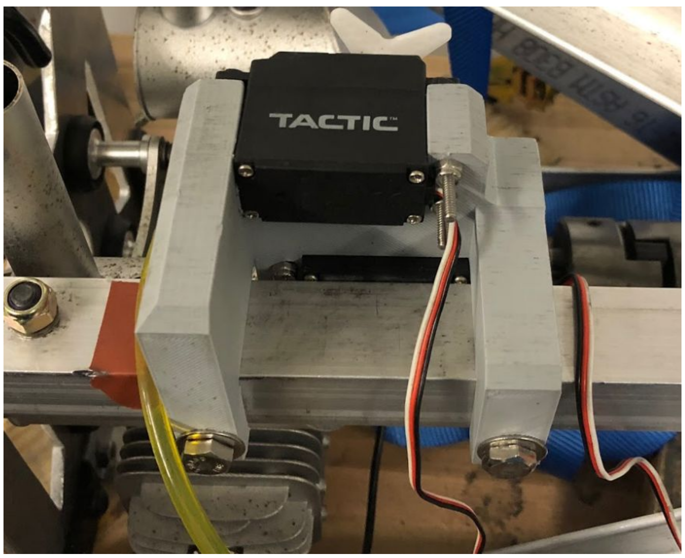
Hybrid Engine Team

Progress

Our group has expanded on the work done in the past aimed to run the engine autonomously with servo motors to control the choke and throttle. We mounted the two servos on the engine's frame and connected the servo arms to the choke and throttle.



We then calibrated the servos. To calibrate the servos we had to figure out what values, in terms of microseconds, to send to the the servos in order to open and close the choke and throttle as needed to run the engine. This process included finding what values to initially send to close both, and how to secure the servos to the frame so that the same values would work every time. We had been using zip ties to secure the servos, but as they did introduce some play to the set up we ended up bolting the 3d-printed casing that held both servos down to the metal frame. We tested different angles, measured in microseconds, of the servo shafts that would correspond to the choke and throttle closing, without over rotating. Specifically, we noticed that the servos responded to values differently than standard Arduino documentation would expect. Most servos rotate between values of 1000 and 2000, and will not move if a value outside that range is entered. However, the servos we had actually rotated between approximately 1500 and 2500. We set up the servos so that 2500 would close both the choke and throttle. We found that the throttle began to open around the value 2150, and the optimal value for opening the choke fully as the engine ran was even lower, around 1900. Eventually we updated the code that controlled the servos and motor so that the servos would not rotate to a set position, but rather a relative position based on what was happening. This code can be found in the appendix of this document. For example, the choke servo increments in values of 100 microseconds (either opening more or closing more) and the throttle increments in values of 50 microseconds.

After setting up the servos, we started to run the engine, with procedure listed in appendix, for as long as we could with the new control of the choke and throttle. Even by the end of the previous semester, the engine wouldn't start reliably, due to a variety of problems. We made a number of small adjustments, and the engine now starts and runs consistently. A list of possible fixes is in the appendix. As it stands, we generally encounter a few more minor issues that prevent the hybrid engine from being fully ready to be integrated with the flying drone frame. Perhaps the most significant of these issues preventing integration is the vibrations the running engine causes and how that will affect the drone in the air, but that is the primary focus of the mechanical design team. Our primary concerns will be covered in the next section.

Looking ahead to the final utility of the hybrid engine system, we have also taken some measurements to better understand necessary future steps. We set up a current sensor, and found 6.7 mV/A to be the slope of the output. This was confirmed with the datasheet in appendix 5. We confirmed this reading with two other claw current sensors and found them to be accurate within 1A. Current and Voltage readings of our final tests are listed in the table below

Configuration	Resisitance	Voltage	Ampere	RPM
1 Load Full Throttle	0.8	40	58	9100
2 Load Full Throttle	0.4	30	83	6400
1 Load ¾ Throttle	0.8	32	48	7500

Issues

The issue we noticed was that after the engine ran for more than 30 seconds, it would slowly start to die. When it was operating at its peak, the system would be pushing 70-75 amps through the two water heater loads, equivalent to 0.4 Ohms. But after a certain amount of runtime we noticed the current would drop fairly quickly to about 50 amps and then the motor died.

Our first hypothesis was that the motor is getting too hot, as it is designed to have airflow from a propellor constantly cooling it. The head temperature reached about 380F. Which is toward the upper range of 2-stroke motors continuous operating range. But after we used two desktop fans the issues of the motor dying went away. For the case where the hybrid system will be mounted on the drone, there should be enough airflow from the rotors themselves to cool down the system.

On our last run, 3/22, a few bolts on the coupling mechanism failed and caused the system to vibrate violently, even more so than it already usually does!!! This was a very perplexing issue because it was just the heads of the bolt that sheared off, which isn't where the load should be on these bolts.

As you can see, the loading should be where the gray and black pieces of metal meet (in shear), but when the heads flew out the thread remained inside. In addition to the bolt failures, small pieces of the rubber inserts from the lovejoy coupling have also sheared off during recent tests (as can be seen in the right side of the above picture).

Next Steps

The current motor we have is a 195Kv 80cc equivalent motor [1]. This motor was designed to run on a 12s system (44.4 V). Since our 2-stroke motor generates peak power at 9000 RPM this is where we would ideally want to run it. This means that the electric motor would generate 9000/195 = 46.15V. This was a concern that Dr. Brooke had mentioned since the drone will run on a 6s battery (22.2 V). Currently we are not sure if this output voltage will sag once a load is put on the system, or if will sag enough to be safe for the rest of the system. Concerns would include overvoltage on the ESCs and the batteries themselves.

