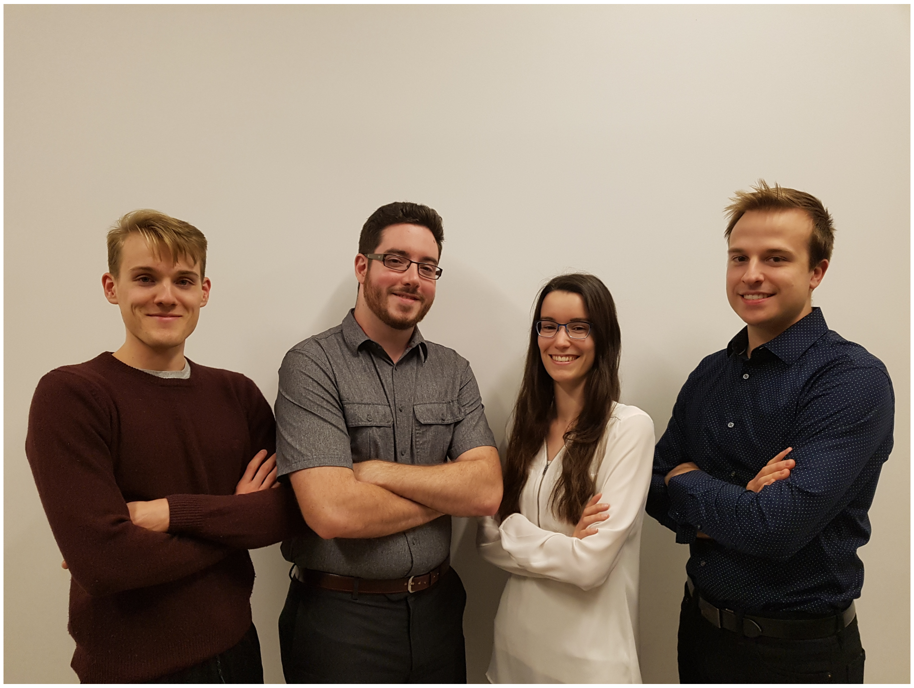
Waterfront 2A - Concepts Report
MCG4322



Waterfront Robot 2A

Marc-André Arsenault (8172498)
Mathieu Carroll (8089784)
Alexane Lahaie (8204533)
Joshua O'Reilly (8359885)

University of Ottawa
Department of Mechanical Engineering
September 25, 2019

Contents

List of Figures

List of Tables

1 Project Charter

1.1 Mandate

The goal consists in creating a rugged device which uses a biomimetic inspired locomotion system to remove waste from waterfronts. It must be self-reliant and be resistant to exterior environments such as areas with minimal accessibility, weather and rough terrain.

1.2 Requirements

The design is to be solar powered, with a locomotion system inspired by biomimetic morphologies. The device must be able to operate in waterfront environments and difficult terrain such as sand, mud, rock, plants and bramble. It must be completely sealed to the elements such as rain, water, humidity, wind, sand, dust and high heat. It is also to be self-reliant and only require human intervention to empty the waste holding tank. This includes the consideration for potential vandalism. The design created by this group (2A) must interface with the litter collector of a size of 1 to 5000 cm^3 and litter capacity from 1 to 5 kg, which is designed by another group (2B).

1.3 Constraints

As the design project is open-ended and covers a relatively new technology, there are very few constraints. The only constraint is that the device should not have any continuously rotating joints.

1.4 Criteria

The following criteria were selected as guides to optimize the design. First, the power consumption per kilogram (device and litter) is to be minimized. Additionally, the operating time of the device is to be maximized for more waste collecting efficiency. More specifically to the above required operating terrains, the ability to operate on sandy and pebble beaches as well as shallow water, mud and small plants (foot design, mechanical stability) should be optimized. The range of mobility of the device, such as turning and operating on slopes, is also to be optimized. Lastly, as the device will operate in public areas, the aesthetic appeal is to be considered.

2 Design Concepts

2.1 Concept 1 - Linkage

This concept uses the basic principle of a rotary-to-linear linkage by imposing movement restriction. The rotary movement is created by the motor, which is connected to the crankshaft. The rod connected to the crankshaft is modified to allow vertical sliding and rotation around the fixed guiding pin. The crankshaft mechanism allows for the leg/connecting rod to be lifted off the ground. The guiding pin restricts certain movements of the connecting rod, creating a pendulum movement. By combining both mechanisms, the connecting rod is moved front to back on the ground and back to front off the ground. By combining the pattern for each leg of the robot, a walking sequence is achieved. Figure 1 shows the concept of the mechanism.

