

Hand-Crank Phone Charger

Design document: objectives, the numbers behind the claim, the mechanism, the electronics, how it is made and how it will be judged

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11 October 2026 (designed, printed, parts ordered; not yet assembled with its electronics, not yet tested)

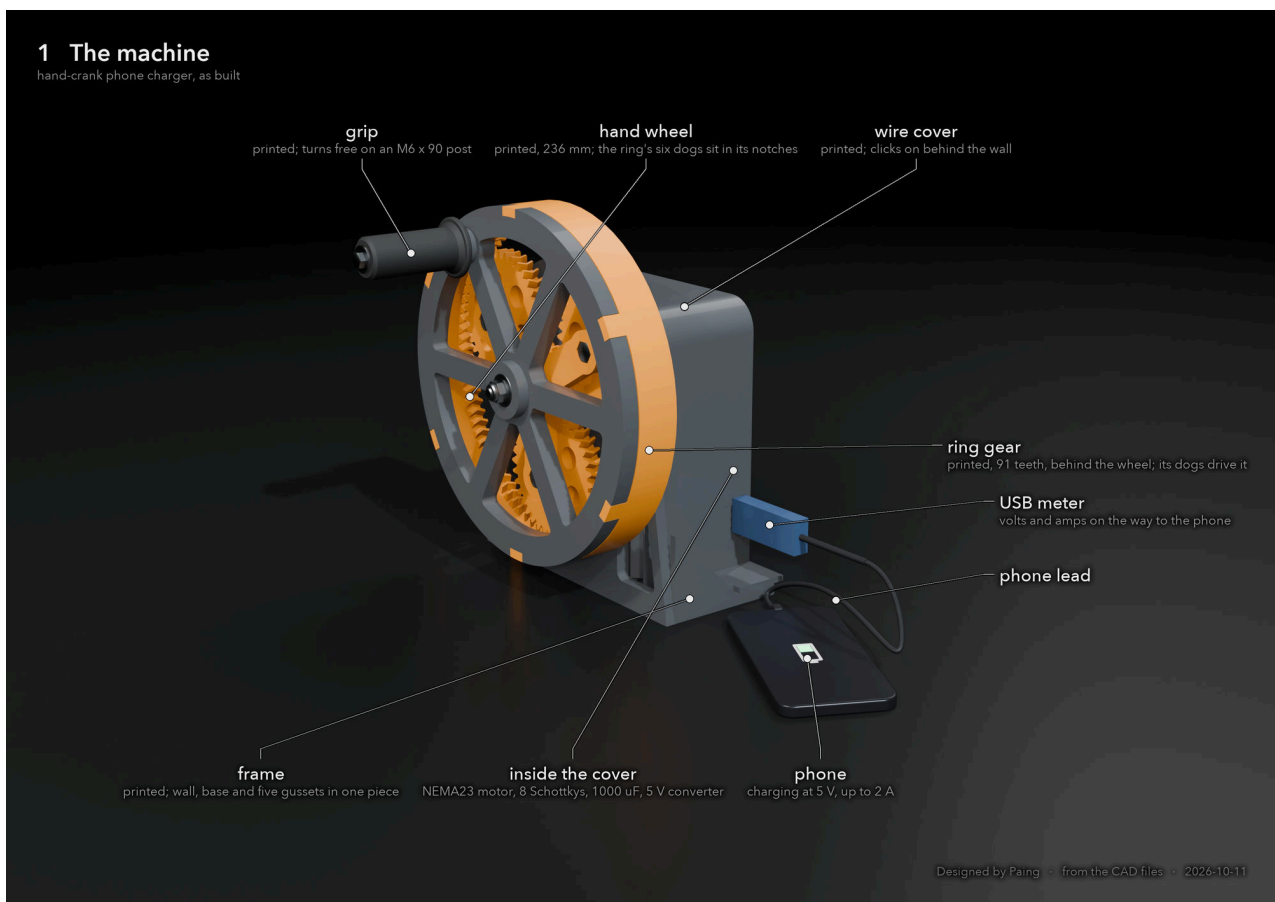


Figure 1: The machine as designed. A 236 mm hand wheel drives a printed planetary gear train that spins a NEMA23 stepper motor as an alternator; a printed cover behind the wall holds the rectifier card and the 5 V converter; a USB meter stands in the lead to the phone. Every picture in this document is rendered from the build's own part files (CadQuery to Blender), so a picture cannot show a part that was not printed or bought.

Summary

A hand crank turns a 91-tooth ring gear. Three 37-tooth planets on fixed steel pins drive a 17-tooth sun on the shaft of a NEMA23 stepper motor, so the motor turns $91/17 = 5.35$ times faster than the hand. Run backwards, the stepper is a two-phase alternator; two Schottky bridges and a $1000\mu\text{F}$

capacitor make a DC bus, and a buck converter brings it to USB 5 V for the phone. All plastic parts are 3D printed on a Bambu P1S, the gear train in one job, already meshed. The design predicts **10 W into the phone for about 17.5 W at the hand** at a 90 rpm cadence. Section 3 shows where every one of those numbers comes from, in fifteen lines of arithmetic. The prediction is locked before the first crank and judged by one filmed test on 25 October 2026.

1 Objectives

1. Build a hand-powered USB source entirely from printed parts plus a stepper motor, bearings, bolts and three off-the-shelf electronic modules. No surface-mount parts, no bare ICs, nothing that needs hot-air soldering.
2. Make a *prediction* of its output before it turns, and then measure it. The number matters less than whether the model that produced it was right.
3. Learn, by building one, how a drivetrain, an alternator and a power chain trade torque, speed, volts and watts against each other, and against a human arm.
4. Produce something legible: a short film with the meter in shot, this document, and the print files, so the result can be checked and repeated.

Exit test (the only definition of done). Filmed: 60 s of continuous cranking, the phone plugged in, the charging icon on for the whole minute, a USB power meter in shot, and the measured watts written next to the number `design.py` lock predicted before the first crank. By 2026-10-25. STLs are not done. A render is not done. A lit LED is not done. A multimeter reading with no phone attached is not done.

2 What is claimed, and what is not

Every number in this section comes from a model (`design.py` on top of a SPICE sweep of the motor), not from the bench. They are claims about what the machine *should* do; the film on 25 October is what it *does*.

