

TECHNICAL NOTE



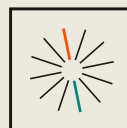
WHEELIE

ROTATIONAL RHYTHM INSTRUMENT

Model of 2026

Periodic rates in machines and bodies · why many of them fall near two per second · the spectrum of a turning wheel · where a click rate becomes a pitch · the equation of motion, and how each control on the panel enters it

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CARD-IN-SPOKES SYNTHESIS

PERIODIC RATES

Rhythm is not only something a musician imposes on time. It is the ordinary output of any process that repeats, and most of the processes around a body repeat. A wheel turns, a piston returns, an escapement releases, a heart fills and empties, a leg swings forward and is caught. None of these were designed to be music. They produce a periodic signal because periodicity is the cheapest way for a mechanism to do the same job twice.

What is worth noticing is how narrow the resulting band is. The rates below were not selected to agree with each other. Two are clinical guidelines, one is a legal requirement, one is a measurement of pedestrians who were not told they were being measured, and one is the modal tempo of recorded popular music. They agree anyway.

EVERYDAY PERIODIC RATES

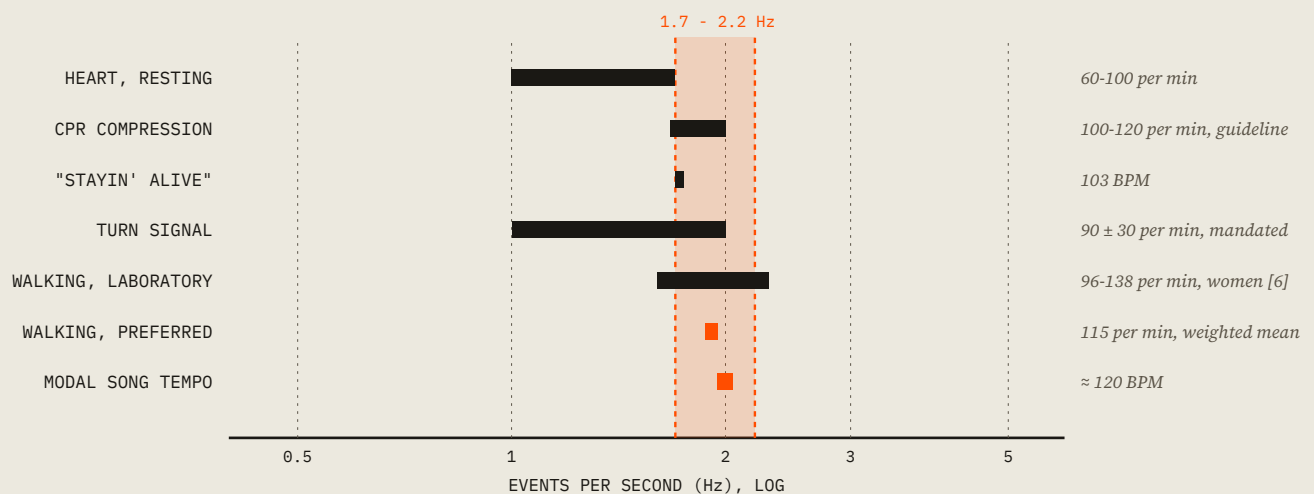


fig. 1: Seven unrelated periodic processes on a log rate axis. The shaded span is 1.7 to 2.2 Hz; six of the seven intersect it. Only the last two are musical.

The disco example is not a joke, or not only one. Compression rate is the variable rescuers most reliably get wrong, and a study of medical providers found that pairing the guideline rate to a song at 103 BPM held rates inside the guideline window when retested at least five weeks later without the music [3]. A tempo was used as a unit of measurement because people store tempo better than they store numbers.

NOTE

This document makes no claim that any of these processes caused any other. The claim is narrower and is developed in section 2: a single mechanism, resonance, sets the preferred rate of the legs and of the perceptual system that tracks a beat, and both mechanisms have roughly the same time constant.

RESONANCE

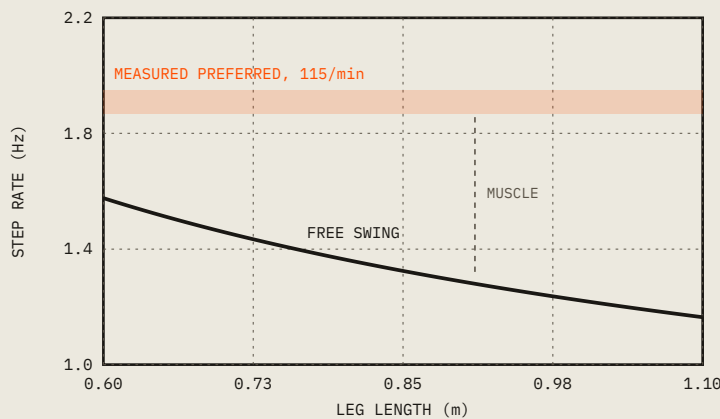
A leg is a pendulum hung from the hip. Treated as a uniform rod pivoted at one end it has a swing period fixed entirely by its length, and a step is one half swing:

$$T = 2\pi \cdot \sqrt{(2L / 3g)}$$

$$L = \text{LEG LENGTH} \quad g = 9.81 \text{ m/s}^2 \quad \text{STEP RATE} = 2/T$$

