

FP1: Requirements Specification Document

Sound: Mitsuba Hub Motor

Description:

The Mitsuba Hub Motor is a small, 2-5 horsepower motor that is used in solar car racing, which is directly mounted on the wheel. The motor has a very distinctive 'spin up' sound as it accelerates from a stop up to speed. This spin up sound differs mainly based on how much weight the motor is loaded with (for example, the being mounted on a wheel that is in contact with the ground) and how fast the driver is trying to accelerate. Additionally, the motor controller used to send control signals to the hub motor has two different control schemes called trapezoidal and sinusoidal. These names come from the shape of the control PWM signals. When the motor is under trapezoidal control, it has a lower pitch and also more of a beat to the sound. When the motor switches to sinusoidal drive, the pitch goes up and the oscillations become smoother, so that you do not hear as much of a cyclical dip in frequency.

The motor itself sounds very much like sound-effects out of a space or sci-fi movie. The sound of the motor is made up of several layered frequencies, with harmonics that change depending on speed or acceleration. The motor starts off with a sort of heavy low rumble. You can also hear a sort of metallic rubbing – almost a light grinding sound – from bearings and other mechanical parts of the motor as it spins up. At first there are not many high frequency sounds on top of the grinding. Then, as the motor starts accelerating more we can hear the pitch continuously increase upward, with the higher harmonics started to dominate any low frequency sounds of mechanical components. However, there can be a very high-pitched somewhat pure tone (like an alarm) sound right as the motor starts to speed up. This is often a sort of error signal, alerting you to the fact that you may be demanding higher speed or current at that moment than the motor can immediately provide. Depending on the acceleration, this spin up stage can take anywhere from 5-20 seconds. As the motor starts to spin faster and faster, we hear this as the whine of the pitch because shriller and higher. In addition, we start to hear a sort of beat from the motor every cycle. This beat is a little bit lower pitch than the main whir. Right in the mid stage there is a very harmonic spot, where the pitch seems to be a bit deeper and more complex than the high pitched whir we first hear. There are still elements of metal-on-metal scraping sounds, and by listening to the sound of the motor you can distinctly hear when a revolution starts and ends by the cyclical nature of the scraping sound. Once at speed, the sound of the motor is still a fairly layered harmonic sound, akin to several stacked oscillators.

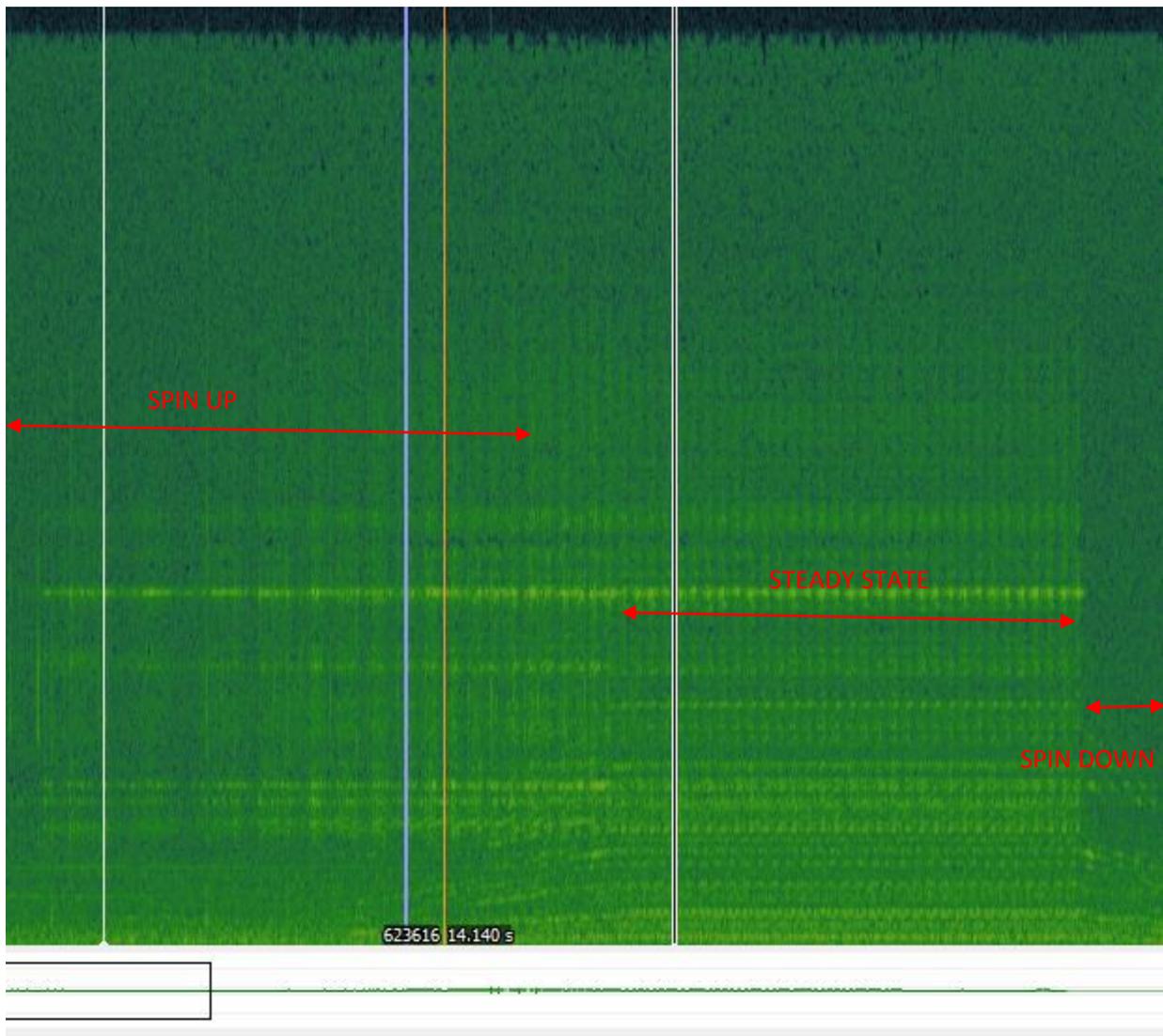
When the motor spins down, it has yet another distinctive sound, different from when it speeds up. The sound suggests a power-down quality, as the speed of the 'cycle' can drop very quickly if the motor stops quickly. The pitch drops along with the speed. This spin down sound can be made to be longer if the motor or driver is taking longer to decelerate.

