Motors & Gearboxes

FRC Team 1640

11-June-2017

Clem McKown

Energy Sources in FIRST

- **Motors**
- **Servos**
- Pneumatics
- Springs
- Changes in Center of Mass

Motors in FIRST

- Motors are prescribed in robot rules
- Only listed motors may be used
- Maximum quantities set
- All are brushed D.C. motors

Motor	Number Available	Unloaded rev/s	Unloaded A	Stall τ (ft lb_f)	Stall A	P_{max} (W)	M (lb_m)
CIM	6	88.5	2.7	1.79	133	337	2.80
West Coast RS775 Pro		312.2	0.7	0.52	134	348	0.80
Minicim		102.7	3.7	0.93	70	204	2.17
Bag Motor		233.3	0.7	0.37	65	182	0.69
am-0912		266.7	1.2	0.32	64	180	0.50
am-2194 (188:1)		0.5	0.6	33.00	22	33	2.10
am-2235 (Snow Blower)		1.7	5.0	8.33	24	30	1.11
am-3104 (NeveRest Motor)		110.0	0.4	0.05	12	11	0.55
BaneBots RS550-12		321.7	1.4	0.37	85	252	0.48
BaneBots RS775-12		121.7	1.1	0.32	30	82	1.39

R32. The only motors and actuators permitted on 2017 ROBOTS include the following:

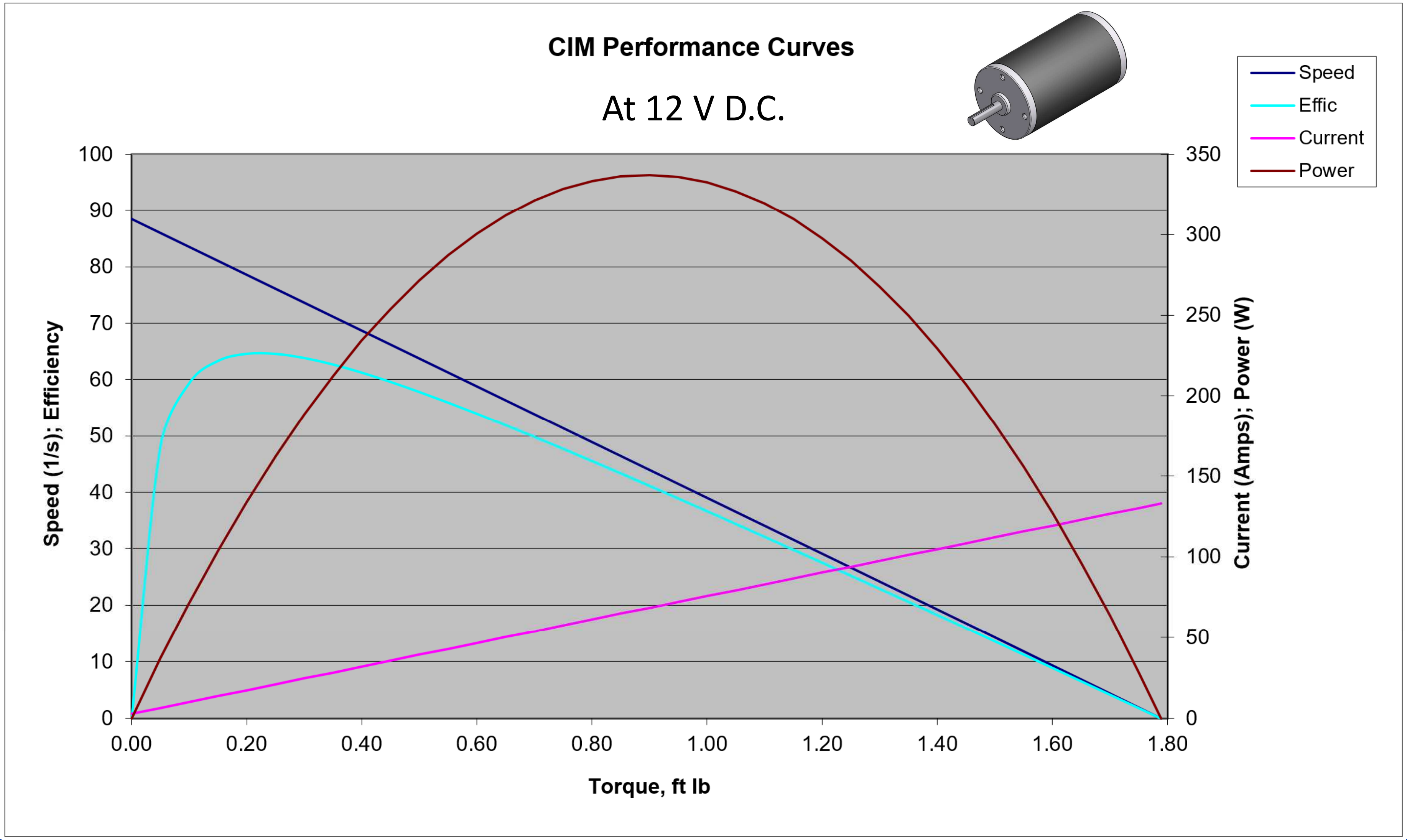
Table 8-1: Motor allowances

Motor Name	Part Numbers Available	Max Qty Allowed
CIM	FR801-001 M4-R0062-12 AM802-001A 217-2000 PM25R-44F-1005 PM25R-45F-1004 PM25R-45F-1003 PMR25R-45F-1003 PMR25R-44F-1005	6
West Coast Products RS775 Pro	217-4347	Unlimited
Banebots	M7-RS775-18 RS775WC-8514 M5 – RS550-12 RS550VC-7527 RS550	
AndyMark 9015	am-0912	
VEX BAG	217-3351	
VEX mini-CIM	217-3371	
AndyMark PG	am-2161 (alt. PN am-2765) am-2194 (alt. PN am-2766)	
Select Automotive Motors (Window, Door, Windshield wiper, Seat, Throttle)	Various	
Snow Blower Motor	am-2235	
AndyMark NeveRest	am-3104	
Electrical solenoid actuators, no greater than 1 in. (nominal) stroke and rated electrical input power no greater than 10 watts (W) continuous duty at 12 volts (VDC)		
Hard drive motors or fans that are: included in any Kickoff Kit, distributed via *FIRST* Choice, part of a legal motor controller (including manufacturer provided accessories), or part of a legal COTS computing device		
Factory installed vibration and autofocus motors resident in COTS computing devices (e.g. rumble motor in a smartphone).		
PWM COTS servos with a retail cost < $75.		
Motors integral to a COTS sensor (e.g. LIDAR, scanning sonar, etc.), provided the device is not modified except to facilitate mounting		

Motor Performance Curves

- Every motor has a set of performance curves providing rotational speed, efficiency, current draw & power output as a function of torque at a fixed voltage
  - Curves may be calculated from:
    - Free (unloaded) speed
    - Unloaded current
    - Stall torque
    - Stall current

    at known, fixed voltage



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Sealed versus Air-Cooled Motors

- Air cooled motors use forced air circulation through the motor to provide cooling.
  - There are holes in the motor body and a fan on the motor shaft to provide this cooling
  - Allows high power/weight ratio
  - Burns out quickly if maintained under power without rotation
- Sealed motors are cooled through exterior surfaces
  - Can be maintained under power without rotation
  - Heavier than air-cooled motors, for same power

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Some useful FRC motors

Motor		Number Available	Unloaded rev/s	Unloaded A	Stall τ (ft lb_f)	Stall A	P_{max} (W)	M (lb_m)		
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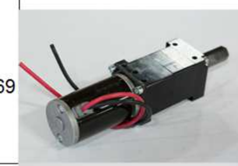
Bag Motor			233.3	0.7	0.37	65	182	0.69		
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Powerful & nearly indestructible. Sealed. Heavy. 8mm keyed shaft. These are drive-train standards. They can also hold stationary loads

Most powerful motor available to FRC. Air-cooled and relatively light. 4mm shaft. Almost needs Versaplanetary gearbox.

Lighter and bolt-compatible with CIM. Sealed. Rugged like CIM. 8mm keyed shaft. Able to hold stationary loads.

Air cooled. Light. Reasonably powerful. Usable with BaneBot P60 or Versaplanetary.

Air cooled. Light. Powerful. Easy to use with BaneBot P60 or Versaplanetary.

Selecting and Designing with Motors

Designing for Motors

- What’s the job that needs to be done?
- How much force needs to be applied?
- How rapidly must it move (rev/s)?
- How quickly must it accelerate?
- What’s the likelihood of stalling the motor?
  - Risky for air-cooled motors
- Will you need to hold (stationary) against a load?
- How much space and mass can you afford?