The square root is the whole content of the law. Period scales with the square root of length, so cadence falls as legs get longer: a child steps faster than an adult for the same reason a short pendulum ticks faster than a long one, and no amount of effort changes it. The model is deliberately crude and it is low by roughly a quarter, because a real leg carries its mass near the hip, flexes at the knee, and is driven by muscle rather than left to swing. What it predicts correctly is the slope and the order of magnitude.

■ PENDULUM PREDICTION



■ PREFERRED PULSE

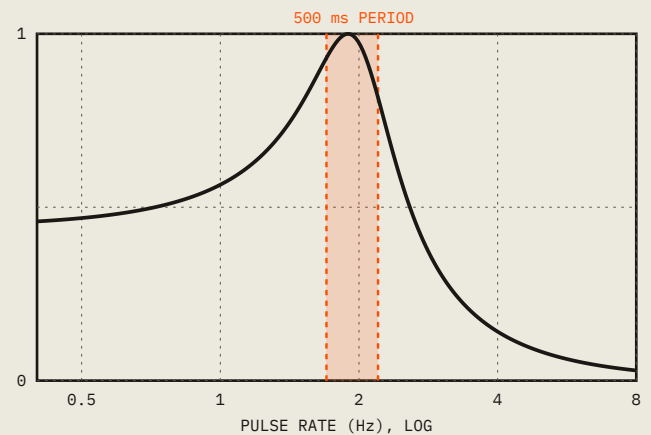


fig. 2: Left: swing rate of a free leg against its length. The model sits below the measured preferred cadence by about a quarter, which is the contribution of muscle; the slope is what it gets right. Right: the resonance model fitted to preferred-tempo data [1], peaking at a 500 ms period.

The right-hand curve is not a property of legs. It is the response of the mechanism that tracks a beat, fitted to listeners asked to tap along, and it peaks at a period of about half a second [1]. Two different systems, one mechanical and one perceptual, are tuned to very nearly the same rate. That is enough to explain why a rhythm found in a machine so often feels like it was meant: not because the machine intended anything, but because a listener arrives already resonant at the rate that machines of human scale tend to run at.

A turning machine does not emit one frequency. It emits a structured set of them, and the structure is standardised enough that an entire diagnostic discipline reads faults off it [4]. Frequencies are quoted as orders, in multiples of the shaft rate. A wheel of N spokes struck once per spoke produces its principal line at order N , the direct analogue of the blade-pass frequency of a fan. That line is all a perfect wheel emits. Anything that differs from one part of a revolution to another modulates it, and shows up as a family of sidebands spaced at the shaft rate.