After doing analysis off the motor with Sonic Visualiser, the base frequency of the steady-state spin of the motor seems to be around 600 Hz, although there are several layered harmonics and

mechanical sounds. See Figure 1. Note this recording was taken on an unloaded motor. A loaded motor will be a bit quieter overall, and can have a lower pitch throughout the spin up, steady-state, and spin down stages.

The spectrogram clearly shows how the spin up sound gradually becomes more and more layered with added harmonics with some multiples of the fundamental being much stronger than others. The steady state however has very set pulses along the horizontal time axis, as well as a much more even and wider harmonic spread of the vertical frequency axis. The spin down in this particular recording happens very quickly, and you can see the higher fundamentals quickly vanish as the lower fundamentals seem drop in frequency and volume as part of the motor sound decay.

Figure 1. Sonic Visualizer spectrogram of motor sound from spin up to spin down



Note: this recording is provided as `assn_fp1_motr.mp3`

Components of Mitsuba Hub Motor Sound:

1. **Metallic scrapping (as in bearings, casings, etc.)**

Can be heard throughout entire sequence of start up, steady state, and slow down. However, it is not very audible in the spin down portion if the motor slows down quickly. Additionally, the grinding during the start up phase when the motor is just starting to accelerate is much more granular (not as smooth) and has a lower pitch. The pitch bobs in a steady rhythm during steady state. So the time oscillations and the pitch of the metallic scrapping should increase as the motor spins up, and then drop as the motor spins down.

2. **Motor pitch**

The pitch starts from a low grumble to around a steady 600 Hz oscillation with layered harmonics during steady state operation. At times the pitch is very close to a pure tone or layers of pure tones. However, you can also hear the physical cycling of the motor as a sort of beat in the frequency. This beat depends on the speed of the motor.

3. **High pitched whine**

At times, there is a high pitched whine or alarm like sound, that is sometimes present if the motor doesn't like the drive signal (for example, you're commanding a speed higher than what the current you're giving the motor can achieve). This is not always present in the motor sound.

User Parameters

1. **Speed**

The sound of the motor is very dependent on speed, as it sets what the frequency of the rotation oscillation is, which is very dominant in the overall sound. Additionally, reaching higher speeds can change how long the acceleration ramp up takes.

2. **Acceleration / Deceleration**

The user could choose to accelerate or decelerate very quickly. The effect will be more pronounced with deceleration, as the motor has to have a certain minimum amount of time to get up to speed, but can slow down smoothly or be abruptly halted. An additional affect could be added immediate halts, which causes the motor to have a jerky sound with lots of clunking mechanical sounds overlaid as the rotor abruptly comes to a halt. Also, you could pulse the acceleration, as though revving an engine, to get a harder sort of growl out of the motor.

3. **Loaded vs Unloaded**

If the motor is loaded, the sound becomes a bit quieter and the pitch drops slightly. Changes in pitch are also not as dramatic. The user could choose how they are loaded the motor with extra weight (e.g. putting it in a car vs testing it on the bench) to change the overall quality of the sound.

4. **Ground noises**

If the motor is being replicated in a loaded condition, the user could also add gravel crunching sounds underneath the wheel, or splashing sounds of puddles on the ground.

However, this starts to enter a different sonic space than I wanted to focus on with the motor, so I would only add this in the case that I finish everything else early.

Timeline

4/9/2015 – FP1 due: write Requirements List for sound design of motor

4/16/2015 – FP2 due: create a detailed model of the sound. Will use several different audio sources to investigate the harmonic overtones during the different periods (start up, steady state, slow down). Investigate composition of mechanical sounds, and how this differs from the more pitched sounds. Figure out control parameters that should be exposed to the user. Create geometric model and block diagram for sound scene.

4/30/2015 – FP3 due: start to create PD models for different segments. Make basic oscillator overtone series, and match fundamental pitch to recording of Motor. Start to try to design PD patches that could generate the mechanical sounds. Start with hardcoded sounds with no user inputs.

5/14/2015 – FP4 due: expand on PD models and combine them together / make the transition from startup to steady state to slow down seamless. Add user inputs that can change speed, acceleration, loaded vs unloaded etc. Finalize complete sound design project.

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