PREDICTED, NOT YET MEASURED

Gear ratio	5.35 : 1 (star drive, 17 / 37 / 91 teeth, module 2.4)
Hand cadence assumed	90 rpm, 100 mm crank arm
Generator speed	482 rpm
DC bus	7 V (the converter's minimum), 12.4 W available
Into the phone	10.0 W (5 V, 2 A, the USB port's ceiling; the phone decides what it takes)
At the hand	17.5 W = 1.85 N m = 19 N on the grip
Hand to phone	57 percent
Pitch of the gear whine	136 Hz (the sun's teeth passing)
One percent of a 15 Wh phone	0.9 minutes of cranking
Unloaded, spun 1.5 times faster	24 V on the bus (the converter dies at 32, the capacitor is rated 50)

What is deliberately not claimed: that it "works". Until the film exists, the honest status is: designed, checked by script, printed, not yet assembled with its electronics, not yet turned under load. Two known optimisms in the model: iron loss in the stepper is not modelled (it grows with

speed, so the watts at the top of the curve are too high), and mesh plus bearing efficiency is a guess of 0.9 per mesh. The payoff is also stated plainly: at 10 W a phone gains about one percent per minute of hard cranking. This is a demonstrator of a drivetrain and an energy chain, not a practical way to charge a phone.

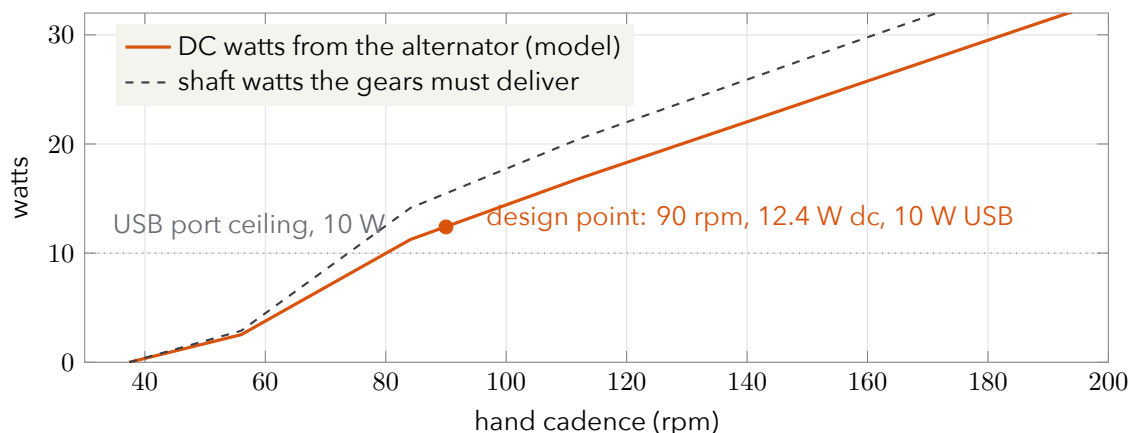


Figure 2: The alternator model (`sim/alternator_sweep.py`, NEMA23 constants $R = 0.9\ \Omega$, $L = 2.5\ \text{mH}$, $k = 0.318\ \text{V per rad/s}$, 50 pole pairs), re-plotted against the cadence of the hand through the 5.35:1 stage. Below about 50 rpm the bus cannot reach the converter's 7 V and nothing comes out; above the design point the extra watts would mostly be wasted, since the USB port caps the phone at 10 W.

3 The numbers, step by step

One running example, the design point: a hand turning the wheel at 90 rpm on a 100 mm arm. Every line below is a sum anyone can repeat with the motor's label and a calculator; the two lines that need the circuit simulation are marked.

3.1 From the hand to the motor shaft

The ring has 91 teeth and the sun 17, so one turn of the hand is 5.35 turns of the motor. Physics wants angular speed in radians per second: one turn is 2π radians, one minute is 60 seconds.

$$\begin{aligned} \text{ratio} &= \frac{91}{17} = 5.35 \\ n_{\text{motor}} &= 90 \times 5.35 = 482\ \text{rpm} \\ \omega &= 482 \times \frac{2\pi}{60} = 50.4\ \text{rad/s} \quad (\text{and the hand: } \omega_{\text{hand}} = 9.42\ \text{rad/s}) \end{aligned}$$

3.2 From speed to volts: Faraday, with the motor's own constant

A hybrid stepper has a magnet rotor with 50 teeth and two separate windings, coil A and coil B, a quarter of a tooth apart. Turn the shaft and the magnet's flux through each coil swings up and down 50 times per turn. Faraday's law says the voltage is the *rate of change* of that flux: the flux wave has the same height at any speed, but a faster turn squeezes it sideways, and a squeezed wave is steeper. So the peak voltage grows in a straight line with speed, and everything fixed about the motor (turns, magnet, teeth) collapses into one constant k :

$$E_{\text{peak}} = k \omega$$

The constant is not guessed: the same k that links volts to speed links torque to current ($T = k I$), and the label gives holding torque 1.26 N m at 2.8 A with both coils on, which is $\sqrt{2}$ times one

coil:

$$k = \frac{T_{\text{hold}}}{\sqrt{2} I_{\text{rated}}} = \frac{1.26}{1.414 \times 2.8} = 0.318 \text{ V per rad/s}$$

$$E_{\text{peak}} = 0.318 \times 50.4 = 16.0 \text{ V per coil}$$

3.3 The current ceiling: why this motor behaves the way it does

The coil is three things in a row: the source E , the wire's resistance $R = 0.9 \Omega$, and its inductance $L = 2.5 \text{ mH}$, which resists any *change* of current. The faster the wave, the harder the inductance pushes back, and that push-back is measured in ohms like a resistor:

$$f = 50 \times \frac{482}{60} = 402 \text{ Hz}$$

$$X = 2\pi f L = 2\pi \times 402 \times 0.0025 = 6.3 \Omega$$

$$Z = \sqrt{R^2 + X^2} = \sqrt{0.9^2 + 6.3^2} = 6.4 \Omega$$

$$I_{\text{max}} = \frac{E_{\text{peak}}}{Z} = \frac{16.0}{6.4} = 2.5 \text{ A}$$

The one fact that shapes the whole machine. Crank faster and E rises, but X rises by exactly the same factor, so the current the coil can pass stays near 2.5 A at any speed. A ceiling on current is a ceiling on torque ($T = k I$), and the circuit simulation puts that ceiling at about 0.33 N m for the loaded motor. Power is torque times speed, so with the torque pinned, *the only way to more watts is more rpm*. That is why the hand's 90 rpm is multiplied, not reduced, and why a bigger ratio makes the crank heavier before it makes more watts.