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Case Study – 2017 rope climb

- A 150 lb_m robot must climb 36 inches in 10 sec.
- Now working against gravitational force – an acceleration
- An object accelerates due to an applied force $F = \frac{m(g+a)}{g_c} = \frac{m}{g_c}\left[\frac{dv}{dt} + g\right]$ therefore $\frac{dv}{dt} = \frac{F}{m} g_c - g$
- Drive force applied at wheel is $F_d = \frac{\tau_w}{r_w}$ (r_w radius to CL rope)
  - Note – if (when) rope coils over itself, r_w increases, proportionally increasing the torque needed to climb at same speed
- Max velocity is based on geared rotation speed under robot weight load

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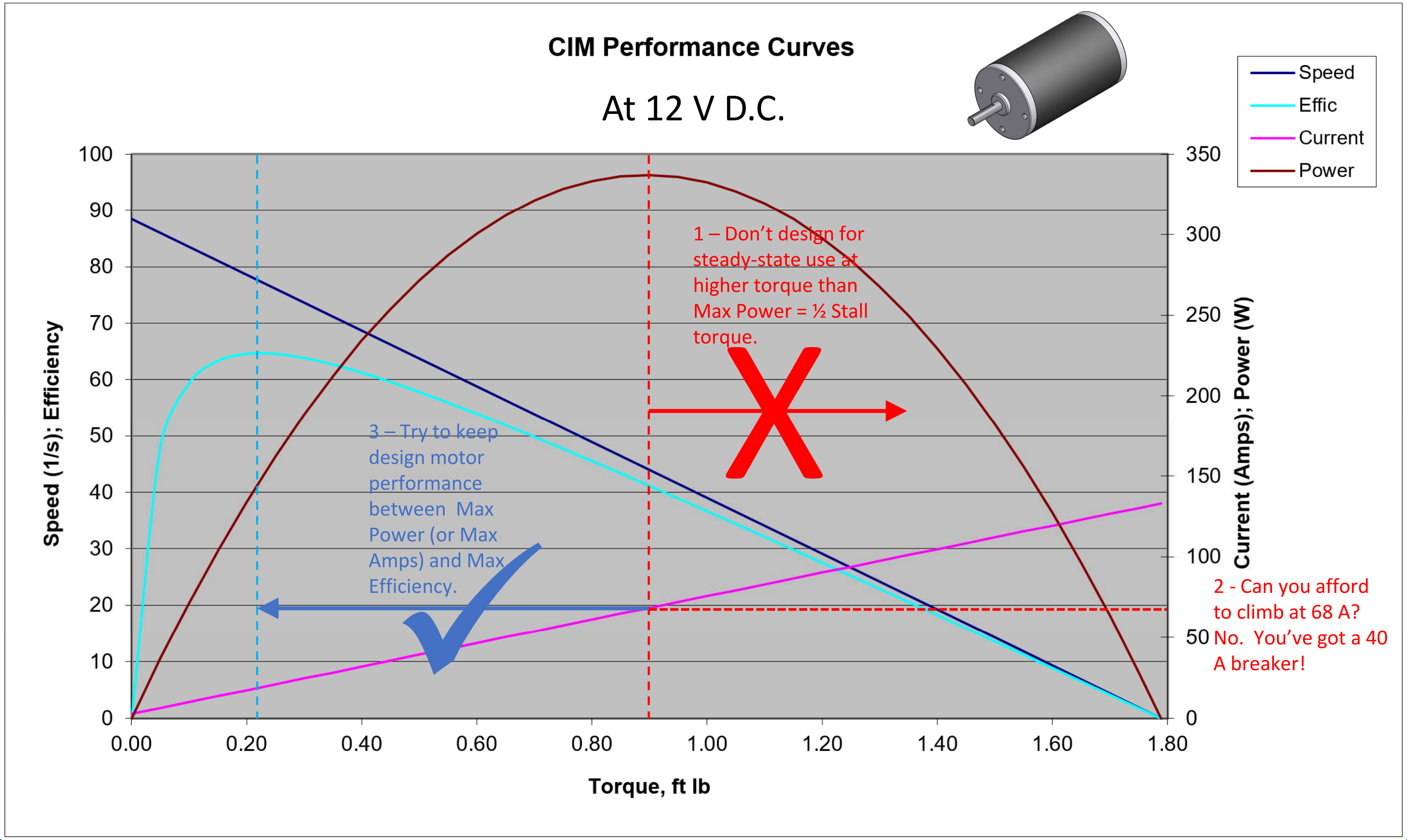
How to use Motor Performance Curves

