A Primer on Motors in FRC

The intent of this document is to teach you (the reader) enough to go and do your own research and make your own informed decisions using the muscle between your ears about motors and their use in FRC. It is not an end-all-be-all but hopefully will introduce you to the tools we'll be using throughout and teach you to use them yourself.

For any of the resources sections that are store pages, I ***highly*** suggest scrolling to the bottom and looking under Downloads, Resources, and other categories where key technical information, like data sheets, can be found.

Tim Flynn

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Cothron Theiss, Hayley (3132), H. Newman, Calvin Tran, Luke (2796 Alum), Nick Hammes, Abby Petruga, Lenna (488), Maddox (2197), Molly (1747), Howard Cohen.

Tips, Tricks and Advice

"Steal from the best, invent the rest." - Mike Corsetto

"Trust the process, keep iterating, chase excellence." Team 148 & John V Neun

"Touch it, own it." - Fabled FRC Proverb

K.I.S.S (Keep It Simple, Stupid) - Less parts means easier to build, easier to repair, easier to operate, and the more time you can spend practicing, iterating, and improving.

Motors & Actuators

Most motion in FRC is achieved through rotation, using something whose existence is pretty well known: motors. Brushed motors take some sort of power input via a motor controller, and spin in either direction depending on given anywhere between -12 and 12 volts from said motor controller. The rate at which they spin is called “rpm”, or rotations per minute.

Most teams in FRC stick with one of four motors: the CIM, the miniCIM, the BAG Motor, or a 775pro. All can be valid options given appropriate context. Some motors that won’t get their own section in this document are the window motor (the bag you get in the Kit of Parts), the RS550, RS775, and others. Window motors are low power and difficult to use with FRC-designed components without serious work, and the RS550 and RS775 share the same flaws as the 775pro does and have become functionally obsolete since the release thereof.

Now, this isn’t to say that smaller motors aren’t useful, but it’s important to realize a balance must be struck. Replacing every motor on your robot with a CIM isn’t a good idea, and neither is using window motors for your drive train. This is why analysis is essential.

Glossary:
Stall - When a motor is held in place by forces on the output shaft and electrical power is being applied. Typically results in permanent motor damage, and /or electrical issues for the duration of the match.
Peak Power - The most energy (usually in watts) a motor can output. Not all motors can maintain peak power for very long, or maintain it at all.
Magic smoke - The smoke emitted from a motor (or other Control Systems component) when it is irreparably damaged.

CIM

The CIM ("CCL Industrial Motor") is a staple of FRC motion, first made legal for use in the 2002 FRC season. Since then, they've become a standard for drivetrain, elevator, arm, and plenty of middle stage motion components. Their main advantage is the stall tolerance, being able to survive for several minutes in a dead stall without causing electrical failure or fire. Of course, this benefit comes at a hefty cost, weighing in at a significant 2.82lbs. Despite this fact, teams stick with the CIM due to continued reliability, season-in, season-out.

Mention reliability

Resources:

[AndyMark Page]

[VEX Motors Page]

(CIM, VEX Robotics)

MiniCIM

The MiniCIM is a lower-power motor compared to the CIM, but it fills a needed role in terms of electronics benefits to the control system. The miniCIM was specifically designed for use in FRC by VEX, and has found a home in many places: drive-trains, high power middle stage components, and occasionally end-effectors. With approximately 2/3rds of the peak power of a CIM though, they don't exceed the fuse rating for a 40 amp channel at stall. Even at full stall on a 6-miniCIM Drive, the robot's fuses won't trip at all.

An added but less commonly noted feature of the MiniCIM is it's relatively lower weight, clocking in at a 2.16lb versus the 2.82lb of a CIM, can save teams more than two pounds across their drivetrain, as well as occupy less room in their robot, being significantly shorter than a CIM.

Paul Copioli of VEX Robotics had this to say on the application of miniCIMs as drive motors:

> *"I much prefer the 6 miniCIM drive we used this year.* [2018] *No breaker trips; acceleration for days; could practice for hours at a time and the motors just didn't care. As a matter of fact, our limiting factor for practice was the main breaker getting so hot it would just trip itself (this took hours of continuous practice before it would happen)."*

Resources:
[VEX Motors Page]
[This Chief Delphi thread].