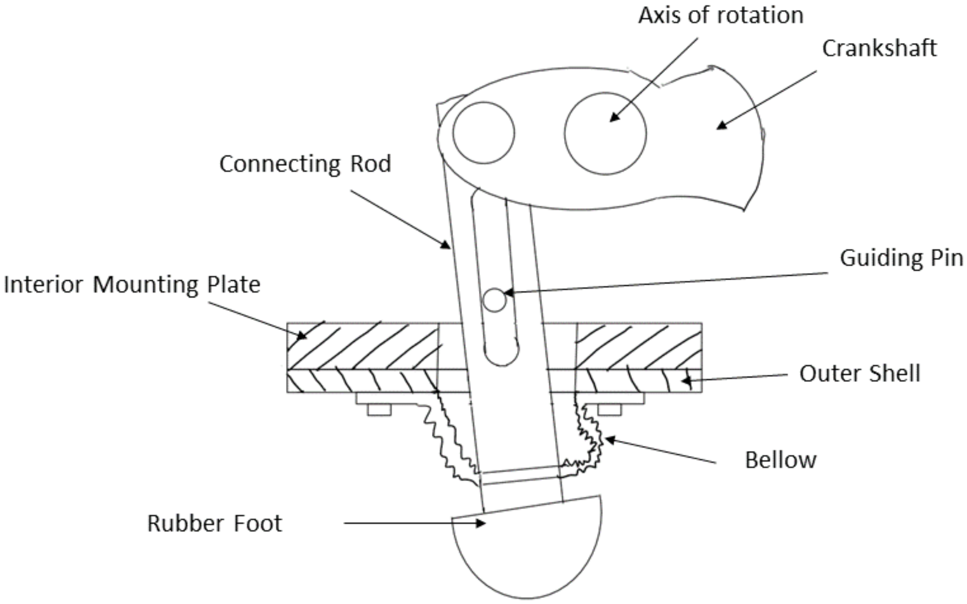


Figure 1: Linkage Side View - Concept

In this concept, all legs are powered by their respective gearmotor. The shaft assembly from the gearmotor to the crankshaft is shown in Figure 2. The gearmotor is face/flange mounted on an L bracket mounted to the structural mounting plate (not shown in figure). The crankshaft is coupled to the gearmotor using a setscrew shaft coupler, and the crankshaft is supported on the opposite end of the gearmotor by a pillow mounted bearing.

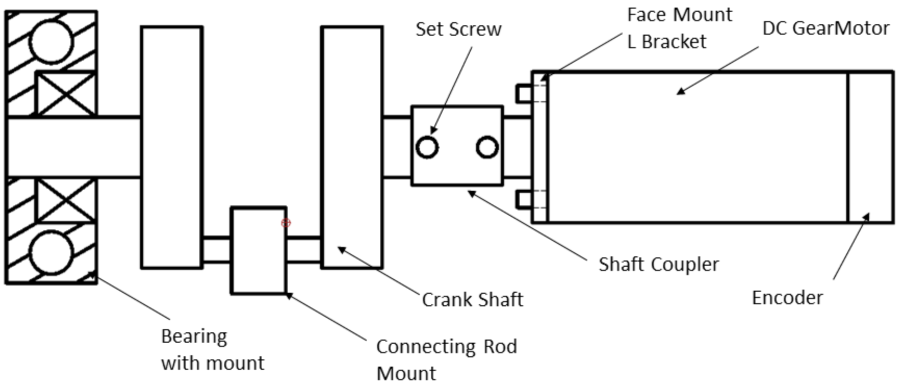


Figure 2: Linkage Top View - Motor Crankshaft Assembly

The connecting rod is the leg/limb of the robot. It is coupled to the crankshaft using typical mounting procedures. As shown in Figure 3, the connecting rod is mounted on the crankshaft using two bolts and nuts and will rotate around the crankshaft through the use of bushings.