■ ORDER SPECTRUM • $N = 24$ SPOKES, SHAFT RATE 2 Hz

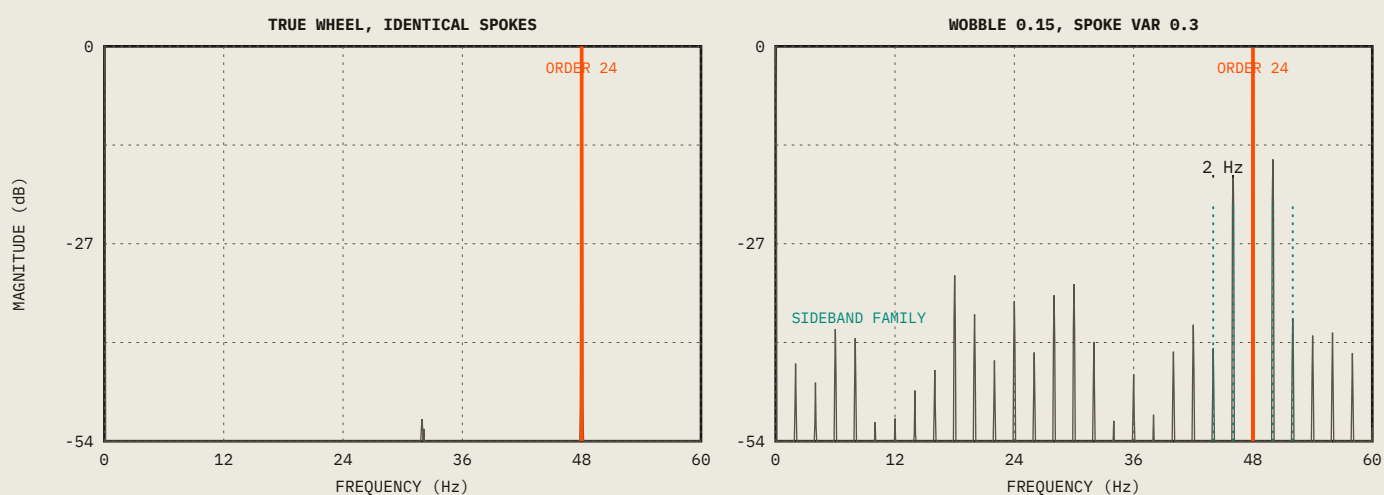


fig. 3: Both panels are the plugin's own click generator, 24 spokes at 2 revolutions per second. Left: with the rim true and every spoke identical the output is periodic, so the spectrum is one line at order 24. Right: at the panel's defaults, Wobble moves each spoke's arrival and Spoke Var its strength, both once per revolution, and both fill in a sideband family spaced at exactly the shaft rate.

ORDER	NAME	SET BY	HEARD AS
1	shaft rate	Speed	the bar: one revolution
N	spoke-pass rate	Spokes $\times$ Speed	the subdivision, or the pitch above 20 Hz
$N \pm k$	sidebands	Wobble, Spoke Var, Spacing	wobble, and the sense that the spokes are individuals rather than a repeat

RHYTHM TO PITCH

Everything so far has treated the click rate as a rhythm. That holds only while the rate is low. Felix Savart demonstrated the limit in the 1830s with a toothed wheel and a card held against it, which is the same apparatus as this instrument and was built for the same reason: it is the simplest way to produce a rate you can vary continuously across the boundary. Turn it slowly and you hear separate taps. Turn it faster and somewhere near twenty per second the taps stop being countable and become a tone whose pitch is the rate. Nothing about the mechanism changed.

CLICK RATE AGAINST WHEEL SPEED

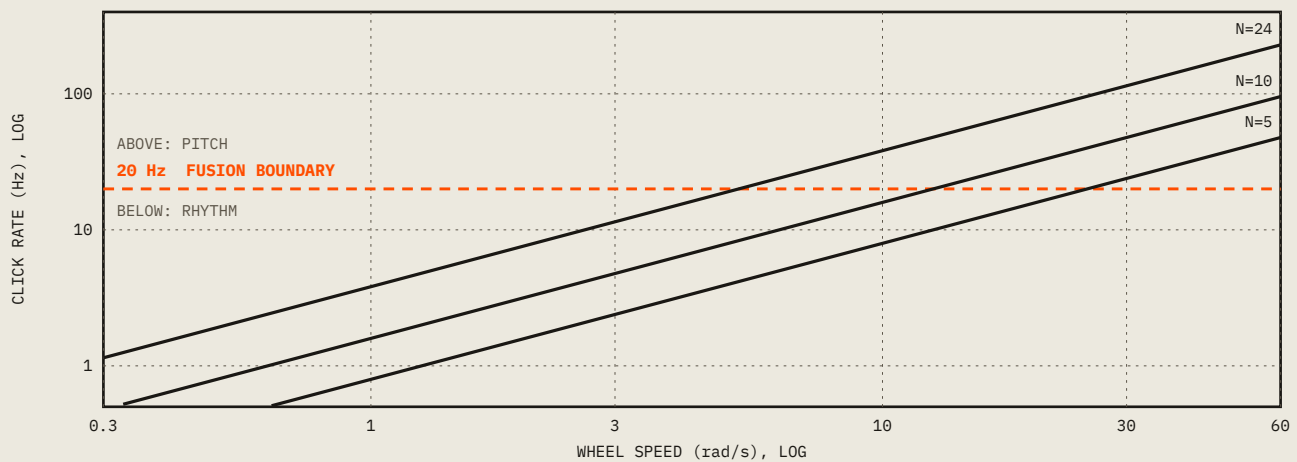


fig. 4: $r = N\omega/2\pi$, so the boundary is crossed at a speed that depends entirely on the spoke count. A 24-spoke wheel becomes a pitch at 50 RPM; a 5-spoke wheel has to reach 240 RPM to do the same thing.

The consequence for playing the instrument is that a single control crosses a categorical boundary. A wheel left to coast from above the line to below it is not performing a filter sweep or a tempo ramp. It is passing through the point where the ear stops integrating events into a pitch and starts counting them, and it does so on a curve set by friction and drag rather than by an envelope. Section 4 gives that curve.