3.4 From AC to a 7 V bus: diodes, capacitor, converter

Each coil's voltage swings from +16 to −16 V. Four Schottky diodes round each coil flip every negative dip upward; the current always passes through two of them, each taking about 0.5 V (a silicon diode would take nearly double). The two coils are a quarter wave apart, so when one is at zero the other is at its peak, and together they never fall below about 10 V. The 1000 μF capacitor is a small tank that fills on each bump and gives back in each gap, so the bumps become a flat bus.

$$\text{after the diodes} = 16.0 - 2 \times 0.5 = 15 \text{ V peak (nothing plugged in)}$$

$$\text{bus current at 10 W out} = \frac{11.4 \text{ W}}{7 \text{ V}} = 1.6 \text{ A}$$

$$\text{ripple on the bus} \approx \frac{I}{4fC} = \frac{1.6}{1608 \times 0.001} \approx 1 \text{ V at most}$$

$$\text{diode heat} \approx 1 \text{ V} \times 1.6 \text{ A} \approx 1.6 \text{ W}$$

Why the bus sits at 7 V and not 15: once the phone draws current, that current has to come through the coil's own 6.4Ω , and most of the 16 V is used up inside the motor pushing it. The diodes and the capacitor clamp the coil's two ends 8 V apart ($0.5 + 7 + 0.5$), the other 8 V is dropped across R and X . Draw nothing and the bus floats back up to 15 V. The converter needs about 7 V to make 5 V (it keeps about 88 percent of what it takes), which fixes the design bus at 7 V. The slowest useful crank follows from the same lines: the coil must give $7 + 1 = 8 \text{ V}$, so $\omega = 8/0.318 = 25 \text{ rad/s}$, 240 rpm at the motor, about 45 rpm at the hand with nothing drawing, nearer 55 rpm with the phone on.

3.5 Back to the hand: the loss budget

Now walk backwards from the phone. Two rules: power out equals power in times efficiency, and power equals torque times angular speed.

$$P_{\text{in, converter}} = \frac{10}{0.88} = 11.4 \text{ W}$$

$$P_{\text{shaft}} = 11.4 + 2.8 = 14.2 \text{ W} \quad (2.8 \text{ W of copper and diode heat, from the simulation})$$

$$T_{\text{motor}} = \frac{14.2}{50.4} = 0.28 \text{ N m}$$

$$P_{\text{hand}} = \frac{14.2}{0.9 \times 0.9} = 17.5 \text{ W} \quad (\text{two meshes in series, } 0.9 \text{ each: a guess})$$

$$T_{\text{hand}} = \frac{17.5}{9.42} = 1.85 \text{ N m} = 0.28 \times 5.35/0.81$$

$$F_{\text{grip}} = \frac{1.85}{0.100} = 18.5 \text{ N} \quad (\text{about } 2 \text{ kg on the handle})$$

$$\text{whole machine} = \frac{10}{17.5} = 57 \text{ percent}$$

Where the 7.5 W goes	W	What it is
Gears and bearings	3.3	friction at the two meshes and five 608s (the 0.9 per mesh guess; the drivetrain rig would measure it)
Coil copper and diodes	2.8	I^2R in the windings plus about 1 V across two Schottkys
Converter	1.4	switching and conduction loss in the buck module

Table 1: The loss budget at the design point. The gears multiply torque on the way back: 0.28 N m at the motor becomes 1.85 N m at the hand. With nothing plugged in no current flows, so there is almost no torque; plug the phone in and the crank goes heavy.

4 Mechanical design

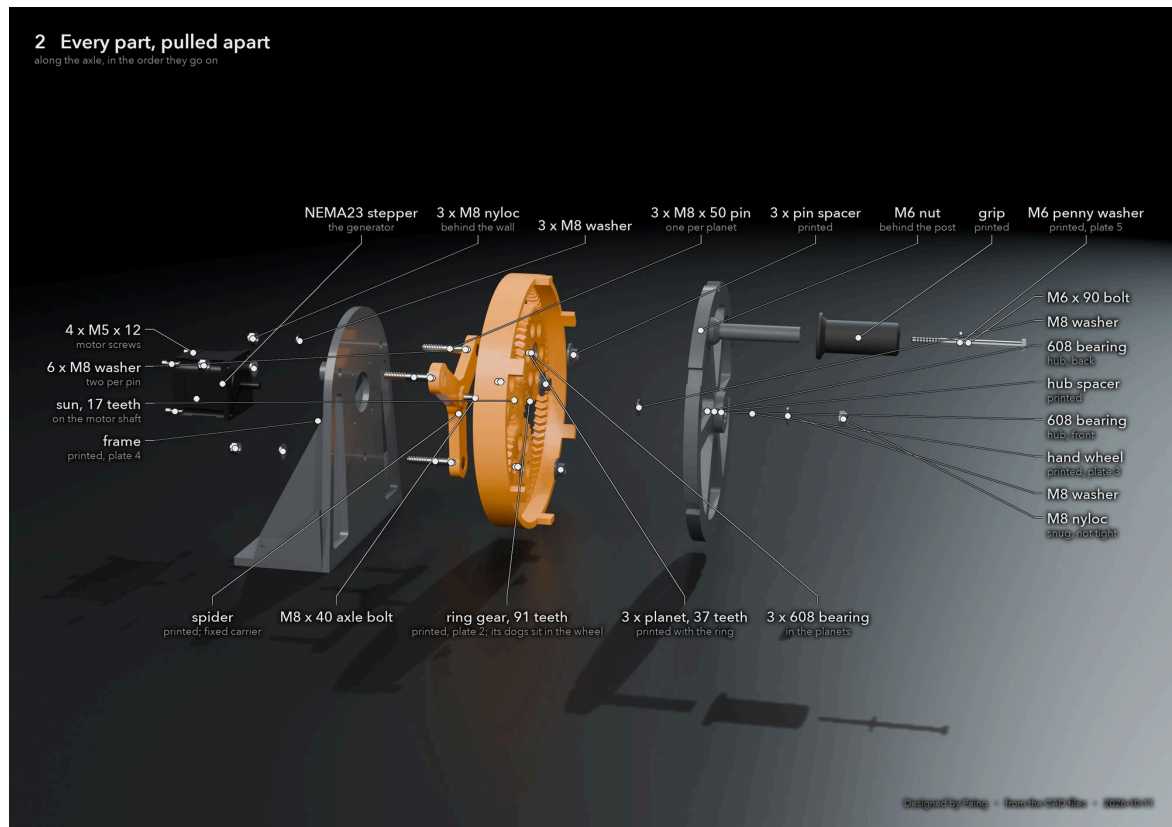


Figure 3: Every part of the machine pulled apart along the axle, in the order it goes on: motor and its four screws behind the wall; the wall; the spider cartridge with its three pins and six washers; the one-piece gear set and the planets' bearings; the pin spacers; the wheel with its hub bearings and spacer; the axle washer and nyloc; the grip, its penny washer and the M6 bolt.

