Designing and building *Knights Battle*

Problems and solutions

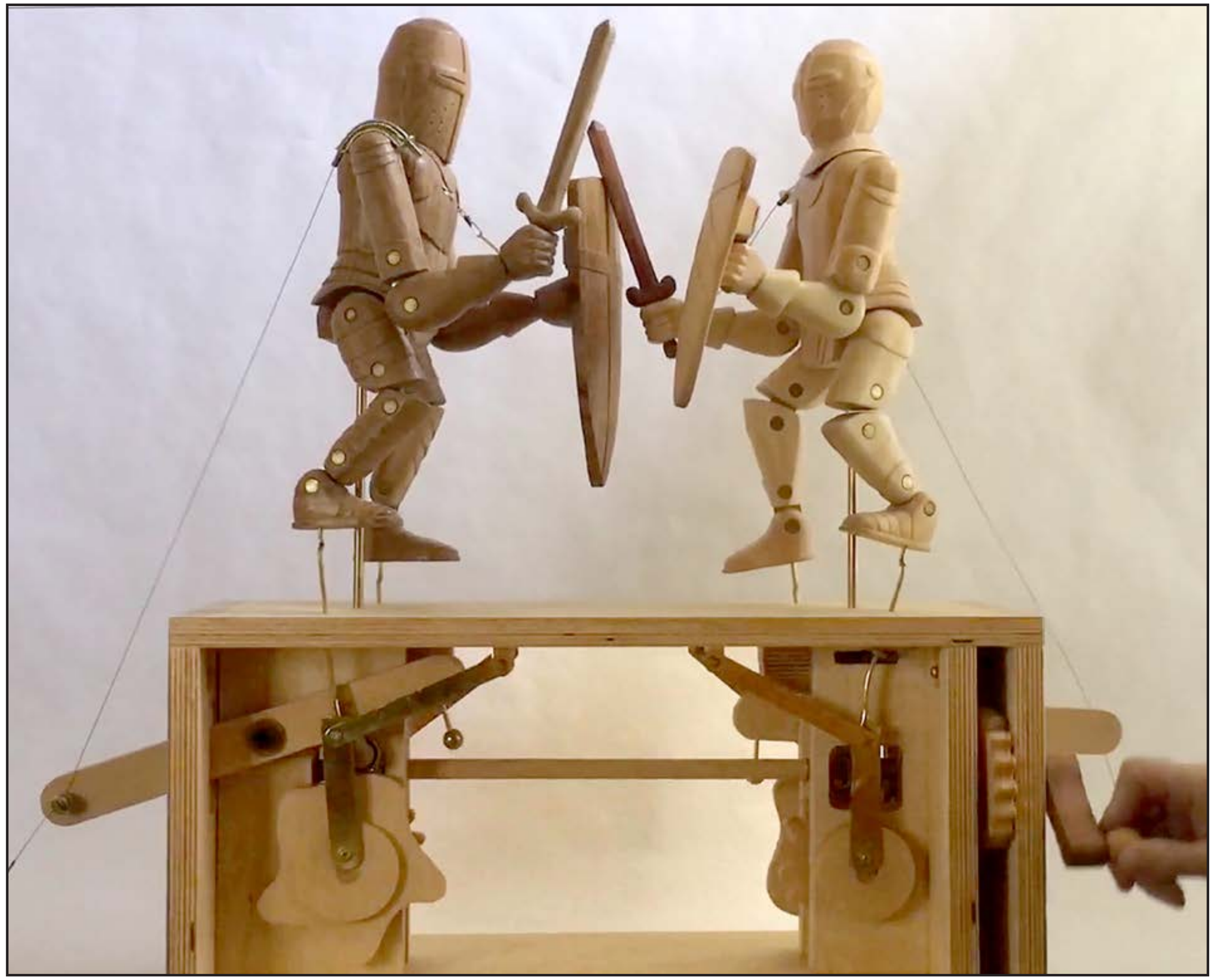
by Chris Hughes • Owen Sound, Ontario, Canada • Photos by the author

Knights Battle (**photo 1**) grew out of my previous piece, *The Swordsman*. I thought that if one swordsman is good, then two joined in battle would be even better.