CAUTION

The boundary is not sharp and is not a property of the instrument. It depends on level, on the material setting, and on how much the spokes differ from one another. Between roughly 15 and 30 Hz both percepts are available and attention selects between them.

EQUATION OF MOTION

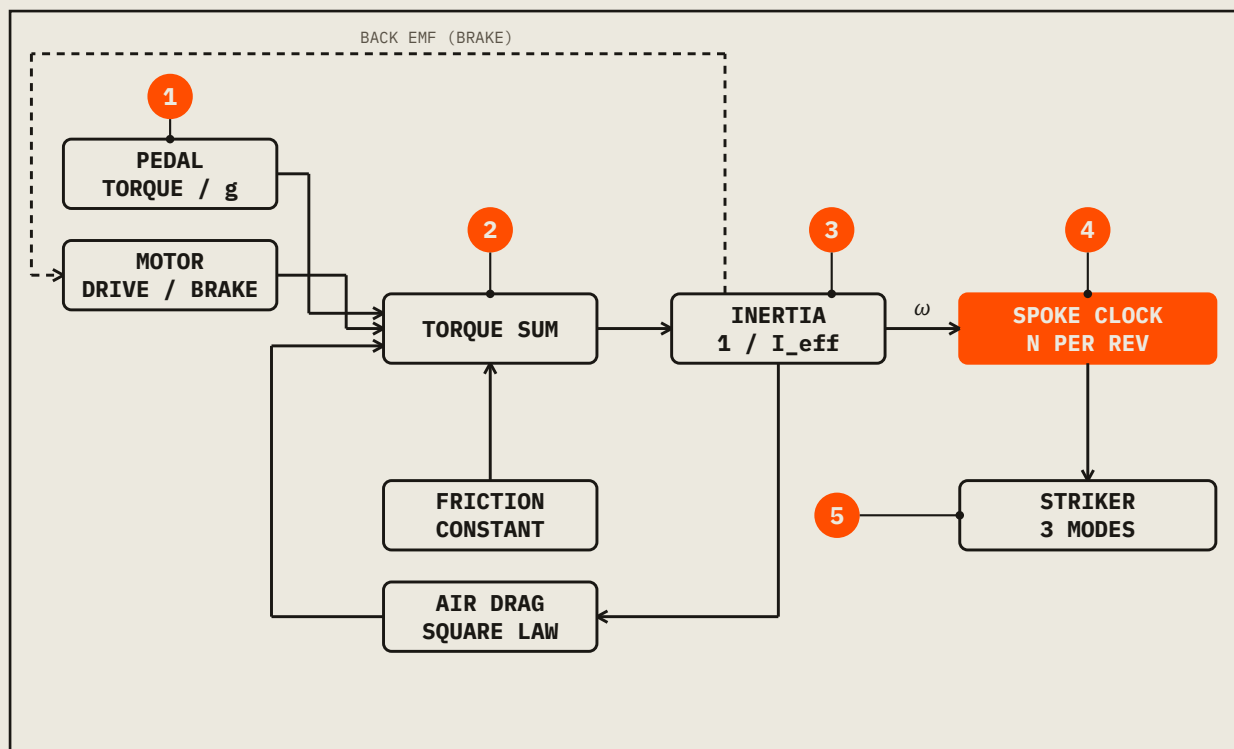


fig. 5: The equation of motion, as wired. The dashed path is the one that surprises people: a motor left unpatched has its terminals shorted, and a shorted motor is a brake.

STAGE	WHAT IT CONTRIBUTES
1 drive	Pedal delivers torque through the selected gear and fades out as the crank approaches 124 rpm. Motor is a true bidirectional port: it drives on applied volts and brakes on its own back EMF.
2 torque sum	Everything that can speed the wheel up or slow it down meets here. Losses are signed against ω , so they can never reverse it.
3 inertia	$I_{\text{eff}} = I(1 + 0.1L^2)$, where $L = 1 + 1.6r$ is the leverage of the gear r . Reflected inertia rises with its square, which is why a tall gear is slow to move and slow to stop. At 1:1, I_{eff} is 1.68 times I .
4 spoke clock	The only place a rhythm is generated. Every event in the instrument, including the arpeggiator, is timed by a spoke crossing rather than by a tempo, and each strike is placed at the instant its spoke crossed, between samples.
5 striker	Three exponentially decaying modes plus a contact noise burst, retuned per strike. Strike velocity opens the upper modes.