(miniCIM, VEX Robotics)

BAG Motor

The BAG (“Bad Ass Globe”, no joke) Motor is a medium-power motor designed specifically for FRC usage, especially for intakes. While it looks similar to both the CIM and the MiniCIM, when placed side-by-side, there’s a visible difference. This motor has a relatively high free speed of approx. 14k rpm but shines when geared down for intake usage. Like its older siblings, the CIM and miniCIM, it tolerates stalling better than some of the alternatives, making it a staple for intakes and stall-capable mechanisms. Due to the relatively low output power peak at 149 watts though, it’s applications are typically reserved to intakes.

Resources:
[VEX Motors Page]
FRC 3847 - [2018]

(BAG Motor, VEX Robotics)

(BAG, MiniCIM, CIM, side by side.)

775pro

The 775pro is a newer motor, developed by VEX Robotics specifically for FRC. It intended to be a modern competitor to the (then) antiquitated RS775 from BaneBots in the early 2000s as a motor specifically designed for FRC. With a free speed of approximately 18.7k rpm, they've become a go-to motor for shooter mechanisms and weight-conscious applications, but they require gearing in both situations. The major caveat to the 775pro is its inability to tolerate stalling in typical use. Even stalling it at significantly lower power is enough to seriously damage, or "let the magic smoke out of them."

Resources:
[VEX Motors Page]

(775pro, VEX Robotics)

775 RedLine Motor

Essentially the same as a 775pro but with a lovely red casing. The RedLine and the 775pro are interchangeable in almost all use cases.

Resources:
AndyMark Page

(Redline, AndyMark)

Servos

While typically forgotten in the context of larger FRC, servos are a relatively inexpensive way to have calculated rotation or movement within a range of motion. Typically used in FTC or in smaller applications, there are two major types of servos: both being controlled over PWM and being low power.

Continuous Rotation Servos

Continuous rotation servos rotate 360° in either direction, allowing for basic movement of small things without using a PDP port. While not typically used, their strategic application can be used as parts of larger mechanisms (like 118’s 2018 robot, where the disc brake in their arm was actuated by a servo.)

Positional Rotation Servo

A positional rotation servo moves the output head of the servo from 0° to 180°, where the corresponding signal input relates to a resultant angle. This is useful for moving mechanisms between angles, like shooter wheel hoods.

(Servo, TETRIX)

Motor Overview Chart

Motor	Free Speed (rpm)	Peak Power (W)	Stall Tolerance	Weight (lbs)
CIM	5,330	337	Highest	2.82
MiniCIM	5,840	215	High	2.16
BAG	13,180	149	High	.71
775pro / RedLine	18,730	347	Low	.8
Servos	N/A	< 75 (via 2018 rules)	Medium	Varies

Gearboxes

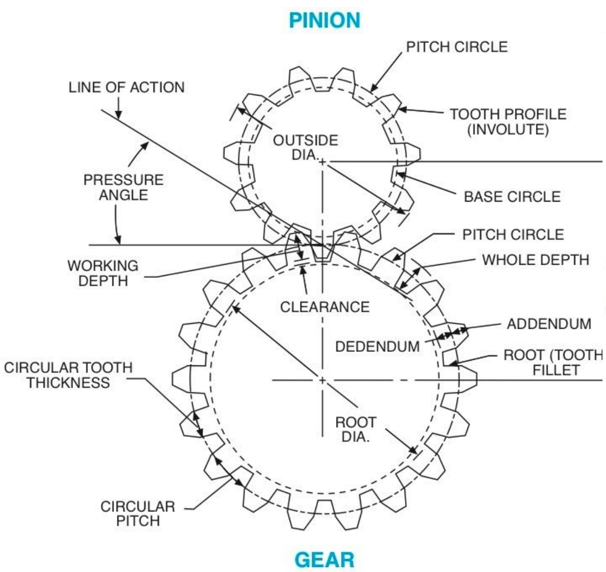
Now that we know what the common motors are, we need to understand their application. Very rarely do we want to run motors at their full speed, as they offer very little resultant torque, or turning force. With gearboxes, we convert the rotational speed into torque, with a loss of some energy in friction. The overall energy of the motor doesn’t change, just how it’s applied. For this reason, some gearboxes are more efficient than others.