- Design your drive so that your motor is running between maximum efficiency and maximum power at steady state
  - Avoid sustained operation at currents above the breaker specs



Case Study – 2017 rope climb

- CIM curves indicate 40 A at 0.51 ft lb_f torque & 63.2 rev/s
- If r_w = 0.75 inch, a 150 lb_m robot climbing at constant velocity requires 9.375 ft lb_f
- A CIM cannot deliver this torque; a CIM is the highest torque ungeared motor available to FRC
- But an 18.4:1 minimum leverage is needed to make climbing work

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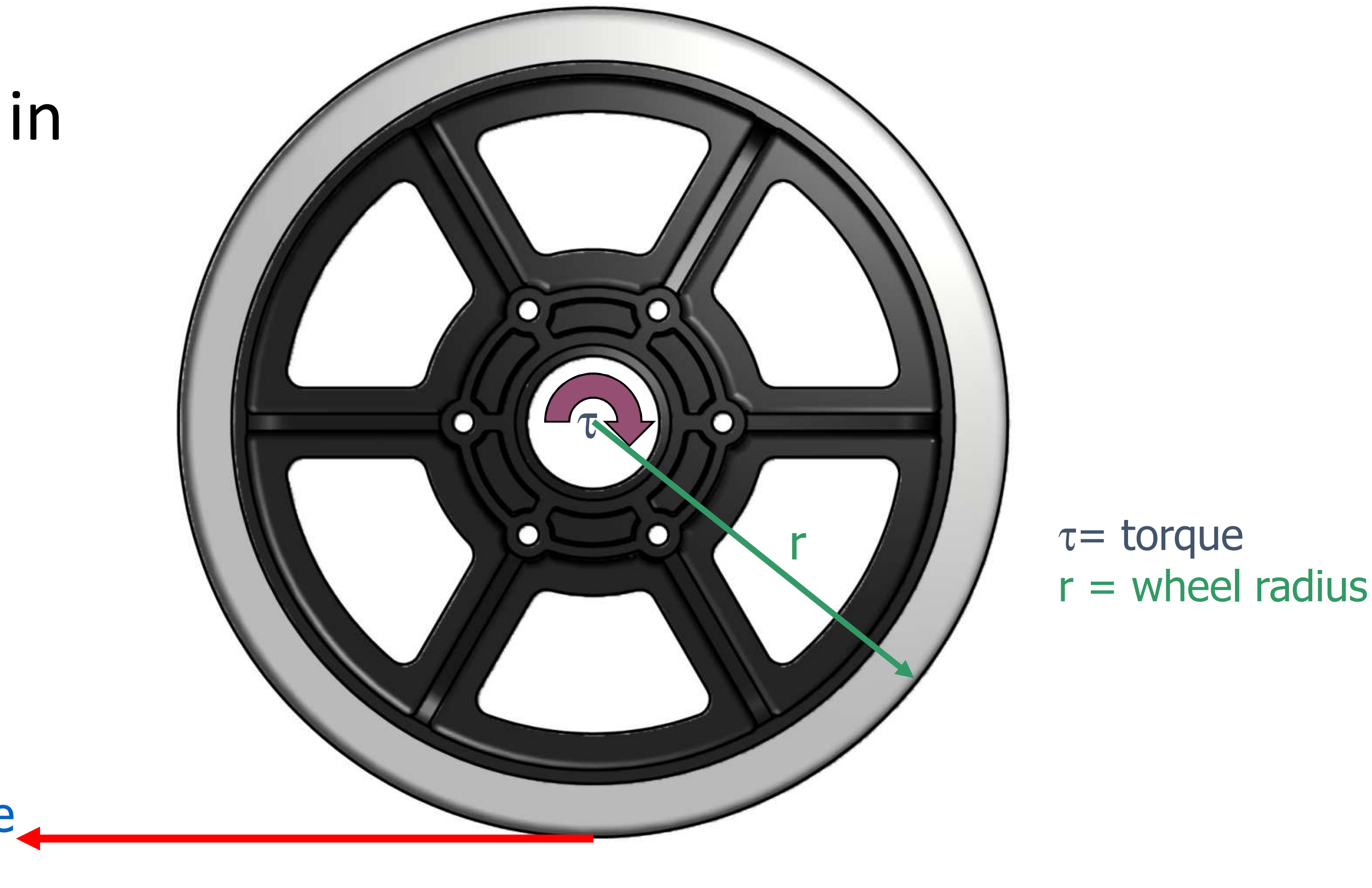
What's torque, anyway?