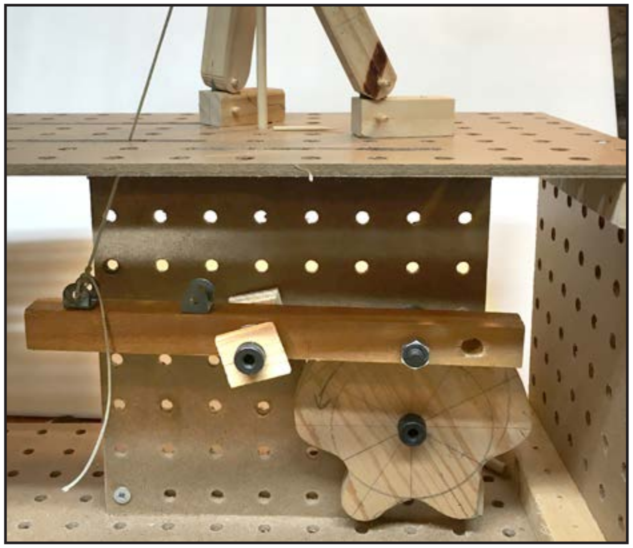
One of the design considerations for this project included the knights interacting as much as possible without snagging on each other and jamming. I also felt that, while the focus is on the figures themselves, the mechanisms should be as appealing as possible and should be part of the show, rather than hidden from view.

During my automata journey I have learned that progress must be made in small increments to avoid frustrating missteps. For example, my second build was going to be a mountain climber. However, after working on a foam-core prototype for a while, I finally acknowledged that my skills were not yet up to that complex a project.

I originally thought to have each knight alternately swing his sword, then duck when his opponent swung at him. I abandoned this as one of those “it would be nice” ideas that would have to wait until my mechanical-design skills catch up to my imagination. I decided instead to go with a tried-and-true method of moving the legs and rotating the bodies using a common but new-to-me mechanism: a cam



1. *Knights Battle*.



2. The pegboard prototyping box with movable partitions.

with a ball-bearing follower and lever to raise and lower the sword arms.

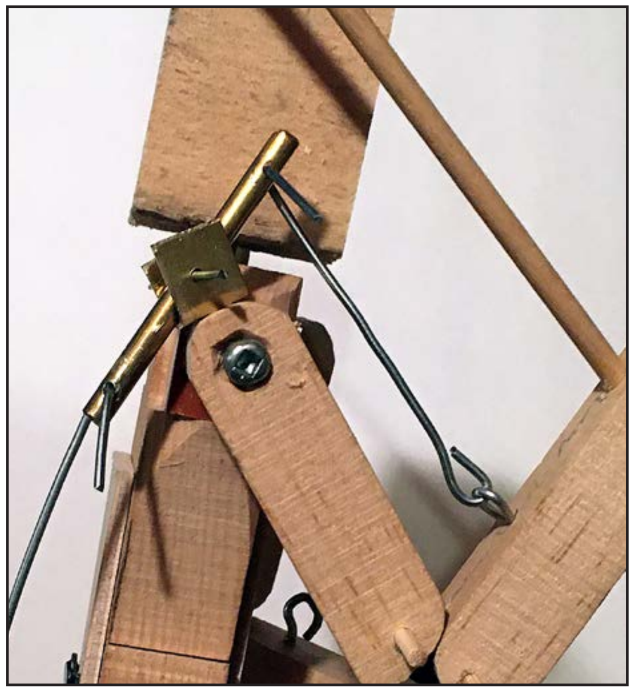
Prototyping

I made quite a few rough sketches before creating a prototype of one of the knights. As the knights are mirror images of each other, I only needed to work out the mechanics for one. I had previously made a prototyping box out of pegboard and ¾" pine (19mm—**photo 2**), which I find extremely helpful in designing the layout for the components. I may yet try to learn how to use a simple CAD program but at this point I'm content to work with paper, pencil, and the prototype box.