4.1 Why a planetary stage, and why it is printed in one piece

A single large ring gear driven by the hand with a small sun on the motor shaft gives the whole 5.35:1 in one mesh pair, inside a 236 mm circle that fits the printer bed. Three planets between them do two jobs: they share the tooth load three ways (the tooth-root stress comes out at 0.6 MPa against a 12.5 MPa allowance, so the gears are far from their limit) and they centre the ring, which is left free to float 0.8 mm along its axle so the teeth, not a bearing, decide where it sits. The teeth are herringbone, a left-hand and a right-hand helix back to back: helical teeth run quieter and mesh more smoothly than straight ones, and the two halves cancel each other's axial thrust. Herringbone gears cannot be slid into each other, so the ring, three planets and sun are printed in place as one job, already meshed, with a 0.28 mm flank gap and a 0.25 mm "foot relief" shaved from the first 0.6 mm of every tooth so the layer closest to the bed cannot weld the gears together.

Why these tooth counts: 17 is the fewest teeth a 20-degree tooth can have without undercut; $17 + 2 \times 37 = 91$ so the planets fit between sun and ring; $(91 + 17)/3 = 36$ is a whole number, so three planets sit at equal angles; 17, 37 and 91 share no factor where they mesh, so every tooth meets every other and wear is even.

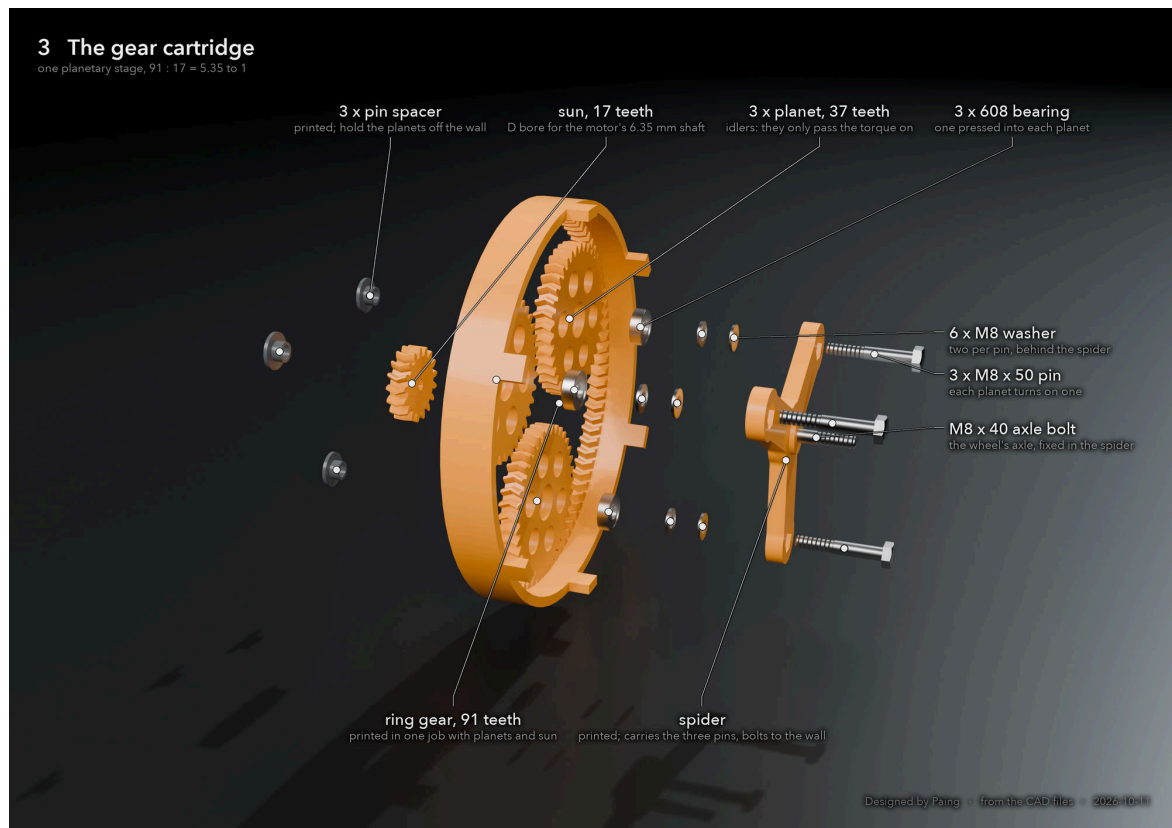


Figure 4: The gear cartridge. The spider is the fixed carrier: it bolts to the wall and carries the three M8 pins and the wheel's axle. Each planet turns on a 608 bearing on its pin; the sun has a D bore for the motor's 6.35 mm shaft; the pin spacers hold the planets off the wall. The planets are idlers: they pass the torque from the ring to the sun and carry none of their own.

4.2 Why the hand's side load never reaches the teeth

The hand wheel is a separate spoked disc on its own axle, carried by two 608 bearings in its hub. The ring gear's skirt carries six dogs that sit in six notches in the wheel, so the wheel turns the ring and nothing else. The axle sits in the fixed spider, the spider on three M8 pins, the pins in the wall. So the sideways force of a hand on a crank goes wheel, axle, spider, pins, wall, and the teeth carry torque only. The grip turns free on an M6 x 90 bolt down a post on the wheel, at 100 mm from the axle.