- Basically, torque (τ) is rotational Force
- Units are ft lb_f, Nm, oz_f in
- $F = \tau/r$



A conundrum

- For the most part, motors are not directly useful
  - They rotate too fast
  - Don't provide the torque needed
- If there were only some way to <u>leverage</u> the excess speed to create more torque!
- <u>Gearing</u> provides rotational leverage, trading off speed for torque
- Not all gearing uses gears
  - Chains & sprockets
  - Belts & pulleys
  - Changes in work radius

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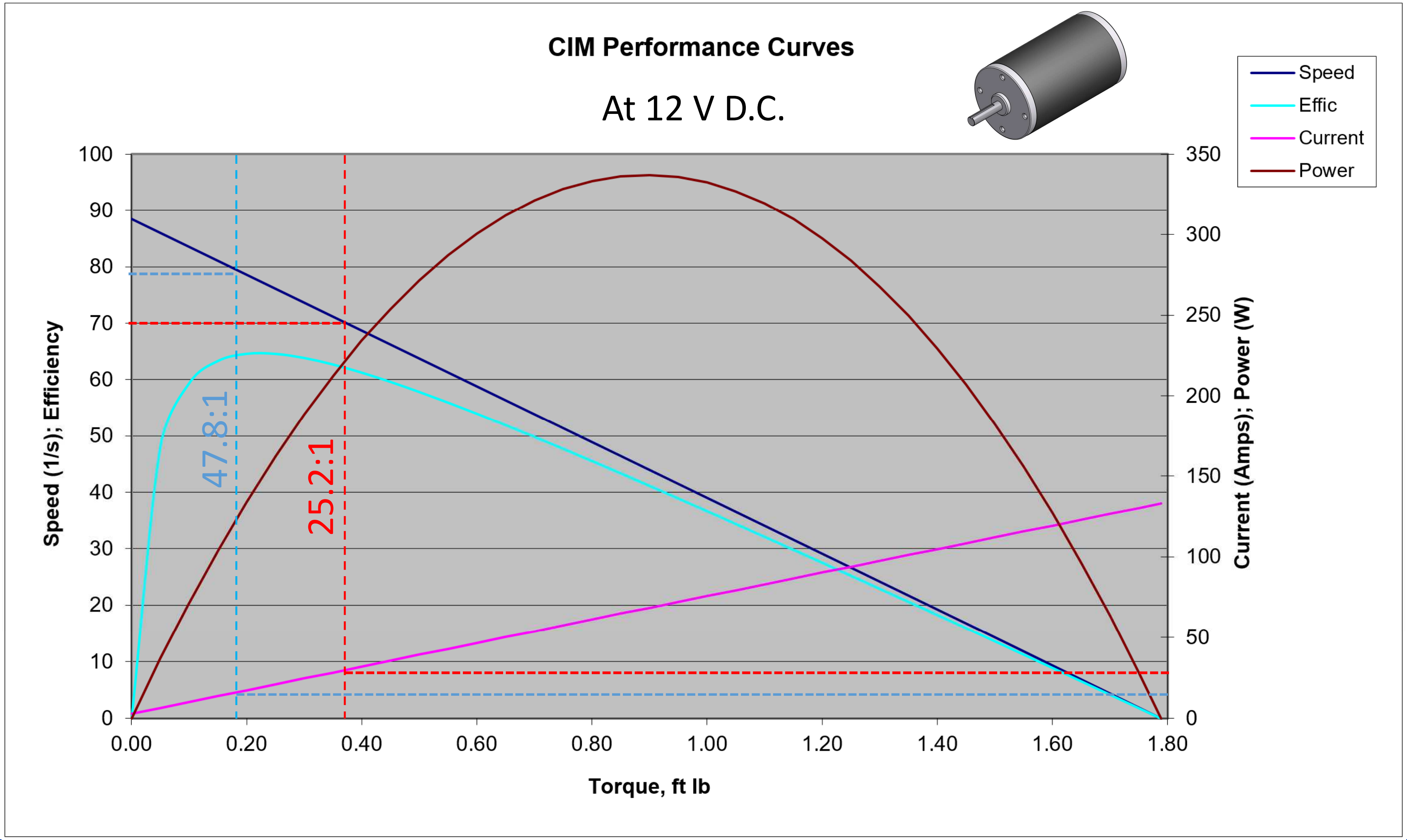
Back to Motor Performance Curves