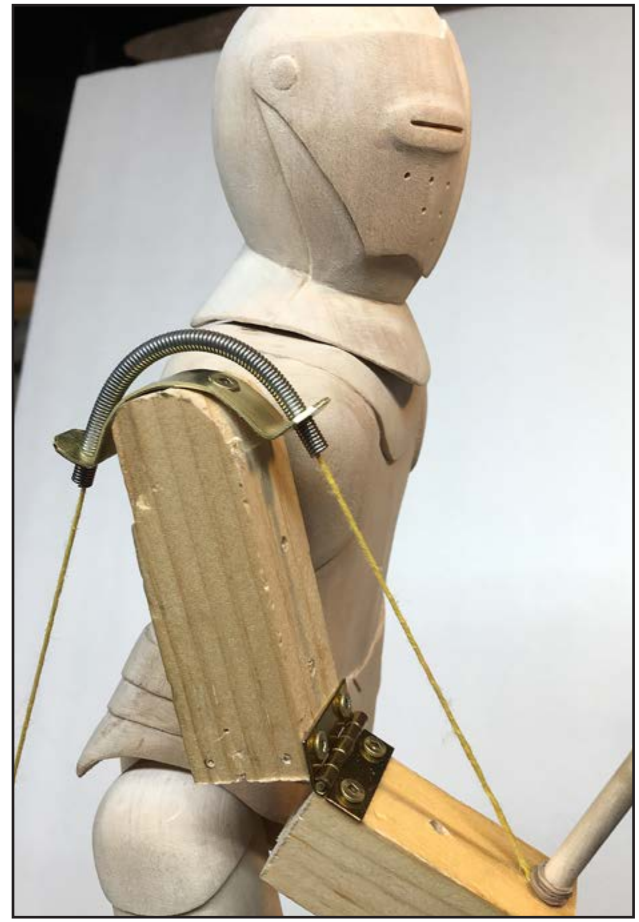
Informed by my prototype, I carved both knights before going to work on the mechanism. While the figures must eventually be mated to the mechanism, I have found it easier to modify the mechanism than the figures. In my first automaton, *The Kayaker*, I had to replace both of the figure's arms in order to get the movement I was after. I'm still saddened when I occasionally happen across those poor, discarded arms in my parts box.

I had originally thought of using a vertical rod projecting through the base to raise and lower the sword arm. However, that proved too difficult to do without limiting the torso's rotation.

The original prototype had a lever on its shoulder to move the forearm (**photo 3**) but this was also abandoned, as it was too visually intrusive. Instead, each knights' arm mechanism now employs a cable sliding through a spring sleeve on the shoulder of his sword arm (**photo 4**).