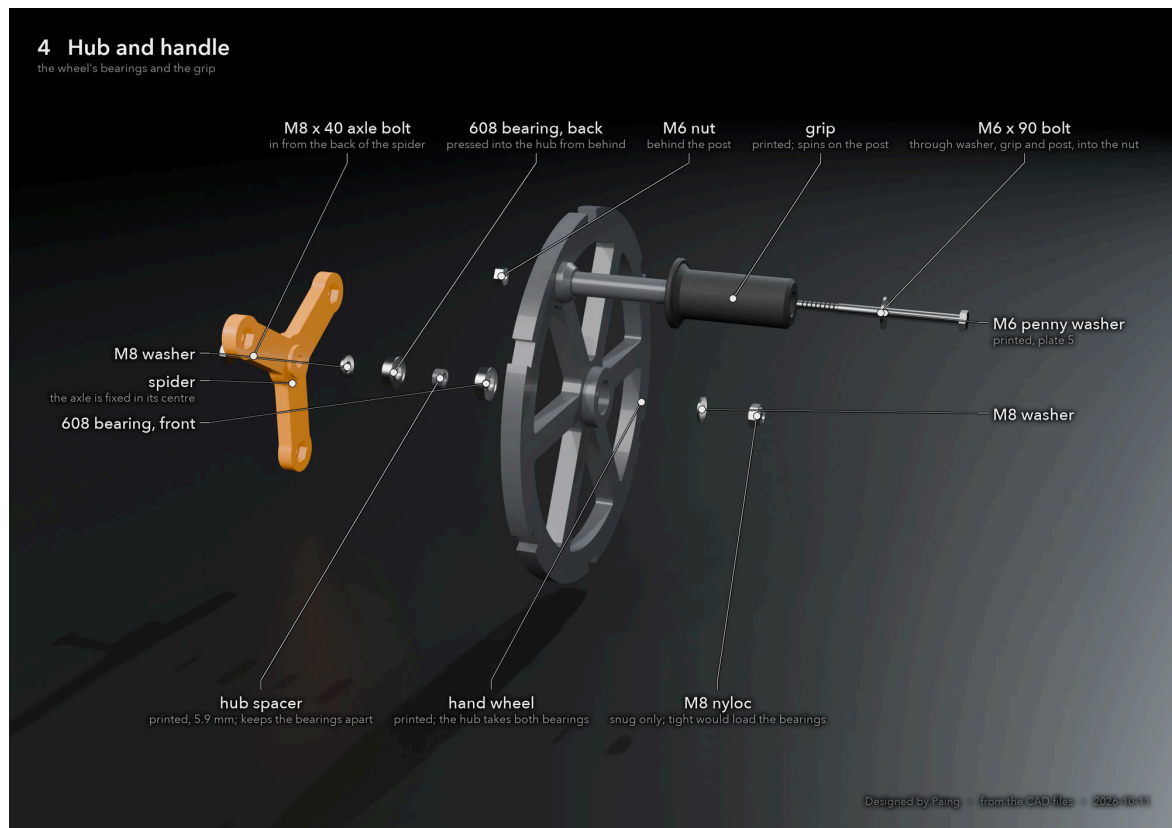


Figure 5: Hub and handle. The M8 x 40 axle is fixed in the spider; washer, bearing, printed 5.9 mm spacer and second bearing go into the wheel's hub from behind; a washer and a nyloc, snug only, hold the wheel on the axle. The grip rides on the M6 x 90 bolt through the post, with a nut behind the post and a printed penny washer under the bolt head.

4.3 Repairs along the way

Three things broke or slipped during the build, and each got a printed answer rather than a bought one: a damaged ring gear got a two-half ring that clips together with printed C-clips, so the good planets and sun did not have to be reprinted; a wheel that slid off the dogs before its axle nut arrived got a spring band, which did not fit, and then a redesigned wheel whose notches lock onto the dogs with a bayonet twist; a broken stand got a frame the cover clicks onto. The clip ring, the bayonet wheel and the click-on frame are drawn and checked by script but none has been tested in plastic, so this document shows the machine with its original wheel, ring and frame.

4.4 Parts

Table 2 lists every part of the machine and the reason for each choice.

Part	What it is	Why this one
Gear set	Ring 91 t, 3 planets 37 t, sun 17 t, module 2.4, herringbone, printed in place (plate 2)	Fits a 256 mm bed; one print, no assembly of teeth
Frame	Wall with motor pilot and three pin bosses, base 85 mm deep, five gussets, one piece (plate 4)	The only part that sees the hand's side load; clamped to the table with two G-clamps
Spider	Fixed carrier: three hex pockets for the pin heads, a hex pocket for the axle head (plate 1)	Lets one 13 mm spanner do every M8 nut
Wheel	236 mm spoked disc, hub for two 608 bearings, six notches for the ring's dogs, handle post (plate 3)	Separates the hand's bending load from the teeth
Grip, spacers, washers	Grip on its disc, hub spacer 5.9 mm, three pin spacers, 12 M8 washers and an M6 penny washer, 1.6 mm (plates 1 and 5)	Printed washers replaced the bought ones
Motor	JoyNano NEMA23, 2.8 A, 1.26 N m, $0.9\ \Omega$, 2.5 mH (datasheet twin of the 23HS22-2804S)	Torque ceiling 0.33 N m gives 12 W dc at 482 rpm; a NEMA17 would give about 2.5 W
Bearings	5 x 608 (8 x 22 x 7)	Skateboard bearings: cheap, M8 bore matches the pins and axle
Fasteners	3 x M8 x 50, 1 x M8 x 40, 4 x M8 nyloc, M6 x 90 + nut, 4 x M5 x 12	Hex heads sit in printed pockets; nylocs because the wheel must be snug, not tight; the M5s cut their own thread in the wall
Cover	Printed shell behind the wall, two pegs in the base and forks on the gussets, held by the same two clamps	Hides the card, module and every wire; one window for the USB meter

Table 2: The parts of the machine. Printed parts are PETG unless noted; bought parts are standard.