- Revisit the 2017 rope climbing case study using two gear reduction ratios



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Case Study – 2017 rope climb

- A 47.8:1 reduction was originally installed
  - 0.196 ft lb_f at 78.8 rev/s @ 13.6 A at motor for constant velocity climb
  - 9.375 ft lb_f at 1.65 rev/s at climber
  - 7.77 in/s – 36 inches in 4.6 sec
- Changed to 25.2:1 for FRC Championship
  - 0.372 ft lb_f at 70.1 rev/s @ 30 A at motor for constant velocity climb
  - 9.375 ft lb_f at 2.78 rev/s at climber
  - 13.1 in/s – 36 inches in 2.7 sec

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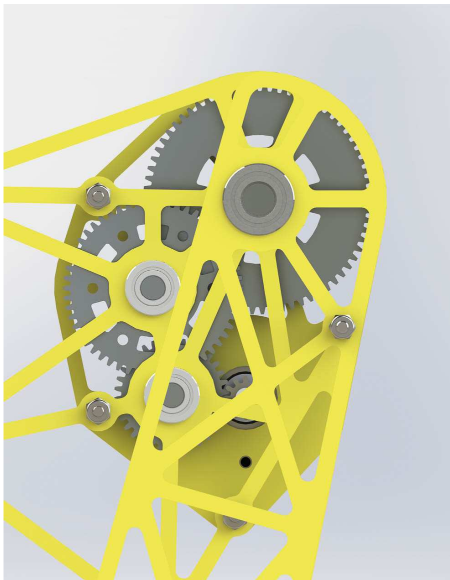
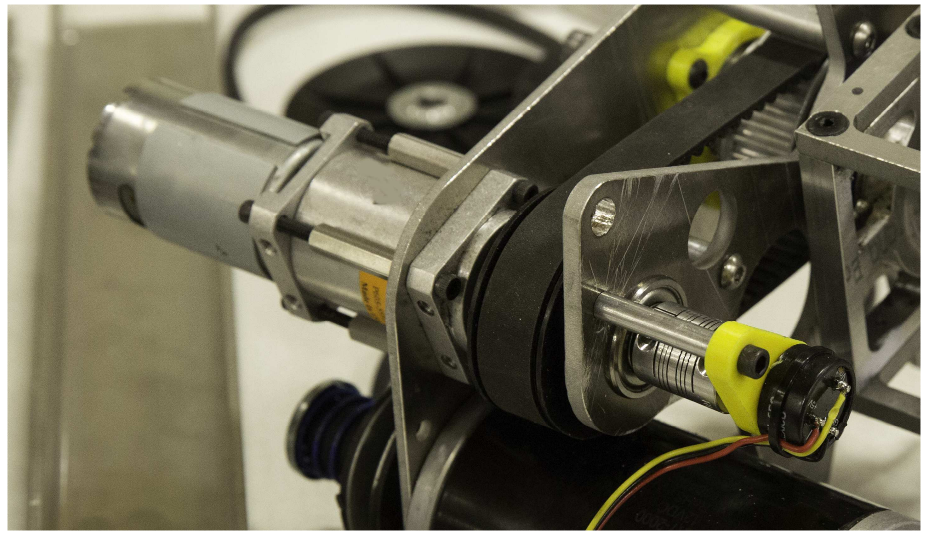
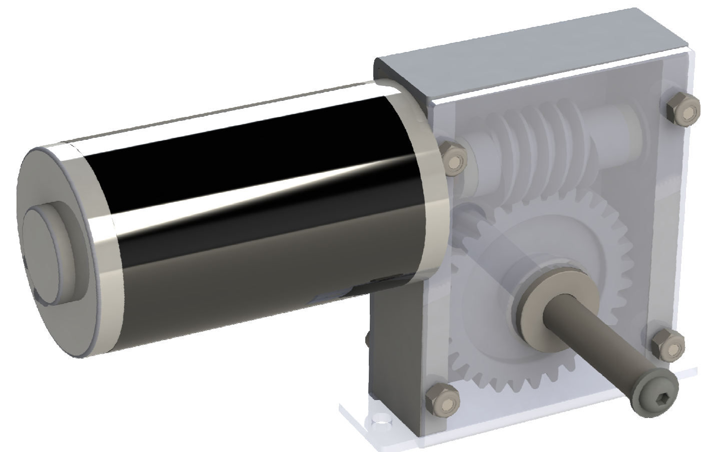
Gear Types