3. A prototype knight with a lever on his shoulder to control his sword arm.



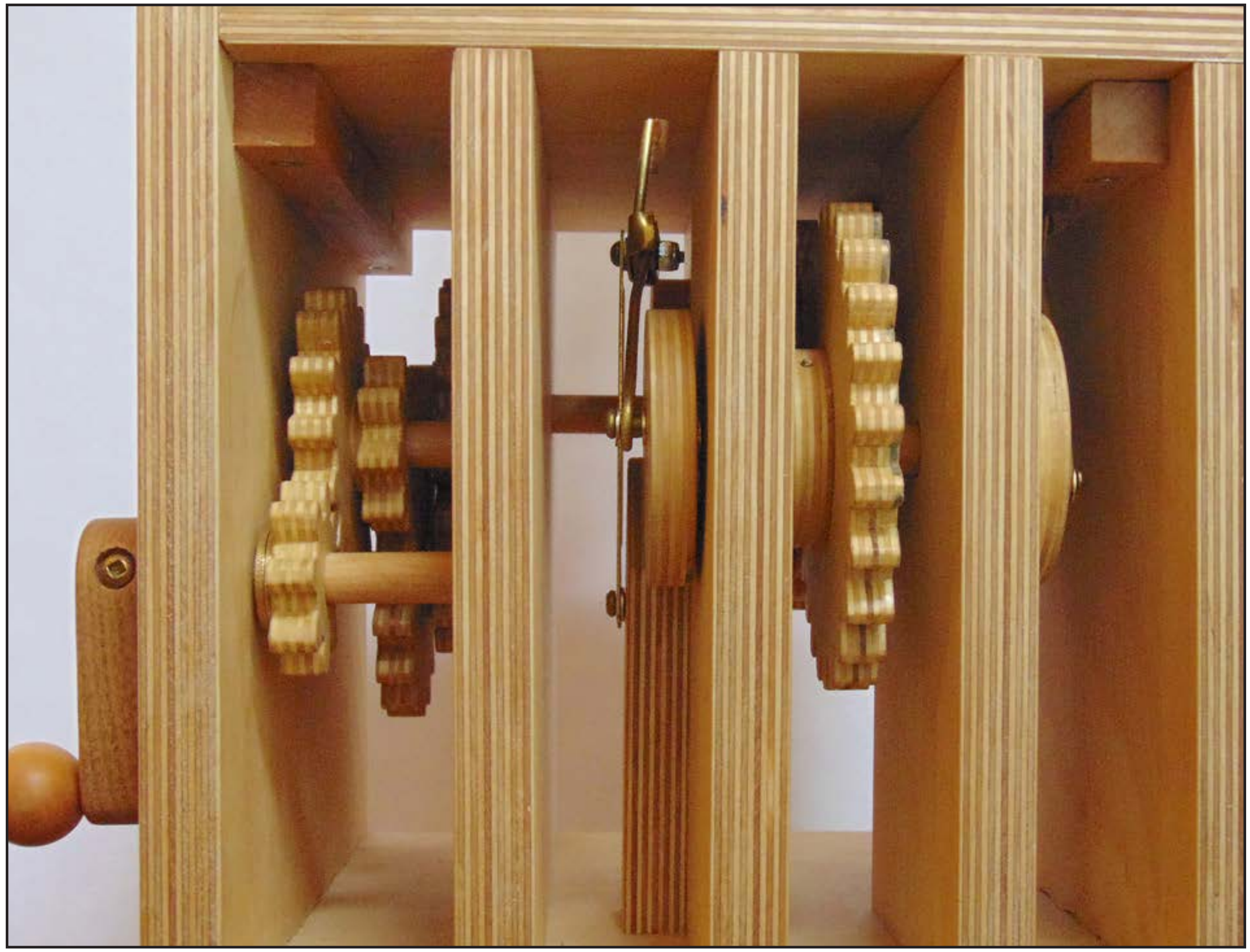
4. This knight has a prototype arm to test the spring cable guide.

Worm gears

To power the automaton, I had planned to use a crank mounted on the long side of the box along with the same type of wooden gear drive that I had used in previous automata. Eventually, though, I decided to go with worm gears after considering how crowded the box would have to be, with gears and supports, to span the distance between both knights.