In the real world, some gearboxes gear the output up, or make it faster than the input, but in FRC almost everything is geared down, with speed reduced in favor of torque. A gear ratio is expressed in the form of “X:Y”, where X is a number of turns on the input, and Y is the number of turns on the output, and the output of one can connect to the input of another. The ToughBox that runs at 10.71:1, means that for every 10.71 turns on the input is a full turn on the output.

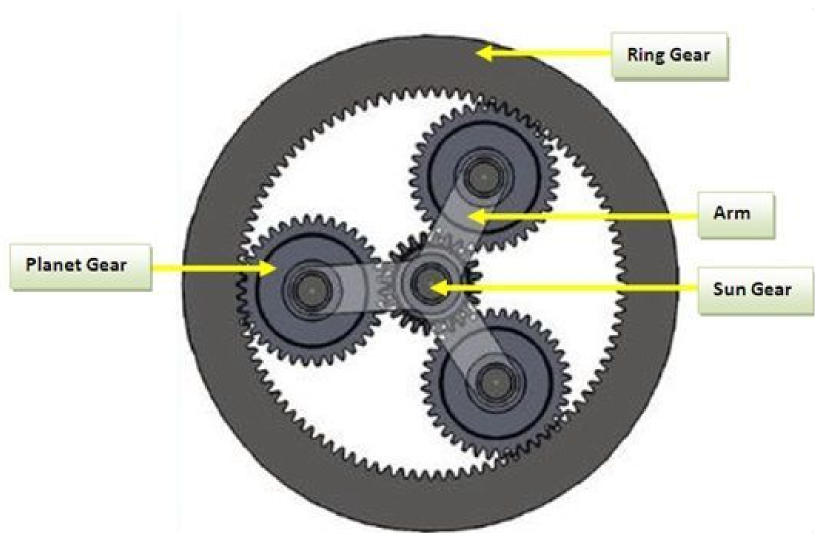
Now, one might ask “well why can’t we just connect our motors directly to our wheels and go as fast as possible”, and the answer is, “because that’s now how physics works.” The robot will need to overcome the weight of the robot itself and the friction of the motor itself to spin, and you may eventually reach the maximum speed of the motor plus the wheel it’s attached to, but it’ll take an infinitely long “field” to do so. If we gear our motors down to be super slow so they’ll get to max speed really fast and have lots of pushing power, they’ll be far too slow to be competitive. There exists a “sweet spot” of having enough pushing power and reaching top speed while maintaining overall agility of the robot. From team to team and robot design to robot design this sweet spot may vary and does not have a single solution.

Planetary Gearboxes

Planetary gearboxes are different than normal gearboxes because rather than a single input gear and an output gear for reduction, they use “planet” and “sun” gears. Using an exterior “ring” gear in an orbital, they transmit the forces equally across the different planet gears.



(Gear and Pinion, MISUMI)



(Planetary Gearset, Instructables)

Toughbox Mini

This is the gearbox that comes with the AndyMark AM14U3 chassis in the Kit of Parts. With a target ratio of 10.71:1, it turns the CIM's 5,300rpm free speed into approximately 10ft/sec of lateral movement (using 6 inch wheels.)

The TB Mini also has other reduction ratios that can be ordered, from 5.75:1 to 12.75:1 from 18ft/sec to 8.4ft/sec respectively. Now including a pre-magnetized shaft for encoders, it's a good choice for teams both new and old, for both versatility, and expandability.