COASTING

Left alone, the wheel loses speed two ways at once, and the two have different shapes. Bearing friction is a constant torque: it removes the same amount of speed per second regardless of how fast the wheel is going, so on its own it produces a straight line to a full stop at a finite time. Air drag is proportional to the square of speed: it is fierce at the top and vanishes at the bottom, so on its own it produces a curve that decays forever without ever arriving. Together:

$$I_{\text{eff}} \cdot d\omega/dt = -\mu \cdot \text{sgn}(\omega) - d \cdot \omega |\omega|$$

$\mu = 0.006 \text{ dry}, 0.00072 \text{ greased} \quad d = 0.00008 \quad I_{\text{eff}} = 0.587 \text{ kg} \cdot \text{m}^2 \text{ at } 1:1$

This is the instrument's only envelope generator and it has no stages. Grease cuts μ by up to 88 percent. It does not decide whether the wheel stops, because the constant term never reaches zero; it decides how long the last slow clicks go on. From 8 rad/s a dry wheel stops after 631 s and a greased one after 2962 s.

COAST CURVES

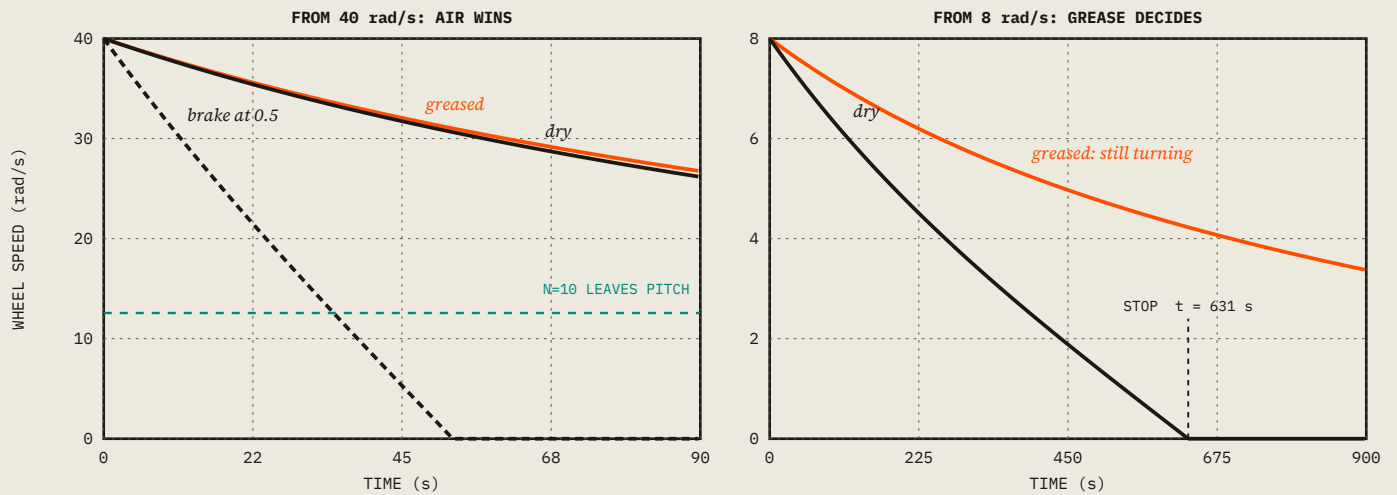


fig. 6: Left: from 40 rad/s the square-law term dominates and grease barely matters, which is why a hard kick always decays the same way at first; with the brake at 0.5 the wheel stops in 53 s. Right: below about 8 rad/s the constant term takes over. The dry wheel stops at 631 s; the greased one is still turning at 900 s and stops at 2962 s.

That is the whole envelope. There are no stages and no curve shapes to choose; Grease and the brake decide how long the last clicks of a decelerating pattern take to arrive.

SEQUENCER CHAINING

■ THE WHEEL IS THE CLOCK

The step sequencer is driven by spoke crossings, not by the host tempo. That is not a limitation. A wheel being braked, geared, or driven by its neighbour drags its own pattern around with it, so the pattern is a property of the mechanism rather than something laid over the top of it. Slow the wheel and the pattern slows; there is no other clock to disagree with.

■ WHY IT LATCHES

Once a wheel runs on its pedal it needs nobody. Once several are chained they all run on their own, and holding keys down to feed the arpeggiator stops being possible -- there is one player and four instruments. A pattern that keeps running without a hand on it is what makes a rack playable, and it is the only reason this feature exists.