An *Automata Magazine* article by Marc

5. A brass worm is soldered to a brass sleeve over the wooden shaft for greater security.



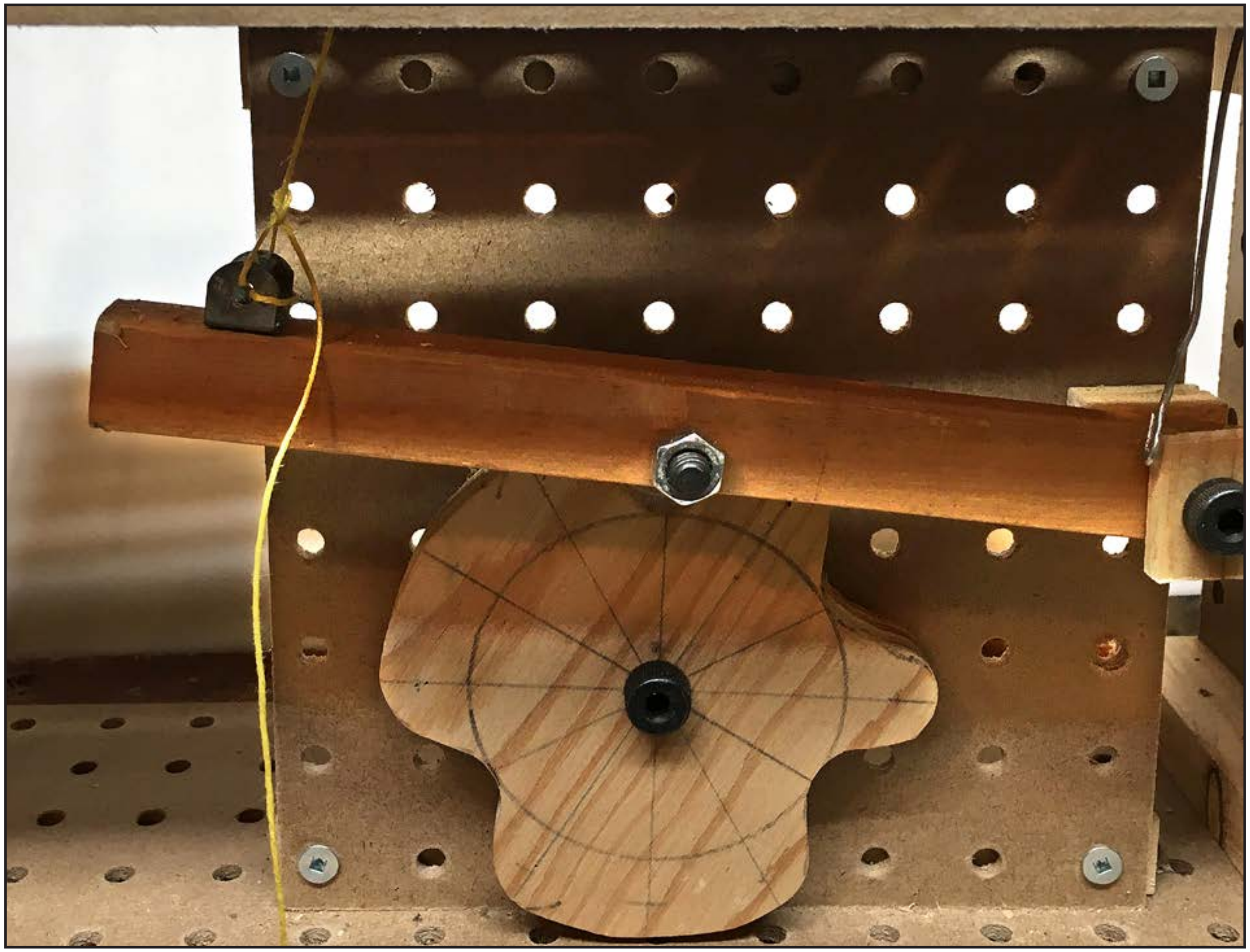
6. *The Swordsman* mechanism has three eight-tooth and three 16-tooth gears to step the rotation down to 8:1. With the *Knights Battle*, a 16-tooth gear on the crank and an eight-tooth gear on the driveshaft initially step the rotation *up* to 1:2 before stepping it down again to 8:1 and 9:1 with the worm gears.

Horovitz (November-December 2019, p. 41) helped me to understand and make wire worm gears. I used ⅛" (3mm) brass rod for the worm and made what I think is an improvement to the worm design by sliding a short section of 17⁄32" (13.5mm) brass tubing over the ½" (12.5mm) wooden drive shaft. I drilled the holes for the worm ends through the brass tube and soldered them to the brass sleeve (**photo 5**). This solved my concern about the brass rod popping out of the wooden driveshaft during use.

I was pleased to find that I could carefully use a butane torch to solder the wire to the brass sleeve without discoloring the wood beyond the sleeve. There is a left-hand worm for one figure and a right-hand worm for the other, so that the two final drive gears mirror each other.

Using worm gears changed the drive train significantly as well as reducing the number of gears needed. I had previously used wooden gears to reduce the rate of rotation at each step to yield one revolution of the final drive for every eight or so turns of the hand crank. My earlier *Swordsman*, for example, uses three eight-tooth gears and three 16-tooth gears to reduce eight turns of the hand crank to one revolution of the final drive (**photo 6**).