Resources:
[AndyMark Page]
[AM14U3 Assembly Manual]

(Toughbox Mini, AndyMark)

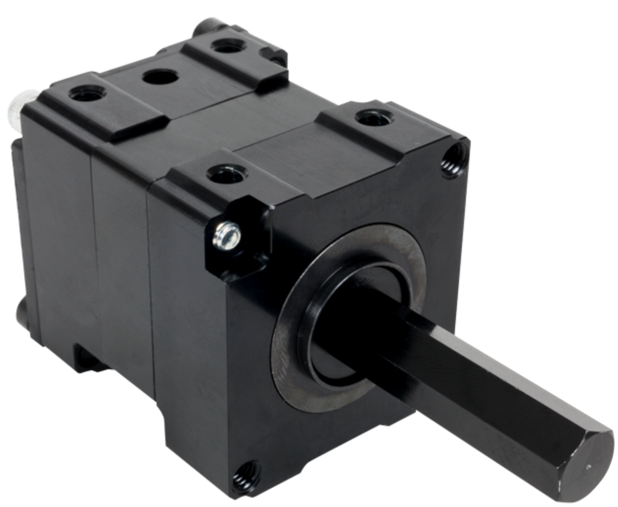
Versaplanetary Gearboxes

The Versaplanetary is a multifunction gearbox made by VEXpro for everything from intakes to shooters to elevators. Anything requiring a simple, low-reduction, or even just an encoder put in series, can have a Versaplanetary used for it. In addition, stages for encoders and ratchets have increased the use case in FRC, as well as output stage options made it easier to use in FTC and other programs.

At super-high reductions (dependent motor to motor input), the resultant forces would be significantly lossy, due to having more than two stages in the gearbox. However, reductions of 2:1 to about 16:1 are super common in FRC, with many teams using 9:1 or 10:1 reductions in the 2018 FRC season. In addition, the gearbox doesn't tolerate stall forces transmitted through it above a certain reduction, typically known as "load rating". Check the link in resources for implementation-specific load ratings.

The Versaplanetary Gearbox is also available in a "Lite" variety for lower-torque applications where weight is more critical, but these should be used with some greater scrutiny of application.

Resources:
[Versaplanetary Order Form]
[Versaplanetary Load Ratings Guide]



(Versaplanetary Gearbox, VEX Robotics)

57 Sport Planetary Gearboxes

The BaneBots sibling of the Versaplanetary, a durable and long-lived planetary gearbox for the Redline, RS775, and RS550 motors. Available in 6 ratios from 4:1 to 100:1. The significant advantage to this is that they come pre-assembled, just add grease, and have an incredible "you break it, we fix it" warranty that if it ever breaks, they'll replace it.

Resources:
[AndyMark Page]
[Motor Installation Guide]

(57 Sport Planetary Gearbox, AndyMark)

WCP SS Gearbox

The West Coast Products Single Speed Gearbox is a singly geared drivetrain gearbox designed for 3 miniCIM or CIM inputs with an output ratio of anywhere between 40:34 and 60:14, with options for both Tank & West Coast Drive style drivetrains. Their high configurability and ease of use with VersaFrame makes them a strong option for teams both experienced and new to the COTS gearbox market.

Resources:
[VEXpro Page]

(WCP SS Gearbox, VEX Robotics)

VEX Single Speed, Double Reduction Gearbox

A single speed gearbox from VEX designed for one of two secondary reductions: 34:20 and 30:24. With a first stage reduction of 40:12, the actual output math comes out to about 5.33:1 and 4.17:1 respectively, it's a good option for small-wheeled single-speed drivetrains.

Resources:
[VEXpro Page]

(Single Speed Double Reduction Gearbox, VEX Robotics)

Output Sections

In the context of this document, output sections are the piece of the motion assembly that contact something, be it the game field, a game piece, or another part of the robot. We'll be looking at some of the more basic ones used in recent FRC, and their method of attachment for some context.

Wheels

Wheels are round things that spin, typically with something on the end, either for a moment or for long periods of time. They can be grippy, soft, or something entirely different. This is a brief overview of some of the typical wheels.

Wheel durability is measured in Shore Durometer readings, denoted with the letter “A”. The higher the number the harder it is, and conversely,the lower the durability typically also means a higher grippiness relative to the field, and relative lack of durability. Most FRC teams stick with greater than 50A as any lower will result in most wheels not surviving a match.