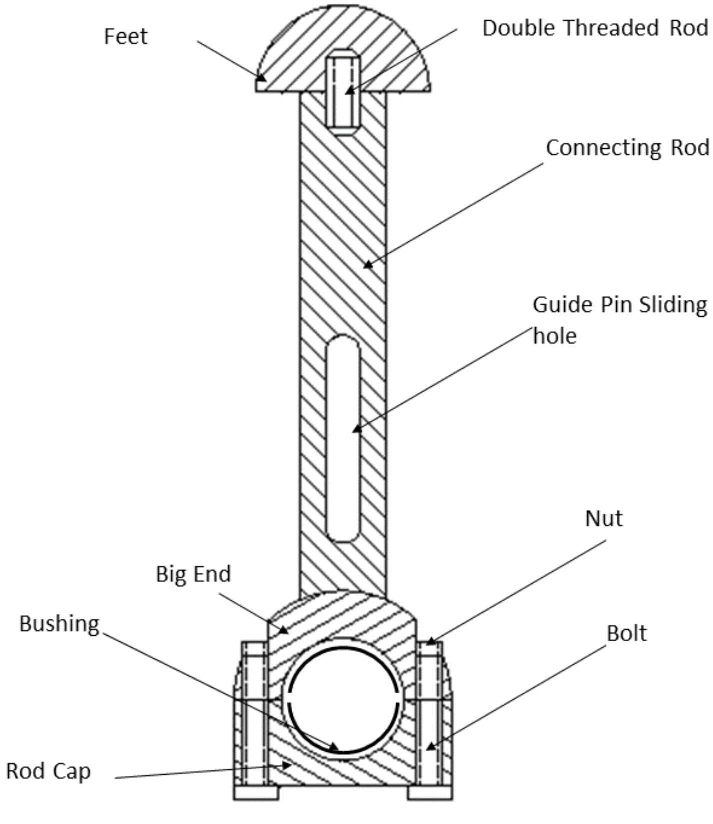


Figure 3: Linkage Side View - Connecting Rod

The guiding pin is the critical component in this concept as it enables the walking pattern and will be subject to multiple forces. The guiding pin is inserted through the sliding hole and fastened using the threaded end to mounting blocks. The sliding hole enables the pin to be supported on both end avoiding a cantilever support. The pin is also mounted with a spacer and bearing to facilitate rotation and reduce wear on the connecting rod. A top view of the guiding pin assembly is shown in Figure 4 and a side view of the guiding pin is shown in Figure 5. The Figure 5 also shows the mounting procedure for the bellow, the mounting plate and the exterior material. The mounting plate is a sheet metal acting as structural element to the chassis of the robot and will support all components. All major equipment are mounted on the mounting plate. The exterior material, most likely polycarbonate due to its weather resistant properties, will be an outer shell protecting electronic and mechanical components from water, salt and other destructive particles. The bellow is face mounted through the exterior material and through the mounting plate to allow for better structural integrity between the mounting plate and the outer shell. The other end of the bellow will be elastically tightened to the connecting rod between the feet and the guide pin sliding hole.

