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now uses closed loop servo digital sync lock servo technology. There is a lower grade "CNC converted" version at about half the price of the advanced CNC version.)

Chris Baron of Robot Power went into more detail:

I've had one of these for years. Got mine from Super Tech using their conversion and controller box. I cut mostly Al but I cut a saw blade to make a replacement firing pin for an old .22 once. Tried to cut Ti once but it was a disaster. Couldn't get the heavy feed needed to cut. I was probably doing it wrong but it is much more difficult to cut than Al, plastic, or steel where you just set the feed speed.

Works well overall as long as you remember it is a light duty machine for small parts. I find the Y axis travel to be frustratingly small. Z and X are fine (I have the 18" table).

They are a pain to keep lubed. I use an old-time oil can with a squeeze handle and a flex tube to reach the ways and screws. I use ATF fluid for the lube. Way oil is way hard to find in small bottles and/or locally.

I find them to be adequate in terms of speed and accuracy. The spindle motor on mine is weak for heavy feeds. The newer ones have larger spindle motors but I haven't upgraded. (Editor's note: According to their website, they now offer a 1/4 hp, continuous duty, 3,400 rpm motor on all CNC mills).

The optimum cutter for my machine is 1/8". Smaller and they break easily. Larger and the spindle lugs down unless the speed is turned way down. Be sure to pay the extra for the TiAlN coated cutters. They are really worth it.


Servo mill.

If I were buying a new machine, I would probably pay the extra and get a low-end Tormac. But for small parts, this will work fine. You will want to get a set of clamps for sure. There are a couple of places that make them sized for this machine. The Taig vise is only okay. I got a nice toolmaker's 3" vise from Enco that is more solid and easier to clamp stuff with.

Like all product reviews, your mileage may vary. I look forward to further input from users of this product. SV

MANUFACTURING: RioBotz Combot Tutorial Summarized — Tooth Design

● Original Text by Professor Marco Antonio Meggiolaro; Summarized by Kevin M. Berry

Editors Note: Professor Marco Antonio Meggiolaro, of the Pontifical Catholic University of Rio de Janeiro, Brazil, has translated his popular book, the RioBotz Combot Tutorial, into English. As in previous editions of the Combat Zone, portions of the tutorial are summarized. In this article, we present a much simplified version of the "Tooth Design" section of Chapter 6 — a major treatise on combot weapons. Marco's book is available free for download at ***www.riobotz.com.br/en/tutorial.html****. For a hard copy purchase (at no profit to Marco) go to Amazon. All information here is provided courtesy of Professor Meggiolaro and RioBotz.*

Tooth Design

One important issue when designing spinning weapons such as disks, bars, drums, and shells is regarding the number of teeth and their height. Too many teeth on a spinning disk, for instance, will make the spinner chew out the opponent instead of grabbing it to deliver a full blow. Everyone who's used a circular saw knows that fewer teeth means a higher chance of the saw binding to the piece being cut — which is exactly what we want in combat.