CONTROL	WHAT IT DOES
SEQ	runs the pattern. It supersedes the arpeggiator rather than mixing with it
LENGTH	steps before it wraps, 1 to 16
STEP EVERY	spoke crossings per step, so a fast wheel can still run a slow pattern
ROOT	the note a step of +0 plays
the grid	one octave of keys down the left, sixteen steps across. Click a cell to put the note there; click the lit one again to turn it off; drag to paint a run. The two thin lanes underneath are accent and slide
ACCENT	how much harder an accented step hits
SLIDE	how long a slid step takes to arrive at its pitch. The time is counted in strikes, so a slow wheel slides slowly
accent	the step hits harder
slide	the striker glides to the pitch instead of arriving at it. A rest advances the pattern and damps the strike without cancelling it, so the spoke is still crossed and the card still bent

■ CHAINING TWO WHEELS

Send one instance's Tach+Gate CV output into another's sidechain input. The first wheel's speed then pulls on the second through the motor law, and the ratio between them is the sender's GEAR OUT over the receiver's GEAR IN.

CAUTION

Send the tach PRE-FADER, with the chain's own fader down. The tach is a control voltage, not audio: it is slow and near-DC and it sounds like a thump and a drone. Post-fader, the level that silences it is the same control that sets how hard it drives the next wheel, so turning it down to silence turns the coupling off. Pre-fader is the only routing where a wheel can drive its neighbour and stay inaudible.

CONTROLS

Each control is one term in the equations above. Nothing on the panel is a macro, a shaping curve, or a post-process. The panel is paged only so the layout follows signal order; every page edits the same model.

CONTROL	SYMBOL	ENTERS	CONSEQUENCE
Kick	ω_0	initial condition	One impulse. Sets where on the coast curve the sound begins.
Pedal	p	$\tau \pm 6p \cdot \sigma(\phi)(1 - \omega_c/13)/L$	Sustained drive, two power strokes per crank revolution, fading out as the crank reaches 124 rpm.
Clutch	—	connects the motor	At zero the motor terminals are open and the wheel freewheels. Closed with no drive voltage the motor is a short, and a shorted motor is a brake.
Brake	b	$\tau \leftarrow 0.8b \cdot \text{sgn}(\omega)$	The brake pedal: a torque against the direction of turn. Brake Type gives it one of three shapes.
Inertia	I	$I_{\text{eff}} d\omega/dt = \tau$	How much the wheel resists every other control. At the 1:1 gear the drivetrain adds its reflected share, so the wheel carries 1.68 times this.
Friction	μ	$-\mu \cdot \text{sgn}(\omega)$	Constant loss: the same deceleration at every speed, so friction alone ends a coast at a definite time.
Drag	d	$-d \cdot \omega \omega $	Air drag, square-law: strong at speed and nearly nothing when slow.
Spokes	N	$r = N\omega/2\pi$	Sets the subdivision, and so the speed at which the pattern becomes a pitch.
Level	—	output gain	The striker's output level. It does not touch the physics.
Pitch	f_1	mode 1 frequency	The struck object's fundamental. Overridden per note when Voice is set to arp pitched.
Decay	t_{60}	mode 1 to -60 dB	How long the struck object rings. The upper modes are shorter in proportion, and the material scales all three.
Bright	—	$\times(1 + \text{bright} \cdot v \cdot 1.4m)$	How much strike velocity opens the upper modes. The wheel gets brighter as it gets faster.
Drift	—	$f_1(1 + 0.09 \cdot \text{drift} \cdot v)$	How much speed pulls the striker sharp, as a real struck reed does.

CONTROLS

CONTROL	SYMBOL	ENTERS	CONSEQUENCE
Wobble	e	$\theta_s = \theta + 0.35e \cdot \sin\theta/N$	The rim runs off-centre, so once per revolution the spokes arrive early on one side and late on the other, by up to 0.35e of a spoke spacing. Periodic, not random.
Spoke Var	v	$1 + v(s_k - 1 + 0.3\delta_k)$	How much harder some spokes hit than others. Each spoke keeps its own strength, so the pattern of strengths repeats every revolution.
Spacing	—	spoke k at $k + 0.35 \cdot \delta_k$	How unevenly the spokes stand round the hub. Each spoke arrives up to 0.175 of a spacing early or late, the same spoke by the same amount every revolution. At 0 the spokes are even.
Ratio	r	V/r in, $L = 1 + 1.6r$	The gear on the input, one of ten ratios from 3:1 to 1:4. It divides the drive a neighbour's tach delivers, trades the pedal's torque for top speed, and adds reflected inertia with its square.
Send	—	tach $\times$ send	The gear on the output: it multiplies the tach this wheel sends downstream. Two chained wheels run at the sender's Send over the receiver's Ratio.
In Trim, Out Trim	—	$\pm 30\%$ of the gear	The continuous part of each gear, as a percentage of it.
Material	—	partial ratios, decay, ring	Five sets of modal constants. Ring is the fraction of the previous strike that survives the next one.
Voice	—	off / fixed pitch / arp pitched	What pitches the striker: nothing, the Pitch knob, or the notes the arp or the sequence is playing.
MIDI Out	—	off / one note / per spoke	Every spoke that passes the card can emit a note. A coasting wheel plays a drum rack and decelerates the groove with it, with no tempo automation anywhere in the path.
Key Mode	—	kick / gear	Kick: a note is an impulse, and velocity is how hard. Gear: a held note drives the wheel to the speed whose click rate is that note's frequency, at any gear, so the keyboard plays rate rather than force.
Governor	—	$ \omega \leq \omega_{\max}$	A ceiling on the wheel's own tempo, in BPM, where one revolution is one bar. Below it the wheel does not know it is there; at it, any further torque is discarded.
Governor Src	—	off / host tempo / free / host lock	Where the ceiling comes from: the host's tempo, the Governor knob, or the host's tempo with a synchronous-motor torque that pulls spoke zero onto the downbeat.
Governor Mult	—	$\times$ host tempo	The ceiling as a multiple of the host tempo, on the same ten ratios as the gears, so the dotted and triplet rates are two of its entries.