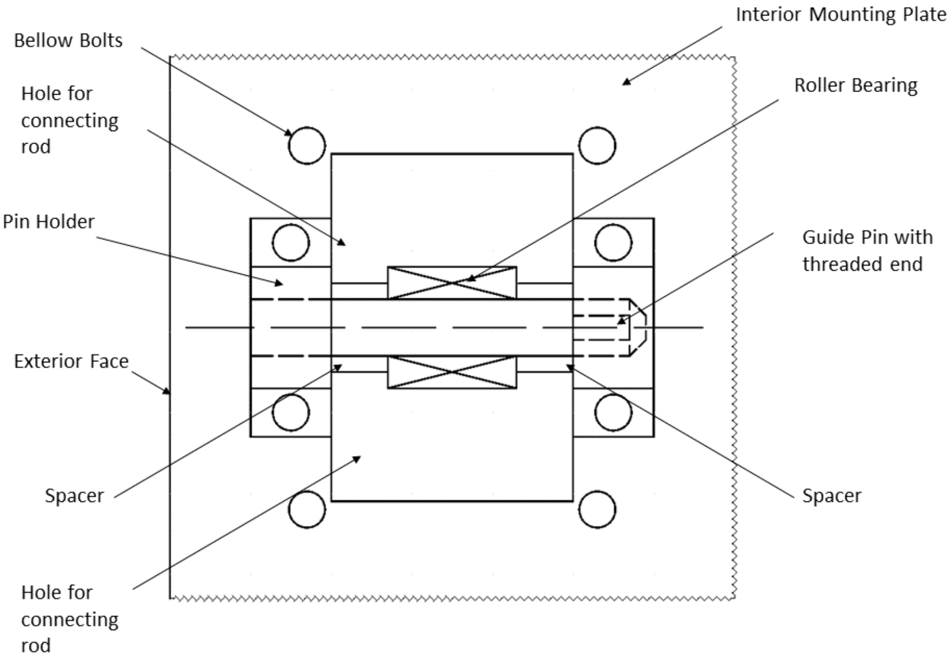


Figure 4: Linkage Top View - Guiding Pin Mount Assembly

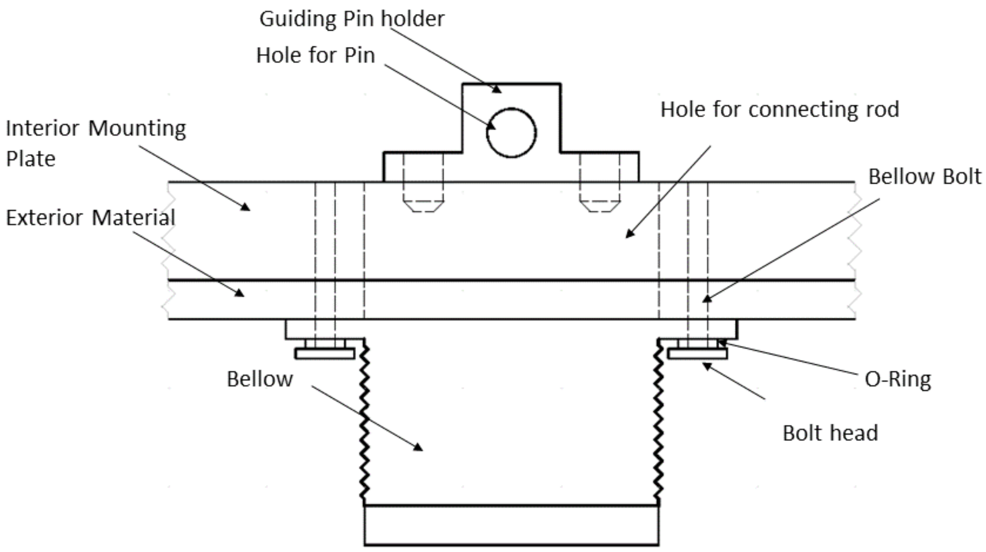


Figure 5: Linkage Side View - Guiding Pin and Bellow Mount Assembly

The case's (or outer shell) purpose is to protect all equipment and components from exterior activities. Access to the components is required as they may be subject to maintenance. The case is thus separated in two parts, the top and bottom as shown in Figure 6. Both parts are sealed using a gasket as shown in 7 and they are fastened together using multiple bolts surrounding the casing. Figure 7 also shows the holes and bolt mounting location of the bellows on the outer shell case.