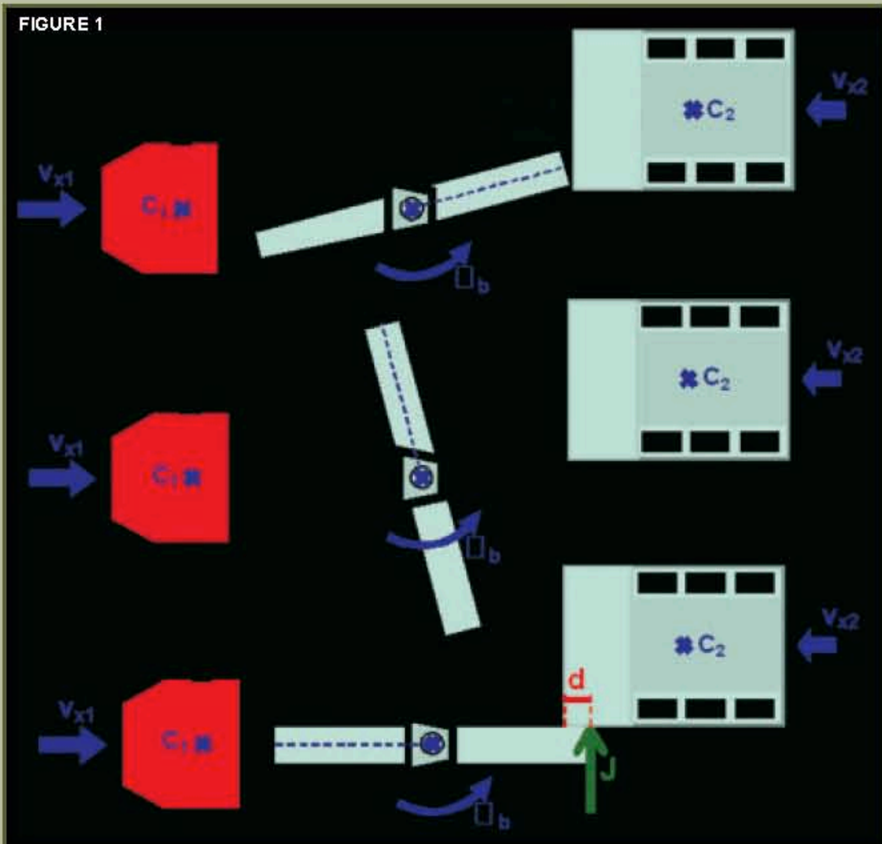


FIGURE 1

Tooth Height and Bite

Before we continue this analysis, we need to define the term "tooth bite," shown as "d" in **Figure 1**. The tooth bite is a distance that measures how much the tips/teeth of the spinner weapon will get into the opponent before hitting it. For instance, if two robots are moving towards each other with one of them having a spinning bar (as pictured in **Figure 1**), then the highest bite would happen if the bar barely missed the opponent before turning 180 degrees to finally hit it. So, the tooth bite is the "overlap" caused by the bots moving towards each other.

Small values for "d" mean that the spinner will have a very small contact area with the opponent, most likely chewing its armor instead of binding and grabbing it. So, a spinner needs to maximize d to deliver a more effective blow. This is why an attack with the drive system at full speed is more effective, since a higher closing speed will result in a higher d. This is also why very fast spinning weapons have a tough time grabbing an opponent, since their very high rotational speed ends up decreasing the tooth bite.

The maximum obtainable tooth bite can be generalized for any toothed weapon (**Figure 2**). A detailed mathematical proof is in the tutorial, but it sums up that there is no point in making the tooth height "y," any longer than the bite distance d. Intuitively, this makes sense, because there is no point in having the teeth any longer than necessary. The tooth bite should not be higher than the maximum value of d since that would decrease its strength due to higher bending moments.

The tooth height can still be reduced if necessary without compromising much of the tooth bite. This is because the equations for the tooth bite in the tutorial assumed that one tooth barely misses the opponent, until the next tooth is able to grab it. But, if instead of barely missing the opponent the previous tooth had barely hit it, it would have hit it with a distance much smaller than d. It is a matter of probability; the tooth bite can be any value between 0 and d, with equal chance (constant probability density). So, in 50% of the attacks at full speed the travel distance will unluckily be between 0 and half of d. In the other 50%, it will luckily be between half and the maximum bite distance. An (unlucky) hit with tooth bite very close to zero probably won't grab the opponent, and it will significantly reduce the attacker's speed until the next tooth arrives, decreasing the bite distance of subsequent hits. If the opponent's speed gets down to zero without the weapon grabbing the opponent, you'll probably end up grinding it. If this happens, the best option is to back up, and then charge again trying to reach maximum velocity and hoping for better luck with a high bite distance.

FIGURE 2

The chance of d being exactly at the

perfect, maximum distance is virtually zero. So if you want, you can make the tooth height shorter than the optimum dimension shown in the tutorial. If you choose, for instance, y = half of optimum, your robot won't notice any difference with this lower height in 50% of the hits since you came in on the short side of the 50/50 odds. On the other 50% (where tooth bite would be higher than half of optimum), the opponent will touch the body of the drum/disk before being hit by a tooth, resulting in a tooth bite equal to the tooth height. Designing y less than half of optimum is not a good idea, as most attacks will end up touching the drum/disk before the tooth.

For instance, the 2008 version of our featherweight Touro Feather had a drum with n = 2 teeth (**Figure 3**) spinning up to 13,500 rpm. Since the robot's top speed is 14.5 mph, then maximum bite distance = 14 mm (calculations shown in the tutorial). Since the overall height of the drum needed to be smaller than 100 mm (4") by design, a tooth height of 14 mm would result in a drum body with low diameter (72 mm or 3"). We then chose y = 10 mm for the tooth to stick out of the drum body. This 10 mm height is usually enough to grab an opponent. Also, in 10 mm/14 mm = 71% of the hits at full speed, the tooth height y will be higher than the tooth bite d. The opponent will only touch the drum body in the remaining 29% of the hits, when the next tooth will be able to hit the opponent with its full 10 mm height (unless the opponent had bounced off immediately after hitting the drum body).

Beware of a frontal collision between two vertical spinning weapons because the opponent may be able to grab your drum or disk body with its teeth before you can grab it. In this case, it is a game of chance. The robot with higher teeth will have a better chance of grabbing the opponent, as long as it spins fast enough. Since a vertical spinning bar does not have a round inner body, it basically behaves as if its tooth height y was equal to the bar radius. So, usually a powerful vertical bar will have an edge in weapon to weapon hits against drums or vertical disks.