Spur Gears

- For each stage, reduction is
  $$\frac{\text{driven gear tooth count}}{\text{drive gear tooth count}}$$
- For multiple stages, multiply reduction
- (2) of these on DB13

Planetary Gears

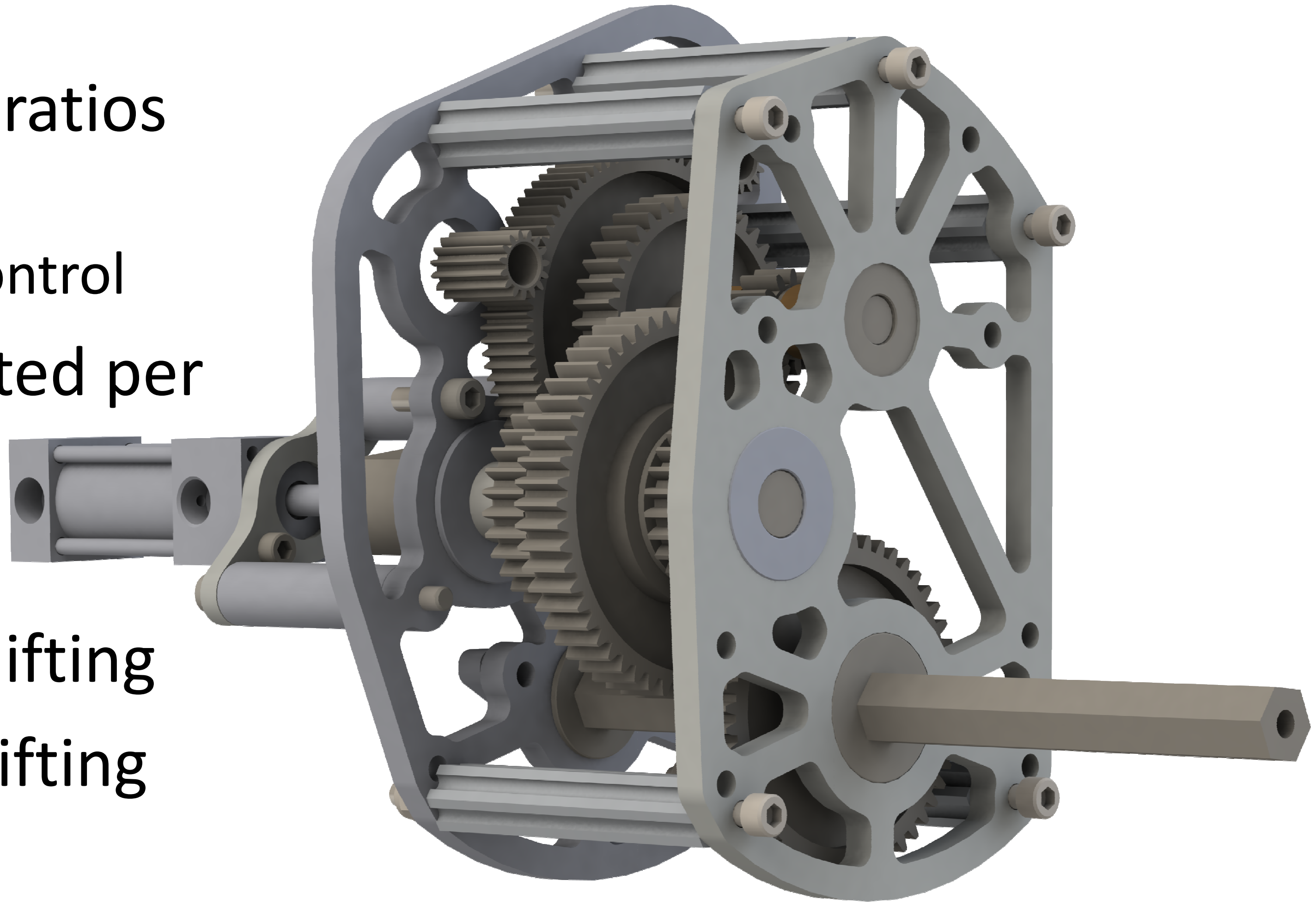
- For each stage, reduction is
  $$\frac{\text{ring gear tooth count}}{\text{sun gear tooth count}} + 1$$
- For multiple stages, multiply reduction
- (7) of these on DB13