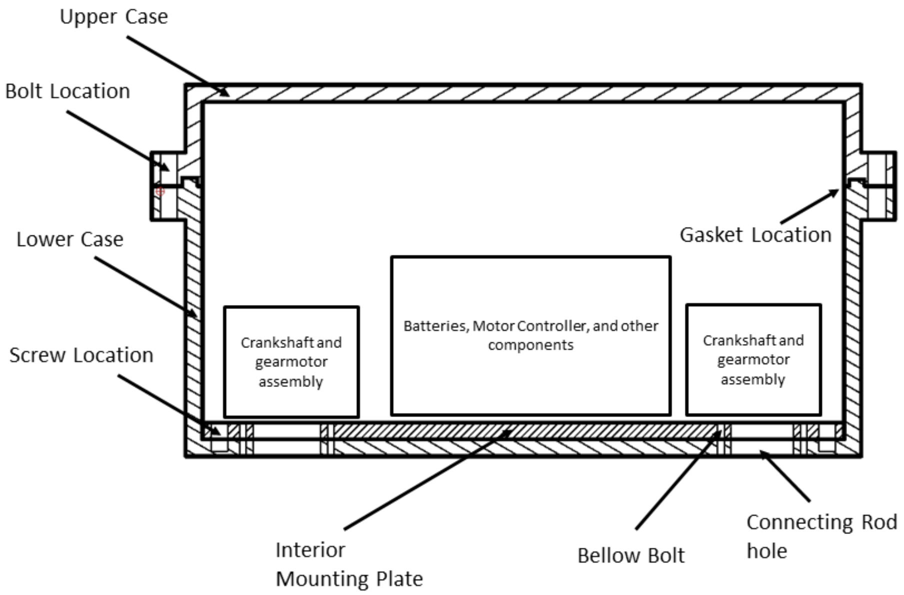


Figure 6: Linkage Side View - Water and Weather proof casing

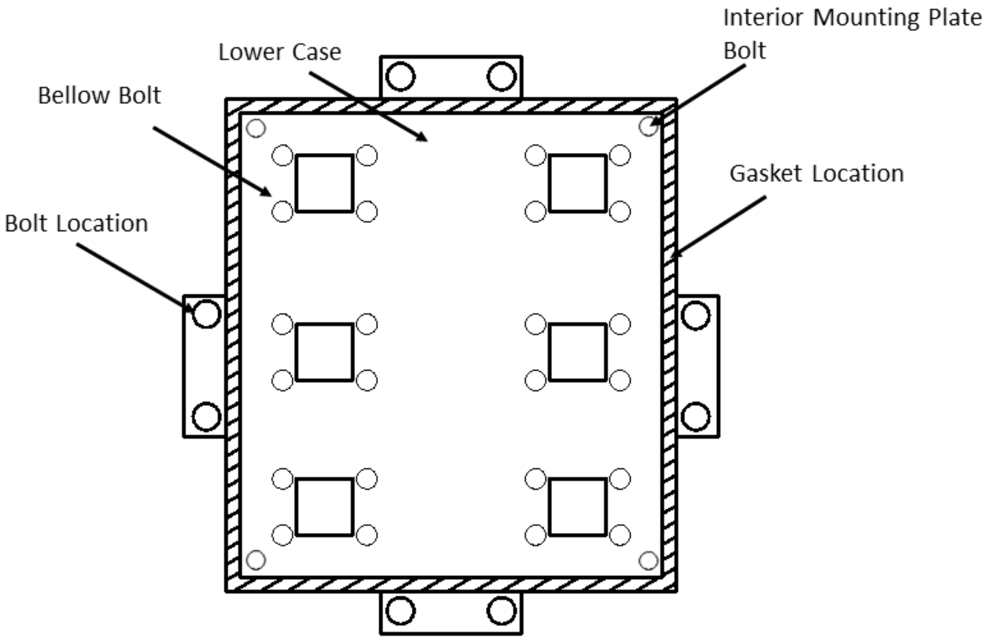
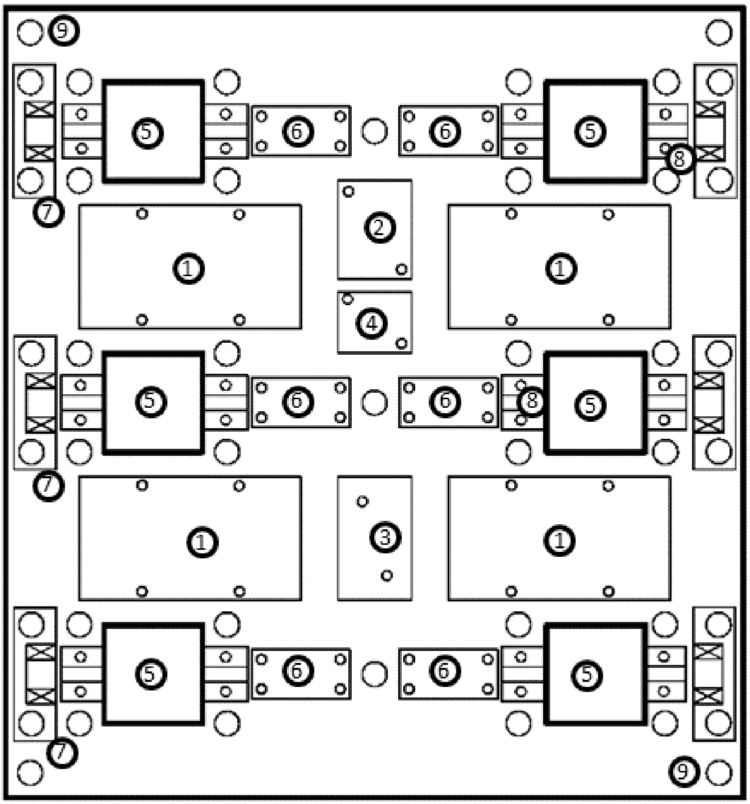


Figure 7: Linkage Top View - Water and Weather proof casing

To achieve a stable and reliable locomotion, the robot will be equipped with six legs. The mounting plate must mount all components required for the locomotion, and power system.

The Figure 8 depicts the layout of the equipment and their respective mounting holes. The robot will rotate using the same principle as a tracked tank, such that on one side the leg will complete the walking pattern more quickly than on the other side.



1. Battery
2. Computer
3. Solar Regulator
4. Motor Controller
5. Hole for Connecting Rod
6. Gearmotor
7. Crankshaft pillow bearing
8. Guiding Pin holder
9. Interior Mounting Plate bolt

Figure 8: Linkage Top View - Structural Mounting Plate

2.2 Concept 2 - Crab

The second concept is based on the movement of sideways-walking crabs. This idea was further developed to include legs at the front and back of the chassis instead of at the sides, as shown in Figure 9. The legs are thus making pulling and pushing motions. There are five legs in total, as a space is left at the front to accommodate the waste collection system.