CONTROLS

CONTROL	SYMBOL	ENTERS	CONSEQUENCE
Brake Type	—	disc / drum / regen	Disc is constant torque. Drum is self-energising: each unit of pressure does more the harder you press. Regen is proportional to speed, so it never quite stops the wheel on its own.
Brake Fade	—	$\text{grip} = 1/(1 + 6 \cdot \text{fade} \cdot \text{heat})$	The pads heat with the work they do and grip less, then recover as they cool. Held at speed, the brake fades and comes back.
Brake Key	—	note mapped to the brake	Any note can be the brake instead of a striker, so a rack of wheels can have each one stoppable without stealing a key another wheel plays.
Brake Lever	—	latching brake	The BRAKE button under the wheel. It latches, so a wheel can be held stopped while you listen to the others.
Sync	—	spoke clock to zero	Momentary. Puts the spoke clock back to spoke zero, so chained wheels that settled at the same speed but a different phase line up.
Stretch	—	$r' = r^{(1+\text{stretch})}$	Inharmonicity. The fundamental is $r = 1$ and therefore never moves; positive values push the upper partials out toward a bell, negative pull them in toward a harmonic series.
Strike Pos	x	$\text{mode } m \times \sin(m\pi x) $	Where along the object the card contacts it. A mode excited at its own node does not sound at all, so striking the centre silences the second partial outright. Normalised to the strongest mode, so this changes the balance rather than the level.
Modes	—	partials that sound	Three is a choice, not a law. One is nearly a sine; three is the full material.
Contact	—	scales the impact noise	The transient burst at the moment of contact, separately from the modes it excites.
Ring	—	adds to the material's survival	How much of the previous strike is still ringing when the next spoke arrives. Pushed up far enough the strikes stop being separate events.
Cards	—	one card on the fork, or two	A second card clipped further round. It is a second object rather than a copy: it carries its own modes and its own bend, so the first is still ringing when the second is struck, and it takes its own energy out of the rotation.
Spread	s	$t = s/r$	How far round the fork the second card sits, in spoke spacings. The gap between the two clicks is set by the speed rather than by a delay line: crawling, it is a flam heard as two rhythms in two ears; wound up, it falls through the precedence window into an image and then a comb whose notch rides the speed. At half a spoke the second card lands exactly between the first card's strikes, so the mono sum doubles its rate while the pair stays two interleaved trains.
Card Var	v	$f = f(1 + 0.06v)$, $t60 \times (1 - 0.18v)$	Two cards out of one deck are never identical. Frequency goes as $1/L^2$, so how far each is clipped in dominates the difference, and a card clipped tighter is both sharper and shorter because the clip damps what it stiffens. The two move together for that reason rather than as separate controls.