One way to solve this issue would just be to run the motor slower than it's peak RPM. However, this would limit how much power we could generate. Another solution is to find a motor with a higher Kv rating, preferable around 375 (appendix 3). But since this size/class of motors is designed to run on 44.4V, it is unlikely that a 375Kv motor would be available as this would mean its operating RPM would be around 16,650 and this is fairly high for the large diameter propellers that these motors are designed for. It is possible to buy a custom wound motor for a higher Kv rating. This would allow us to spin the motor at a higher RPM but generate lower voltage/ more current.

The single greatest concern for next semester's team will be the mechanical robustness of the generator. In our final tests of the semester, the engine vibrated so violently that testing could not continue. The main issue seems to be with the lovejoy coupling. There is play between the shafts and the inner diameter of the lovejoy. When the set screw is tightened, the whole coupling is slightly off-axis, leading to a large amount of vibration. Even with red loctite the set screws always came loose due to vibration. The most significant effect of this vibration is bolt failure, but at one point in the test, the wire vibrations were so significant that a phase wire came loose, damaging the ESC in the process. The connection to the rectifier should be upgraded for safety.

The only solution to this issue is to make up for the play in the shaft. This would be done by machining a larger diameter shaft for the lovejoy. There should not be any room for the coupling to move on the shaft. Furthermore, the axis of the gas motor and electric generator need to be collinear. In our case they were slightly off and this cause the lovejoy coupling to shed slivers of metal as it moved back and forth on itself. The bolts holding the motors in the rubber mounts can be adjusted to change the tilt, this helped alleviate the issue somewhat. Video of vibration linked in appendix 4.

Given that we were not able to make the progress we had hoped on the battery charging system due to these mechanical problems, and the impending competition date, we think that exploring off-the-shelf hybrids may be the best path forward. Having our experimental setup constantly taken apart by the hybrid mounting team slowed our progress considerably this semester, and we suspect that this will similarly affect the next electrical hybrid team, as their progress will be dependent on rectifying these mechanical issues.

Automating the system

At present time, the system load is static, and the choke/throttle parameters to keep the engine running are hard coded. Once the battery is added to the load side of the system, we will need to integrate the current sensors with the throttle control in order to be able to properly power the system without over/under charging the battery. At present time, the starter has been manually controlled. A naive approach (ramping the motor's speed for a few seconds in duration) to powering the starter currently exists as a separate Arduino program. In most cases, the timed run of the motor should start the engine. However, given the desire for robustness in the system, it might be better to have some feedback to figure out if the motor has actually started. A transducer mounted to the frame could determine if, after the motor is started, and based on an FFT, if there are components of noise in the ranges generated by running the motor large enough to conclude that the engine is running. Alternatively, if the FFT shows that the motor is likely not running, the starter could continue trying to start it. In our experimentation, air bubbles have sometimes appeared in the gas lines, so having a more robust way to ensure that the motor is running even if air bubbles stop if would be useful. Also, the current output could be measured to determine if the motor is started. The transducer might be able to, based on magnitude of signal in addition to frequency spectrum, determine if the engine is actually firing, while the tachometer can only confirm that it is turning (like if driven by the starter). While the RPMs get high enough when minimally loaded that it is easy to tell solely based on the tach output that the motor is started (because it jumps to outside the range possible from the starter), if more heavily loaded, this distinction may not be so clear.

References

[1]https://hobbyking.com/en_us/turnigy-rotomax-80cc-size-brushless-outrunner-motor.htmlstore=en_us
[2]http://learningrc.com/motor-kv/

Appendix

1. Procedure for running the motor
    a. Secure the frame of the hybrid assembly using ratchet straps.
    b. Connect all electronics including rectifier, load, and engine ignition system
    c. Verify that the tachometer is reading and the load is properly connected
    d. Confirm that low, non-zero load is set (like 1
    e. Turn over motor using orange PWM controller for ESC
    f. For first turn over, have choke closed and throttle halfway
    g. Once the engine starts (it will be very loud) open the choke and disconnected the battery from the ESC
    h. The system is generating power through the rectifier and load, throttle position can be changed for desired power output
2. Things to look out for/common fixes or adjustments
    a. When first starting, choke should be closed/partially closed. After the engine has been running for a few seconds and has warmed up, the choke may be opened.
    b. If the engine backfires through the carb, you're running the engine backwards. Switch two wires running into the electric motor to start it spinning the right way.
    c. The motor will only start with up to two loads attached, having more loads on it causes the motor to die when batteries are disconnected from ESC.
    d. If there is no combustion it is due to either no fuel or no spark. Check for bubbles in the fuel line and pull off the spark plug wire and see if it can make an arc against the cylinder head.
    e. If there is no combustion and the exhaust smells very rich, pull out the spark plug and check for flooding of cylinder.
    f. The idle screw can be moved in or out to limit minimum airflow for idle. If the motor dies at idle, screw in the idle screw to open the valve more.

3. From http://learningrc.com/motor-kv/
    9000 RPM / 24V = 375 Kv
    5kW/(9000RPM*2*pi/60) = 5.307 N-m Torque
    5kW/24V = 208.3 Amperes
4. Video of vibrations
    https://drive.google.com/file/d/1mHygNdAdssz1aAt3dBNHTw6mwEjp4pq-/view?usp=sharing
5. Data sheet for charge monitor
    https://drive.google.com/file/d/12xlSp7p2yybUADtda7tYcVes3U9l3yXl/view?usp=sharing

CODE
https://pastebin.com/n2zFbQCP