5 Electronics

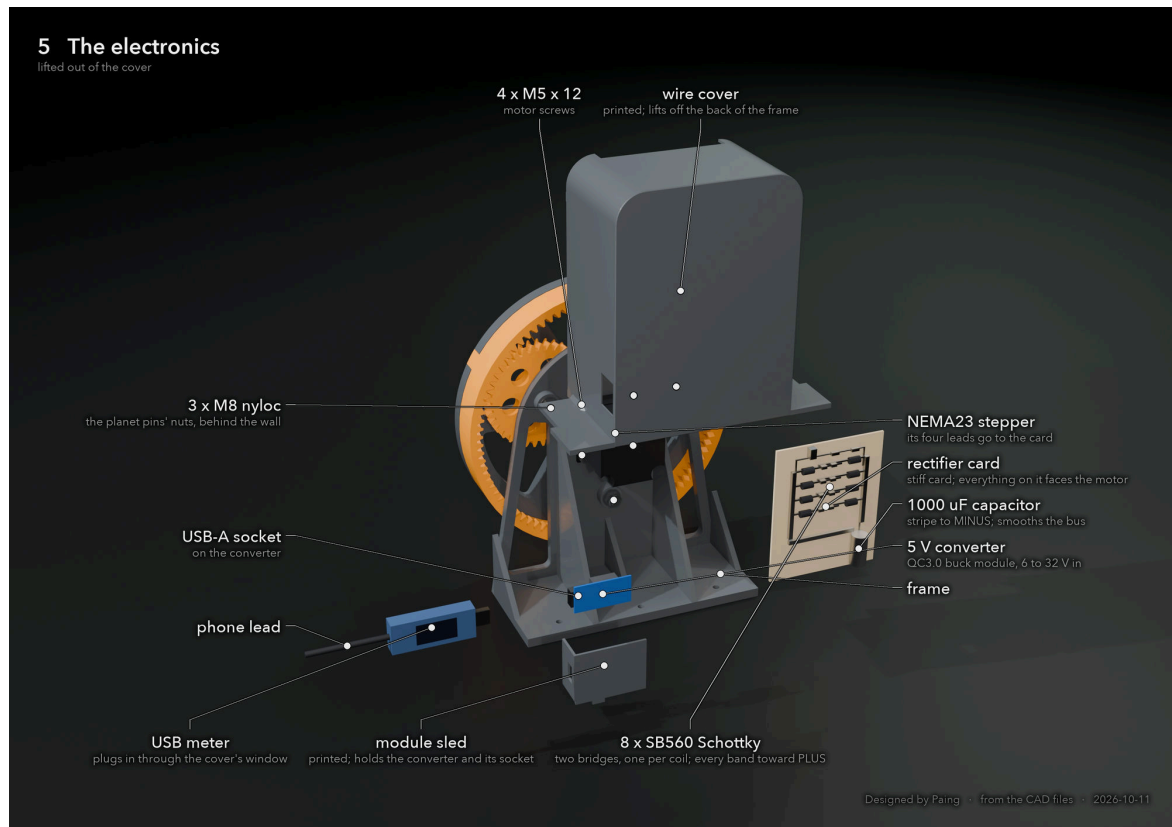


Figure 6: The electronics lifted out of the cover. The rectifier card is turned round to show its face: eight SB560 Schottky diodes soldered lead to lead into a ladder, the 1000 μF capacitor at the low end. The converter and its USB-A socket sit in a printed sled; the USB meter plugs into the socket through the cover's window and the phone lead hangs from the meter. The motor is behind the wall with its four screws; the three nylocs are the planet pins' nuts.

5.1 The circuit

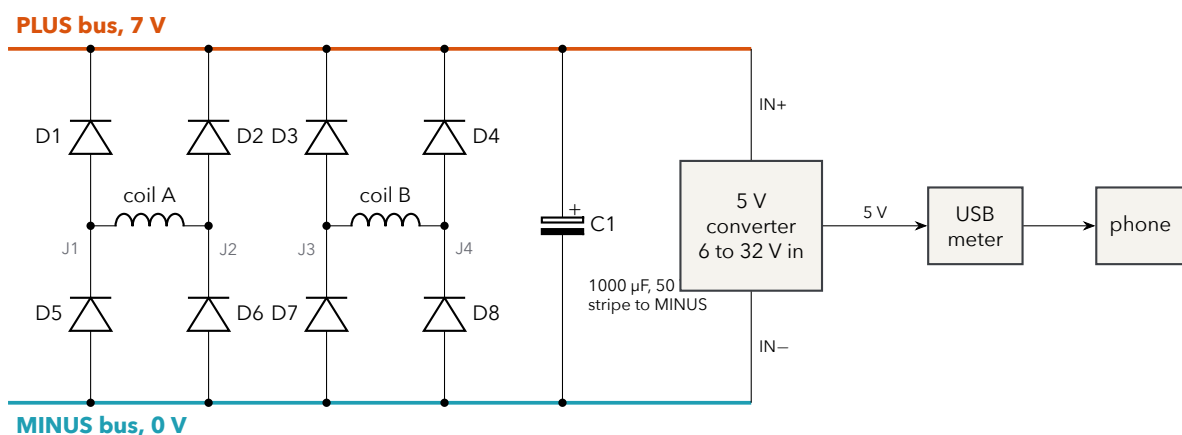


Figure 7: The power chain. The motor's four wires are the two ends of coil A (to J1 and J2) and the two ends of coil B (to J3 and J4). Each coil has its own four-diode bridge and the two bridges share one DC bus; every diode points up, so the rule "all eight bands toward PLUS" builds both bridges without a drawing. The electrolytic capacitor's stripe goes to MINUS. The converter (a QC3.0 buck module) takes the bus on IN+ and IN- and gives 5 V at up to 2 A on a USB-A socket; the meter plugs into the socket and the phone into the meter.

Part	Rating	Its job, and why that rating
8 x SB560 Schottky	5 A, 60 V, about 0.5 V drop	Turn each coil's swing into one-way current; 5 A is twice the coil's 2.5 A ceiling; a 60 V part laughs at the 24 V overspeed bus; Schottky because half the voltage lost means half the heat
1000 μ F electrolytic	50 V	Smooths the bus to under 1 V of ripple at 1.6 A; 50 V because the unloaded bus reaches 24 V and a 25 V part would be marginal
Buck converter	6 to 32 V in, 5 V out, QC3.0, about 88 percent	Makes USB 5 V from a bus that drifts with cadence; its 7 V minimum sets the slowest useful crank
USB meter	4 to 30 V, 0 to 5 A	The instrument of the exit test: volts, amps and watts into the phone, in shot

Table 3: What each electronic part does.