Drive Wheels

Drive wheels are usually relatively small wheels of high durability, ranging from about 50A to 77A.

Common durabilities include:
AndyMark HiGrip (White): 77A
Colson Performa: 65(±5)A
AndyMark HiGrip (Black): 60A
AndyMark HiGrip (Blue): 50A

Resources:
[AndyMark HiGrips]
[Colson Performa Wheels]

(Colson Performa Wheels, Colson Caster Company)

Intake Wheels

As a result of intake wheels having less contact time in motion with game pieces, as compared to drive wheels, they can often sacrifice durability for grippiness, an observed fact during the 2018 FRC season, with many teams opting for the lowest possible durability AndyMark sold on their Compliant wheels. The “touch it own it” spirit of so many teams means that being ability to be in control of a game object the instant you touch it is essential, leading on this decision.

Use of low-durability but high grip wheels typically requires cleaning to prevent normal gunk (debris from the field) from interfering with the normal operations of “touch it own it”.

Common choices include:

[AndyMark Compliant Wheels](#)
[BaneBots T40 Wheels](#)

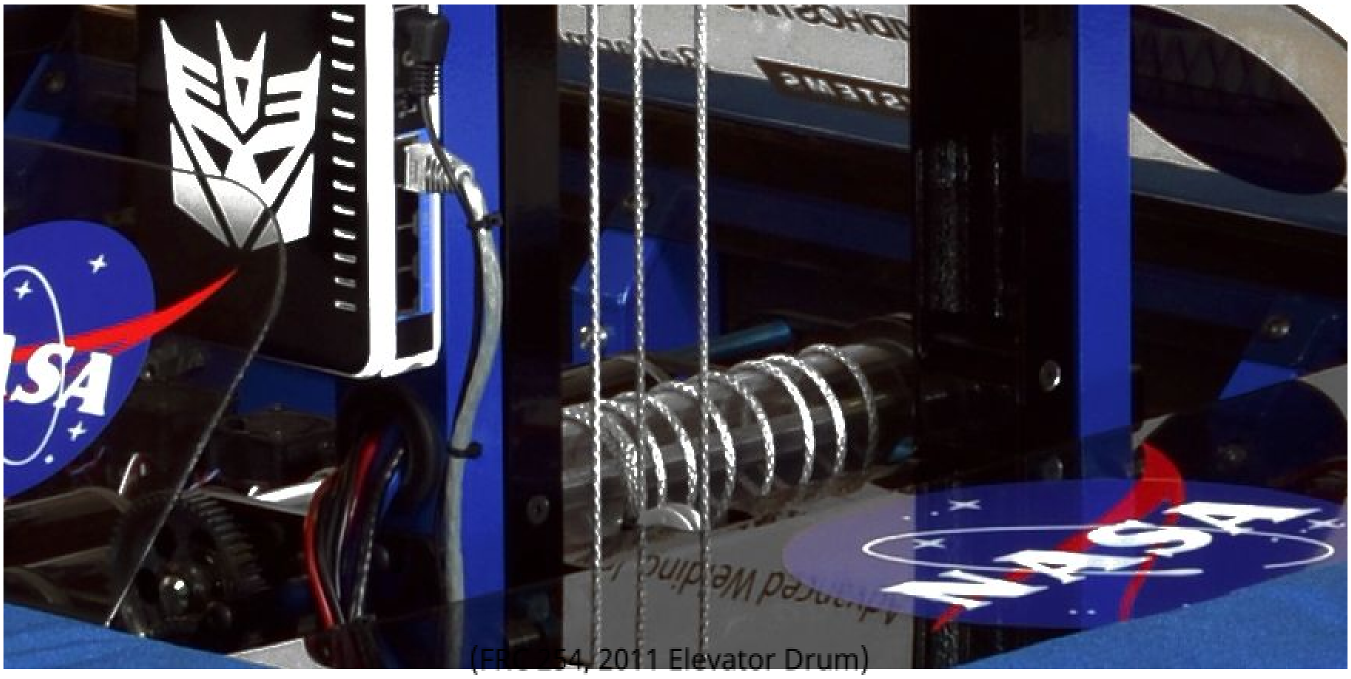
And their options include 30A, 40A, and 50A durability from BaneBots, and 35A, 45A and 50A and 60A from AndyMark with the AndyMark options becoming popular recently for their pre-hubbed options in ½” and ⅜” hex bore.