CONTROL	SYMBOL	ENTERS	CONSEQUENCE
Load	—	$\frac{1}{2}I\omega^2 - E_{\text{struck}}$	The card does not ring for free. Whatever energy the strike hands to the modal bank is taken back out of the rotation, so more spokes shorten the coast and a long-ringing metal costs more than a dead rubber. At zero the sound is free.
Imbalance	$m \cdot g \cdot d$	$\tau = m \cdot g \cdot d \cdot \cos\theta$	Mass off the axis. Gravity does work on the heavy spot, so the wheel gains speed as it falls and loses it climbing. At speed this is a once-per-revolution modulation; below the point where $\frac{1}{2}I\omega^2$ falls under $2m \cdot g \cdot d$ it can no longer carry the weight over the top, and the wheel rocks instead of turning. It always settles heavy side down.
Return	—	release = 1 – bend	How long the card takes to straighten after a spoke lets it go. What you hear is the release, so a strike is worth only what the card recovered since the last one. Wound up far enough it never gets clear and the clicking stops altogether, which is why a real card changes character at speed rather than merely counting faster.
Stiction	—	breakaway = $\mu(1 + 4s)$	Static friction above kinetic. A stopped wheel resists starting until something exceeds the breakaway, then goes at once. Without it a wheel creeps; with it, it lurches.
Motor kV, Motor R	k, R	$\tau = k(V/r - k\omega)/R$	The motor constant and the winding resistance. Together they set how hard the wire pulls: the coupling time constant is $I \cdot R/k^2$.
Tach	k	volts per rad/s	Scales the generator voltage this wheel sends out. It sets both what a neighbour feels and what the CV output reads. Send it PRE-FADER: see CHAINING TWO WHEELS.
MIDI Note	n	base of MIDI Out	The note MIDI Out sends. Per spoke, the spokes climb a minor pentatonic from it, five to an octave, an octave higher on every other five.
Grease	—	$\mu \times (1 - 0.88g)$	Fresh grease in the bearing, cutting friction by up to 88 percent. It stretches the tail of a coast: see COASTING.
Arp	—	clocked by spoke crossings	Eleven patterns over the held notes. There is no tempo anywhere in the path; the wheel is the clock. With the arp off, the held notes still pitch the striker, so it can be played from a keyboard while the wheel decides when.
Chord	—	gates the kick	Notes arriving within this window count as one chord and therefore one kick. A harder note inside the window tops the kick up to its own velocity rather than adding a second one, so there is no latency.
Latch	—	holds the note pool	The arp keeps its chord after the keys are released. The next fresh keypress replaces the chord rather than adding to it. Can be driven from the sustain pedal.
Priority	—	selects from the pool	Which held note pitches the striker when more than one is down: last played, highest or lowest. The striker is monophonic, so this is the note-priority rule every mono instrument needs.
Sustain	—	brake lever, or rider effort	The sustain pedal is assignable to either: a second treadle for drive, or a brake lever.

■ SPECIFICATIONS

ITEM	VALUE
Version	0.13.0-beta
Format	CLAP 1.2, instrument. VST3 via clap-wrapper.
Ports	audio in (CV, non-main) · audio out (striker, main) · audio out (CV) · note in · note out
Integration	Fixed step at the host sample rate; the same wheel at 44.1 to 192 kHz. Strikes placed at the sub-sample crossing. Denormals flushed.
Wheel state	ω , θ , crank phase. Coupling between instances is through the CV port at unity, no gain stage required.
Striker	3 modes, phasor recurrence, per-strike retune with a 0.4% deadband. One or two cards, each with its own modal state, bend and contact noise; the pair is detuned and damped together.
Latency	0 samples
Parameters	62, append-only IDs, per-instance theme

■ SOURCES

- [1] van Noorden, L. and Moelants, D. "Resonance in the Perception of Musical Pulse." *Journal of New Music Research* 28(1), 1999, 43-66. The resonance curve of section 2 and the 500 ms preferred period.
- [2] Kuo, A. D. "The six determinants of gait and the inverted pendulum analogy: a dynamic walking perspective." *Human Movement Science* 26(4), 2007, 617-656. Why the pendulum model is the right first approximation and where it fails.
- [3] Hafner, J. W., Sturgell, J. L., Matlock, D. L., Bockewitz, E. G. and Barker, L. T. "Stayin' Alive: A Novel Mental Metronome to Maintain Compression Rates in Simulated Cardiac Arrests." *Journal of Emergency Medicine* 43(5), 2012, e373-e377. PMID 22445896. Providers trained against the recording kept guideline rate when retested at least five weeks later without it.
- [4] Randall, R. B. *Vibration-based Condition Monitoring*. Wiley, 2011. Order analysis, blade-pass frequency, and the reading of sidebands as once-per-revolution faults.
- [5] Savart, F. *Toothed-wheel experiments on the limits of hearing*, Paris, 1830s. The apparatus of section 3, with a tachometer that tied each tone to a tooth rate. The surviving apparatus is described in the Kenyon College Early Apparatus collection.
- [6] Tudor-Locke, C. and Rowe, D. A. "Using Cadence to Study Free-Living Ambulatory Behaviour." *Sports Medicine* 42(5), 2012, 381-398. The 115 steps per minute weighted mean of eight observational studies of pedestrians, and the laboratory range of 96 to 138 for women.

■ COMPANION MATERIAL

Every figure in this note is generated by `docs/build_wheelie_note.py` from the constants in `src/wheel.h`. The derivations, including the gear trade-off and the coupling measurement, are worked in full in `notebooks/01_wheelie_physics.ipynb`.