However, as the worm gear moves the final wooden gears only one tooth for each



7. A prototype cam lever with the pivot point at the end farthest from the load.

8. The final cam lever, with the pivot point between the follower and the load, proved to be a better solution.

rotation, the initial cranking rate was stepped up to 1:2, so that the worm gear rotates twice for each rotation of the hand crank. This was accomplished by the hand crank turning a 16-tooth gear that then turns an eight-tooth gear attached to the worm-gear driveshaft. The 16-tooth drive gear for the dark knight then rotates once for every eight turns of the crank.

I wanted to increase the randomness of the knights interaction by making them non-synchronized. The final drive for the dark knight has 16 teeth and light knight's has 18 teeth. The gear ratio is therefore 8:1 for the dark knight and 9:1 for the light knight, making the light knight slightly slower. The knights return to exactly the same position only once in every 72 turns of the hand crank.

Since the worms engage regular toothed gears, as opposed to pinwheel gears, I ended up having to do some filing on the final drive gears so that the worms wouldn't jam. This makes sense, as the wooden gear teeth should really be slightly angled to properly mesh with the worm. Next time I will see if I can cut the gear teeth at an angle with my scroll saw.

Second-stage prototyping

Once I worked out how far apart the figures had to stand so that they could interact without snagging each other, I was able to calculate the final dimensions of the

9. The control rod for torso rotation pokes out of the slot at the top of the photo.

box. I find finger-jointed corners to be quite helpful, as the box must be taken apart and reassembled many times during the building process. When I cut and finger-joint the Baltic birch plywood for the box, I also cut and finger-joint an extra top and one end out of some old pine boards I have around. This allows me to do some more prototyping on the final configuration before I cut the final slots and holes in that expensive Baltic birch. In the case of *Knights Battle*, I drilled several holes in the extra pieces to figure out the exact location of the knights' support rods relative to the slots for the leg rods. The dimensions and location of the cutout for the cam lever and the relative location of the hand crank were also laid out on the temporary pine end board.

When the location of the figures was established, I worked in steps from the final drive mechanism outward to determine the location of the hand crank. I found it best to move the hand crank to the left of the end support to avoid conflict with the lever that controls the light knight's sword.

Cam and follower

Having cut the sword-arm cams already, I played around with the follower and lever arrangement to achieve just the right movement in each sword arm. The first prototype had the pivot point at the far end of the lever from the load, with the follower in between (**photo 7**). This resulted in the sword falling when the cam follower lifted, which did not produce a satisfactory motion. Placing the pivot point between the follower and the load (**photo 8**) produced a much more convincing strike with the sword. The brass ball on each cam lever adds a little extra weight to help the sword arm drop more forcefully.

The amount of travel for the sword arm was adjusted by varying the distance from the bearing that rests on the cam to the pivot point of the lever, and the distance from there to the anchor point for the sword-arm cable. Each sword-arm cable can be adjusted at the pivot-bar end to maximize interaction between the figures while not snagging the opponent's shield.

Final adjustments

Each figure rotates on a ¼" (6mm) brass rod set into a bearing to minimize friction. The bearings are sandwiched between two pieces of plywood that are screwed to the underside of the base. This allows the figures to rotate quite smoothly. However, once it was assembled, I found that the leg movement would swing each knight almost 90° to his right, then back toward the center, so that the figures did not engage each other at all. The pull of the sword-arm cable accentuated this motion.

The solution was to install a rod connected from one leg actuator on each figure to the figure support rod in order to control the torso rotation (**photo 9**). A ⅛" hole (3mm) was drilled and threaded in each support rod above the bearing, and a threaded ⅛" brass rod links the left-leg actuator to the support rod, effectively controlling the rotation of each knight.

All in all, the *Knights Battle* was a satisfying project and I learned a lot along the way. Happy building!

LINK

Watch the knights fight it out here: https://youtu.be/MQY6HggOZHE
To see all of this issue's videos in one place, click here