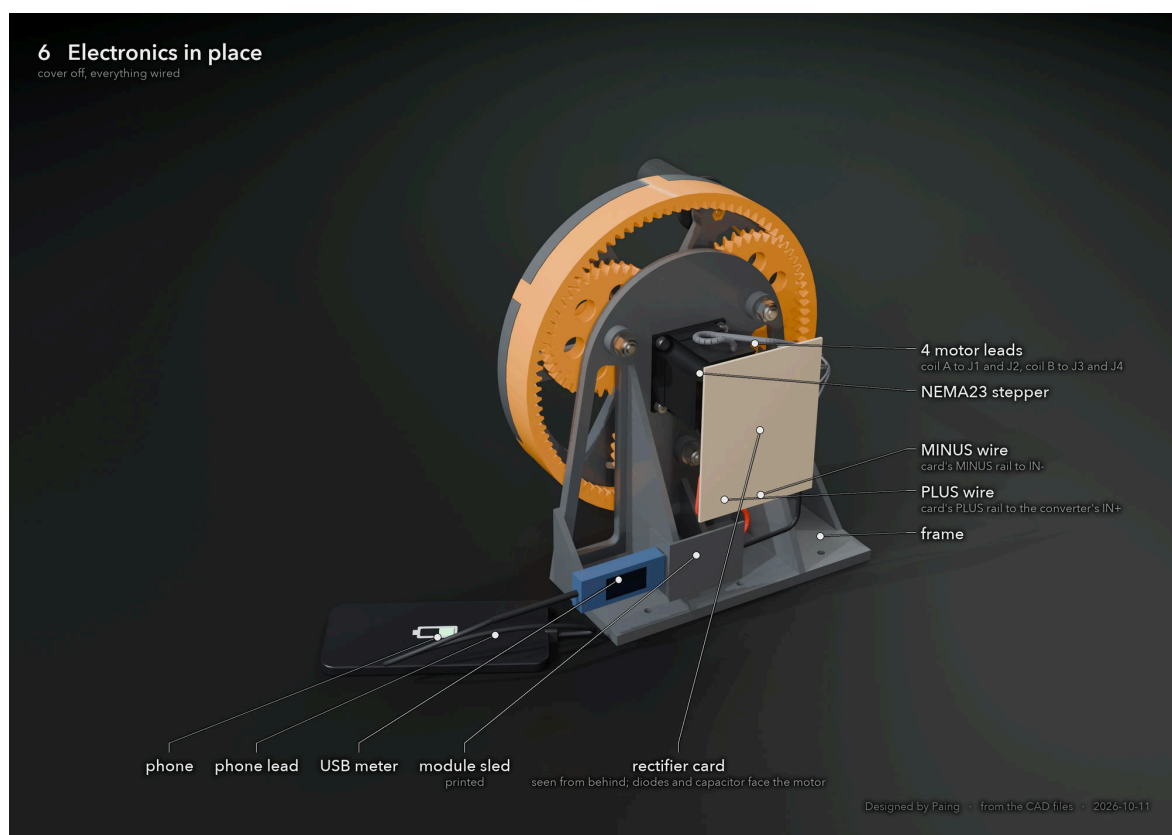


Figure 8: The electronics in place, cover off, seen from behind. The four motor leads come off the back of the motor to the top of the card; the card's face, with the diodes and capacitor, looks at the motor; two wires from the card's rails run down to the converter's input; the meter stands out of the sled's socket with the phone lead to the phone on the table.

5.2 Build method

No perfboard: the DO-201 diode leads are 1.3 mm, too fat for its holes. The eight diodes are laid on a printed full-size card template, soldered lead to lead into a ladder, then taped to a stiff card that stands in the cover. The capacitor's stripe goes to MINUS. The motor's four leads are tied down with a twist of wire through two pencil holes before they reach the ladder, so a tug on the motor never reaches a solder joint. The electronics guide (`electronics/ELECTRONICS.md` and its ten pictures, E1 to E10) is the step list:

E1 Find the two coil pairs with the meter on ohms: a pair reads about 1 Ω , a non-pair reads open.

Flag them A and B.

- E2 Bridge A: four diodes, bands up, soldered into the ladder; coil A's wires to J1 and J2.
- E3 Bridge B the same way, the two rails joined: coil B to J3 and J4.
- E4 Meter check by position before any power: every band toward PLUS.
- E5 First power from the bench supply at 3 V: a single LED on the bus lights.
- E6 The capacitor across the bus, stripe to MINUS.
- E7 Motor wires on, crank with nothing plugged in: bus volts against cadence (about 0.18 V per hand rpm, less the diodes).
- E8 Crank into a dummy load of thirty kit resistors twisted together ($5.7\ \Omega$), ten seconds at a time: real watts out of the alternator.
- E9 The module alone on the bench supply, then in the chain, then the meter, then the phone.
- E10 The film: 60 s, icon on, meter in shot, watts next to the prediction.

5.3 Hazards recorded in advance

The motor cannot push much current into anything (2.5 A even into a dead short), so no diode, wire or coil can burn from cranking; small test resistors can, and a reversed electrolytic can. The first USB meter in the plan was rated to about 7 V; it never arrived and its replacement is rated to 30 V, so a converter negotiating a higher voltage no longer threatens the instrument. The exit test still uses an iPhone, which stays at 5 V, so the measured watts compare directly with the prediction.