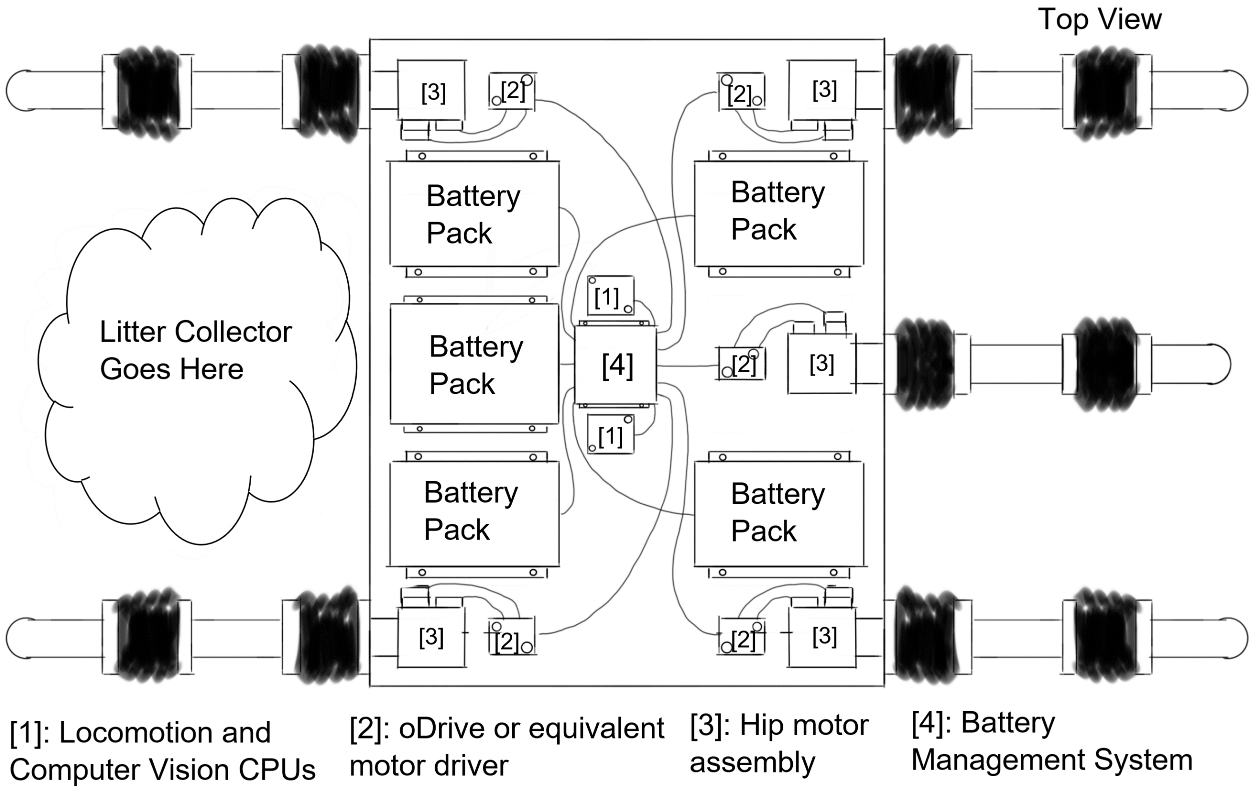


Figure 9: Crab Top View - Concept

Figure 9 also shows the layout of the various electrical components within the chassis. Five battery packs are managed by the central Batter Management System that will then distribute the power to individual motor controllers. In case a battery pack dies, the system should be able to keep running fully with four, three or even one battery pack at reduced run times. The segmentation also allows for better weight distribution. One computer is responsible for locomotion and general computing and the second is used for computer vision/machine learning algorithms to identify litter and obstacles.

Figure 10 shows a side view of a full leg. The legs have two DOF: one up and down rotating motion at the hip, and another one at the knee. This allows for extension of the leg and up and down rotation. Both motors (here Maxon Motor EC 60 100 W, shown in Appendix D) controlling the motion are located inside the chassis, with a belt drive mechanism being used to control the knee. This will reduce the inertia of the leg and the use of electronics outside the chassis. There is no rotating motion on the legs which would cause them to be able to turn the robot left and right. However, this is possible by having the legs on one side walking faster than the other, or having one side walking forwards while the other walks backwards. This method has been used in robots before, such as Stanford Doggo, and is also the method by which tanks turn on themselves [1].

Molded bellow covers are being used to cover the openings at the knee and the chassis. Both the clamping (cuff) mounting method (at the knee) and the flange mounting method (at the hip) are shown as possible options. As the bellows are rectangular/square, the flange mounting is more readily available, and thus was used for the cost estimate (rectangular cuff ends might require a custom bellow). The mounting of a square flange type bellow at the knee would be similar to the method shown in concept 3. The shin linkage has a corner in order to reduce the angle for the bellow. The linkages representing the thigh and shin may vary in length, thickness and material, depending on the results of the kinetic analysis. A carbon fiber square tubing was used for the linkages as a preliminary material for the cost assessment. Mechanical properties are shown in Appendix D