Number of Teeth

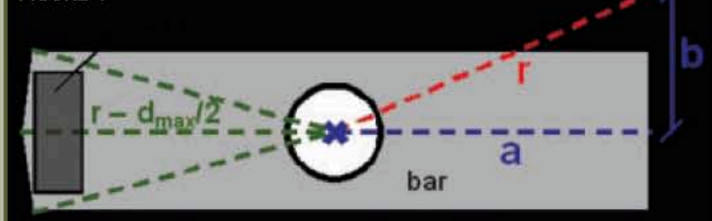
An important conclusion from the tooth bite equations is that you must aim for a minimum number of teeth. The lower the number of teeth, the higher the value of the bite distance. Disks with three or more teeth are not a good option. The best choice is to go for two teeth, as with bars or two-toothed disks. Even better is to try to develop a one-toothed spinning weapon, such as the disk of the vertical spinner Professor Chaos. However, but this requires a careful calculation to avoid unbalancing by using (for instance) a counterweight diametrically opposite to that tooth.

Note that a one-toothed weapon does not have to be too much asymmetric, nor will it need heavy counterweights, if you do your math right. For instance, the one-toothed bar pictured in **Figure 4** can be made out of a symmetrical bar, as long as the short end is chamfered properly. (Editor's note: Another long, interesting, but hard to type series of mathematical equations was deleted here and substituted with the word "properly." See the source document if you want to do the math yourself.) In this way, with the bar at full speed, even if the long end barely misses the opponent, the short end won't touch it because during a half turn, it would approach — at most — half of the optimum bite. After the full turn, it would have approached up to the best bite distance, hitting for sure with the long end. With just one tooth, it is possible to move twice as much into the opponent before hitting it, transferring more impact energy.


FIGURE 3

With this proposed one-toothed bar geometry, the counterweight wouldn't have to be very heavy because its mass would only have to account for the mass of the tip insert plus the removed mass from the chamfers. This bar is also relatively easy to fabricate, with very little material loss. In fact, for wide bars with large inserts — which increase the value of b — it is even possible to design the bar in a way it's almost symmetrical even after chamfering. In addition, if you perform some shape optimization removing some material from the long end, it is even possible to remove the counterweight, being careful not to compromise the bar strength at its most stressed region.

In our experience, to bind well to the opponent, the tooth bite should not be below 1/4", no matter if the robot is a hobbyweight or a super heavyweight. We've tested different tooth heights with our drumbot hobbyweight Touro Jr and featherweight Touro Feather, and values below 1/4" made the

FIGURE 4


Number of Teeth n	Maximun Drivetrain Speed	Maximun Rotational Velocity to Avoid Grinding
1	5 mph (8 km/h)	3,520 rpm
	10 mph (16 kn/h)	7,040 rpm
	15 mph (24 km/h)	10,560 rpm
2	5 mph (8 km/h)	5,280 rpm
	10 mph (16 kn/h)	10,560 rpm
	15 mph (24 km/h)	15,840 rpm
3	5 mph (8 km/h)	10,560 rpm
	10 mph (16 kn/h)	21,120 rpm
	15 mph (24 km/h)	31,680 rpm

TABLE 1

robot grind instead of grab the used dead weights. With this in mind, it is possible to generate a small table with estimated maximum weapon speeds to avoid the grinding problem. Not going over the maximum rotational velocities shown in **Table 1** guarantees that, in at least 50% of the hits at full speed, the tooth will be able to travel at least 1/4". Of course, these are just rough estimates because tooth sharpness and armor hardness also play a role helping or avoiding dents that bind with the opponent.

Summary

In this mere 1,600 words, I've managed to grossly simplify the treatment of this subject in the Tutorial. The detailed calculations and a more thorough explanation of the concepts are available for those wanting the gory details. SV

COMBAT ZONE'S GREATEST HITS

● by Kevin M. Berry

Thomas Kenney of MH Robotics (**http://mhrobotics.com/**) sent in his story.

"This is the only real 'hardcore' damage I've received to my bots as of yet. It was a beetle fight between my bot 'Cloud of Suspicion' and 'One Fierce Lawn Boy.'

Cloud of Suspicion's bottom armor is meant to be taken off between matches to charge batteries and turn the bot on and off. As a result, it's held on with a measly four 6-32 x .625" screws. This design flaw allowed Lawn Boy's drum to catch onto the inside of the carbon fiber plate after cutting through the UHMW that it's recessed into. Although the spray of robot guts was spectacular, there was no real structural damage, and the only internal components that were lost was one LiPo cell that was sliced through (and tossed into a LiPo sack right afterwards!) and the receiver. The motors that were disconnected from their gearboxes still run fine; the grazing impact of Lawnboy's weapon teeth on the motor cans had just been enough to break the grip of the blue loctite and loosen the screws." SV

Before and after photos, brief description of the fight, and builder's name can be submitted to me at LegendaryRobotics@gmail.com. Or, if you have an action shot that clearly shows what's going on, those are welcome too! These don't have to be current, anything you can (legally) submit, clear back to the good old days of wooden bots and iron builders is fair game.