(AndyMark Compliant Wheels)

Drums

Drums are sealed long cylinders, typically attached directly or to a belt system connected to the output of a gearbox to spool some form of rope or string. This enables linear motion and is used frequently for elevators, as seen commonly in the 2018 and 2011 FRC games. Often they are through-drilled to fasten the end of the string or rope to.

Teams To Study:
FRC 254 - 2011, 2018

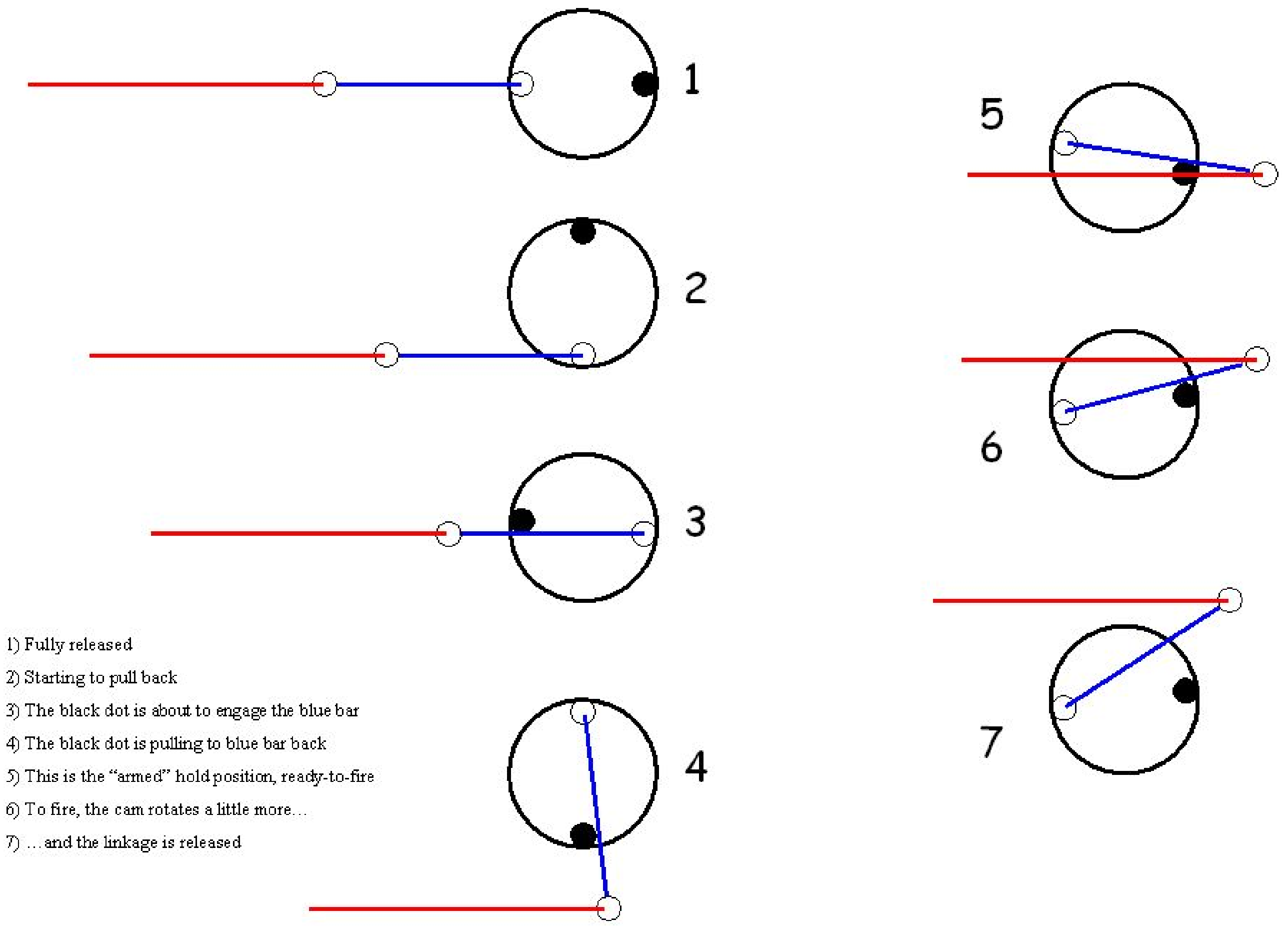


(FRC 254, 2011 Elevator Drum)

Choo-Choo

A choo-choo is a type of motor wheel that has an arm on the end, held back / forward depending on the rotation of the base wheel, enabling slow-charge but fast release of the latter half of the rotation. This typically is used for “charged” launching of large game objects, like 2008 or 2014 balls. Otherwise, application is relatively uncommon and discouraged. Their high-load, high failure rate makes them a less than ideal choice for high-usage tasks.

Resources:
[Choo-Choo Thread on CD]
[Mechanical Design Calc by Aren Hill]



(Choo Choo Diagram, Chief Delphi)

JVN Calc & Application

Now that you (hopefully) understand motors, gearboxes, and some of the applications of them for intakes and other purposes, you can begin to see if they work. Just buying gearboxes and testing them is a expensive proposition though, so some basic mathematical modeling will come in handy.

With a tool called "[JVN's Mechanical Design Calculator]" we can take known things, like motors, and some stock gearbox options, we can begin to see potential options.