Worm Gears

- Usually one stage, reduction is
  $$\frac{\text{worm gear tooth count}}{\text{worm start count}}$$
- Depending on worm angle, don't backdrive
- Capable of high reduction

Shifting Gearboxes

- Allows selection of two discrete gear reduction ratios
  - One for speed
  - One for power & fine control
- 1-3 CIMS may be mounted per gearbox
- Used for Tank Drive
- Pneumatic control of shifting
- Dog gear or Ball-lock shifting
- Installed on DB 3 & 4



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Versaplanetary System

https://www.vexrobotics.com/vexpro/motion/gearboxes/versaplanetary.html

1 – requires purchase of longer bolts

- VexPro has developed a very flexible, modular planetary gearbox system
- Able to accommodate multiple motors – even CIMs
- Motor mount hardware included (but CIM is an extra purchase)
- Dual motor mount available (we've made a triple mount)
- Almost necessary for using the West Coast RS775 Pro motor
- Each stage may be 3, 4, 5, 7, 9, or 10:1 reduction (72 tooth ring)
- Designed for 0, 1, or 2 stages (but 3 stages is no problem[1])
- Heavier and more expensive than equivalent BaneBot P60

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BanePot P60 System

http://www.banebots.com/category/P60.html

- A planetary gearbox system designed for BaneBot motors
- Also accommodates AndyMark's 9015 motor (am-0912)[1]
- Compact and lightweight
- Each stage may be 3[2], 4 or 5.09:1 reduction (45 tooth ring gear)
- Available 1-4 stages; 34 reduction ratios from 3:1 to 672:1
- 1640 has used a lot of these gearboxes
- The 132:1 3-stage P60 is currently used for swerve steering
- Torque limited
- Current tendency is towards Versaplanetary replacing P60s
- BaneBot makes a P80 series for CIMs (heavy – 1 ea on DB12 & 13)

1 – requires motor shaft shortened 1/8"

2 – new product – 1640 has not used yet – not exactly 3:1

Motor, Gear & Gearbox Sources

- AndyMark (www.andymark.com)
  - Spur, planetary, bevel & worm gearboxes
  - Shifting gearboxes
  - Gears
  - Motors
  - FRC & FTC
- Vex Robotics (www.vexrobotics.com/vexpro)
  - Spur gearboxes – 1 & 2 speeds
  - Versaplanetary gearbox system
  - Awesome spur gear supply (7075 Al focus)
  - Motors (CIM, Mini-CIM, Bag & RS775 Pro)
- BaneBots (www.banebots.com)
  - Planetary gearboxes & parts
  - Small motors

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Designing with Gears

- When purchasing gears that must mesh, the gears must share the same Diametrical Pitch (DP) and Pressure Angle
- We commonly use spur gears having 20 DP; 14.5° pressure angle
- Gearboxes must be designed with accurate axle C-C distances: ½ the sum of the two gears' pitch diameter
- Pitch diameter = tooth count/DP (inches)
  - A 40 tooth 20 DP gear has a pitch diameter of 2 inches

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Servos

Servos

- Very low power motors with integral gearboxes
- Restricted motion (typically 180°) or continuous
- Used in DB 2 & 3 (2 ea), they gained a reputation of being *"worthless and weak"*. Pneumatics took their jobs.
- But DB 13 resurrected servos, using (9) for
  - CVT shifting (4)
  - Gear capture & release (2)
  - Gear flap (2)
  - Shooter angle control (1)

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Servos are low-power actuators

- Servos added to the motor performance summary to show limited servo power vis-à-vis motors

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BaneBots RS775-12		121.7	1.1	0.32	30	82	1.39
Servo							
REV-41-1097		1.19		0.98		2.5	0.13
Hi-Tec HS-805BB		1.19		1.79		4.5	0.34
Hi-Tec HS-422		1.11		0.27		0.6	0.10
Hi-Tec HS-485HB		0.93		0.43		0.9	0.10
Hi-Tec HS-75BB		0.49		0.59		0.6	0.08
Hi-Tec HS-81		1.85		0.22		0.9	0.10
Hi-Tec HS-311		1.11		0.27		0.6	0.10
Hi-Tec HS-1425CR		0.87		0.22		0.4	0.09

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Servos

- Unlike pneumatics (which are basically binary), Servos are capable of intermediate outputs. Targeting specific angles.
- Servos used for CVT shifting and the Shooter Angle Control need this feature
- Servos have internal gearing – some have metal gears