6 Making it

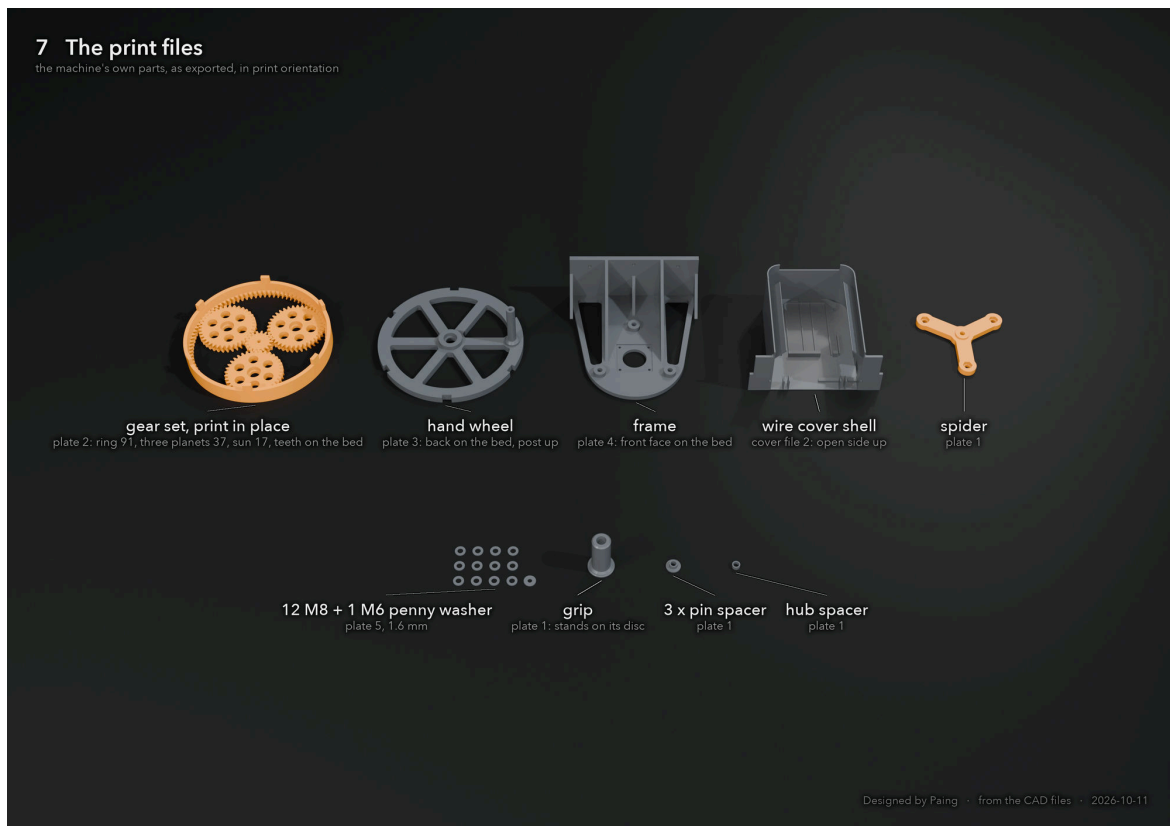


Figure 9: The print files of the machine, each in its print orientation: the frame with its front face down, the wheel on its back with the post up, the gear set with its teeth on the bed, the cover open side up, and the small parts of plate 1 with the washers of plate 5.

Plate	File	Note
1	coupon pair, spider, grip, hub spacer, 3 pin spacers	The two meshed test gears print in an hour; if they pull apart and spin, the gear set will
2	gearset_print_in_place	One job, five bodies, already meshed; 236 mm across so no skirt or brim; measure the motor's D-cut first, the sun is in this print
3	wheel	Back on the bed, post up; 236 mm across, 89 mm tall
4	frame	Front face on the bed; 210 x 225 on the plate, 93 mm tall; no supports
5	plate5_washers	12 M8 washers and the M6 penny washer, 1.6 mm, about ten minutes
cover	1_cover_coupons, 2_cover_shell	Coupons first; the shell waits for the measured sizes of the meter, the module and the clamp

Table 4: Print order. Settings that mattered after the first gear set came out as spaghetti: plain PLA or the printer's PETG preset, 0.2 mm layers, elephant-foot compensation 0.2 mm, 4 walls, 25 percent gyroid, avoid crossing walls on, random seam, no supports, no brim, outer wall 50 mm/s in PETG.

6.1 Assembly order

The picture guide ([assembly/assembly_steps.pdf](#)) shows each of these as a rendered step; the words are here.

1. Free the gears from the print, then press a 608 bearing into each planet.
2. Wheel hub: bearing in the back, then the spacer, then the second bearing.
3. Bolt the motor onto the back of the wall with the four M5 x 12.
4. The three M8 x 50 bolts into the spider's pockets, then two washers on each pin.
5. Lower the gear set onto the pins, then the pin spacers.
6. Cartridge onto the wall: pins in, sun onto the motor shaft. Behind the wall, a washer and a nyloc on each pin.
7. Washer, wheel, washer, nyloc onto the axle. Snug only: tight would load the bearings.
8. Handle: M6 nut behind the post, then the grip, the penny washer and the M6 x 90 bolt.
9. Clamp the base to the table with the two G-clamps.

Then the electronics, E1 to E10, and the cover over the back of the wall.

7 Techniques worth keeping

- **Print in place, coupon first.** Two meshed test gears print in an hour; if they come apart and spin, the full set will. The flank gap was raised from 0.19 to 0.28 mm after the first spaghetti ring, and the foot relief added; the second set turned freely.
- **Everything is checked by script.** The gear generator rolls the whole set through a tooth pitch and measures every gap; `planetary.py` runs about fifty checks and refuses to export if one fails. The cover, the clip ring, the bayonet wheel and the click-on frame each carry their own checks. Every STL then passes a mesh gate: one body, watertight, fits the bed.
- **One source of truth.** The assembly pictures, the explainer video and every figure in this document are rendered from the same part files that produced the STLs, with the labels placed by the renderer at each part's real centre, so a picture cannot show a part that was not printed.
- **Repair without screws.** When the ring gear was damaged, a two-half ring that clips together with printed C-clips replaced it without reprinting the planets and sun. When the stand broke, a frame the cover clicks onto replaced it.
- **Predict, then measure.** `design.py lock` writes the prediction to a file before the first crank. The film is judged against that file, not against a number chosen afterwards.

8 Status, risks and what is left

30 Sep	Layout decided (NEMA23, one planetary stage). First gear set printed too hot and wet: spaghetti ring, good planets and sun.
1 Oct	Fasteners ordered (Accu); motor, bearings, meter and clamps ordered (Amazon). Printed washers replace steel ones.
3 Oct	Motor, bearings and clamps delivered; Accu fasteners delivered. The USB meter's parcel never arrived and was refunded.
4 to 5 Oct	Every plate printed. Picture guide for assembly (steps 1 to 9) and the electronics guide written from the CAD.
5 Oct	Spider broken in handling, reprinted. Ring damaged: clip-together replacement drawn. Cover designed, test pieces sent.
6 Oct	Wheel found to slide off the dogs before its nut: keeper band drawn (printed, did not fit). Bolts, nylocs, M6 x 90, M5 x 12, converter 5-pack and 20 Schottkys ordered. Explainer video rendered with narration.
7 Oct	Bayonet wheel drawn to replace the band. Stand broken: click-on frame drawn. Replacement USB meter (4 to 30 V) bought.
9 Oct	Bolts, converter 5-pack, Schottkys and the new meter due.
11 Oct	This document and the labelled picture set.
Still to do	Measure the new meter and the real module, then print the cover shell; assemble the cartridge and wheel with their nuts; build the rectifier card; bench tests E4 to E9; design.py lock; the film by 25 Oct.

Table 5: Build log. Nothing has been measured yet.

Risks. The predicted 17.5 W at the hand is close to what one arm sustains, so the cadence may droop and the watts with it; that is a finding, not a failure. The converter's 7 V minimum means a slow crank shows nothing at all, which can look like a fault. The printed gears are untested under load: the first minutes of cranking are the real test of the 0.28 mm gap and the foot relief. The wheel's retention on the ring depends on the axle nut being fitted; the replacement wheel design is a fallback, not a plan.