For intakes you select a motor of minimal power (like a BAG or a 775pro) and a change the first ratio slot until it no longer is larger than the target fuse in the electrical system (30A or 40A usually) for stall current, then create that ratio using available stage options.

Intake Mechanism

	Free Speed (RPM)	Stall Torque (N*m)	Stall Current (Amp)	Free Current (Amp)
BAG Motor	13180	0.43	53	1.8

# Motors per Gearbox	Gearbox Efficiency	Travel Distance (in)	# Intake Sides (1 or 2)	Roller Diameter (in)	Drag Load (lb)
2	80%	16	2	4	15

Driving Gear	Driven Gear
1	9
1	1
1	1
1	1
9.00 : 1	<-- Overall Ratio

	Intake Linear Speed	Intake Time to move Travel Distance
No Load:	613.4 in/s	0.03 sec
Loaded:	277.5 in/s	0.06 sec

Current Draw per Motor (loaded)	Stall Drag Load
24.22 amps	27.40 lbs

For the more specific physics-based analysis, one can use the Aren Hill & Dillon Casey Mechanical Design Calculator, which includes electrical resistance and friction.

References

Motors

- CIM (VEX Robotics)
- MiniCIM (VEX Robotics) / (Paul Copioli “4-cim vs. 6-mini-cim drivetrains”)
- BAG Motor (VEX Robotics) / (FRC 3847 2018)
- 775pro (VEX Robotics)
- RedLine (AndyMark)
- Servos (TETRIX)

Gearboxes (MISUMI)

- Planetary Gearboxes (Instructables)
- ToughBox Mini (AndyMark) / (AM14U3 User Guide)
- Versaplanetary Gearbox (VEX Robotics) / (VP Load Guide)
- 57 Sport Planetary Gearboxes (AndyMark Page) / (Installation Guide)
- WCP SS Gearbox (VEX Robotics)
- Single Speed, Double Reduction Gearbox (VEX Robotics)

Wheels

- Drive Wheels (AndyMark HiGrips) / (Colson Performa Wheels)
- Intake Wheels (BaneBots T40 Wheels) / (AndyMark Compliant Wheels)
- Drum (FRC 254 2011)
- Choo Choo (CD Thread) / (Aren Hill Calc)

JVN Calc & Application

- (JVN Mechanical Design Calculator) / (Aren Hill Mechanical Design Calculator)