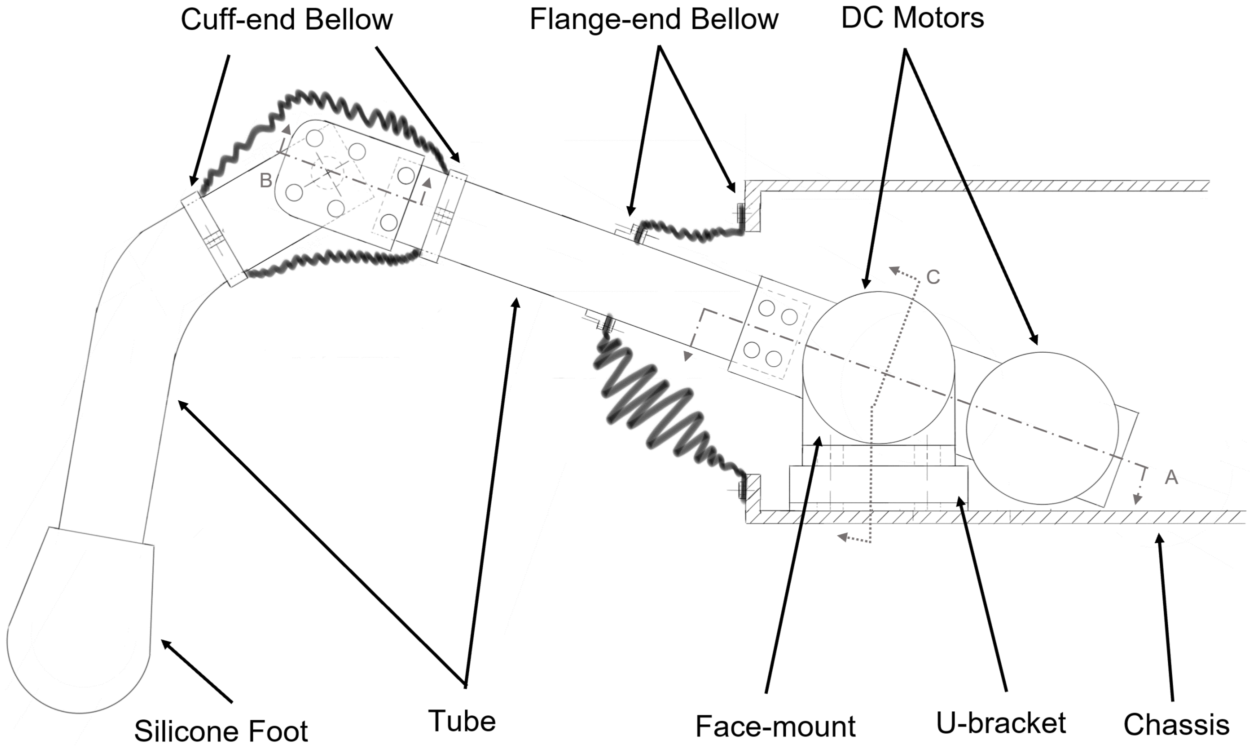


Figure 10: Crab Side View - Full Leg

Figures 11 and 12 show the detailed concept for the hip joint (Sections A and C as per Figure 10). The leftmost motor and gearbox in Figure 11 are attached directly to the leg and turn it from the hip; the second motor (on the right) turns the pulley, in turn manipulating the knee joint. Figure 12 illustrates the bracketing not shown in Figure 11, that connects the hip assembly to the chassis. It is cut perpendicular to the cut shown in Figure 10.

The gearbox is a Harmonic Drive CSD series component set, allowing for high torque in a very thin form-factor [2]. Their outer diameter varies between 50 and 170 mm, thickness between 11 and 33 mm, and output torques between 3.7 and 370 Nm. Their primary weakness is low efficiency (shown in Appendix D).

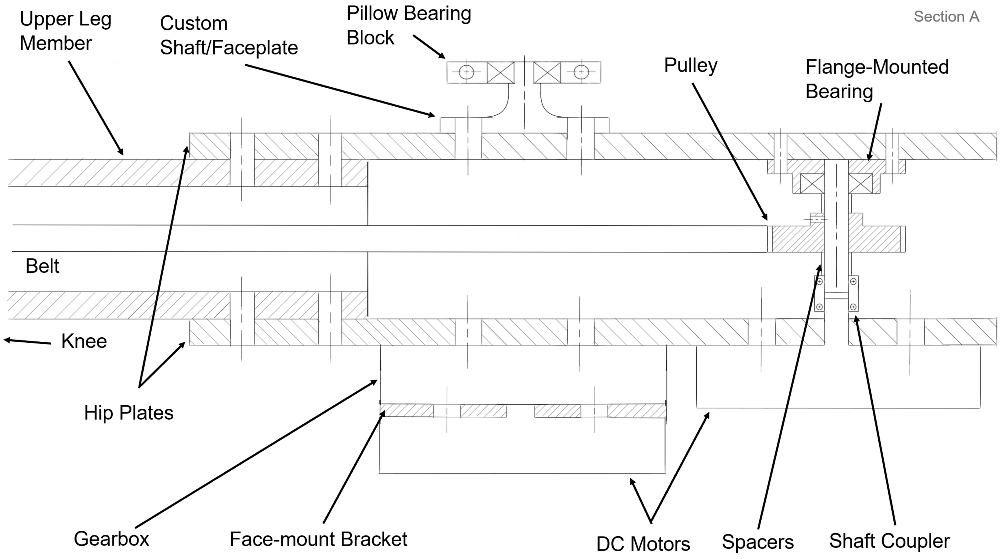


Figure 11: Crab Top Section View (Section A) - Leg and Hip

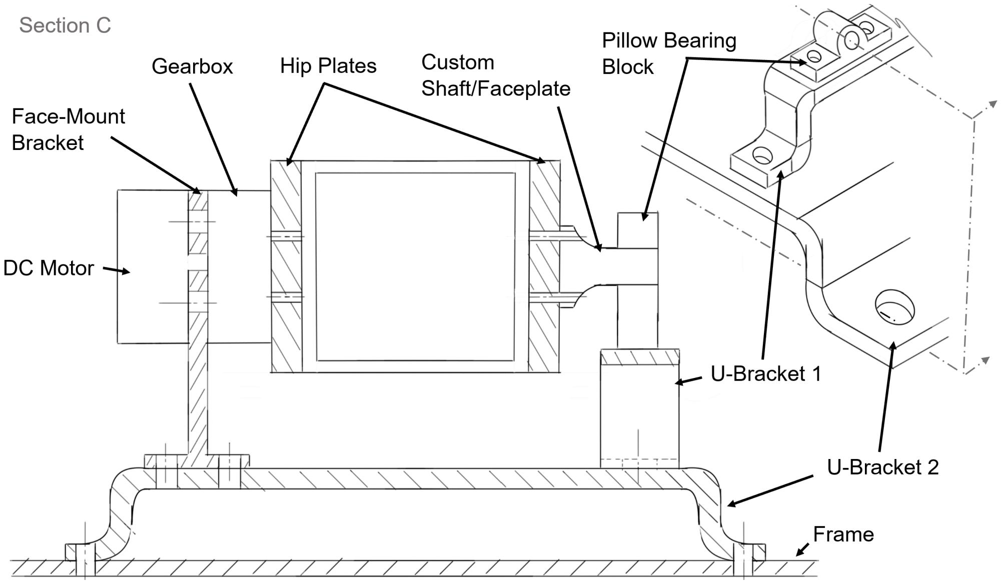


Figure 12: Crab Side Section View (Section C) - U-bracket Mounting

A detailed concept of the knee joint (Section B as per Figure 10) is shown in Figure 13.

It consists of a pulley (driven by one of the motors in the hip) which is directly fastened onto the lower shin linkage. The pulley is free to move on the shaft, which is supported by flange hub bearings on the thigh linkage. For this reason, no hub mount was drawn for this pulley, however in further design it may be required to add one to reduce the shaft size. In this case, a spacer would be added on the other side of the pulley to keep balance between the two sides. The knee can be easily assembled due to the simple shaft and the fastened side plates on the thigh linkage.

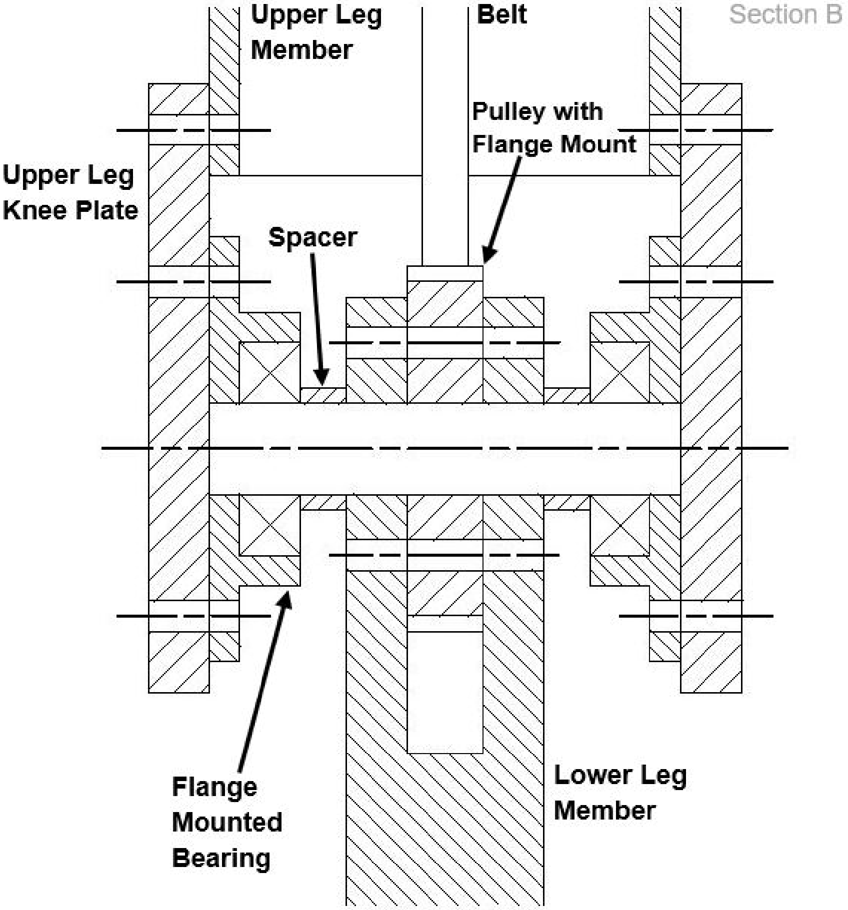


Figure 13: Crab Top Section View (Section B) - Leg and Knee

Figure 14 shows the foot design for the crab. It consists of a molded flexible silicon piece which can be slipped onto the shin linkage and is retained by a protruding ridge.

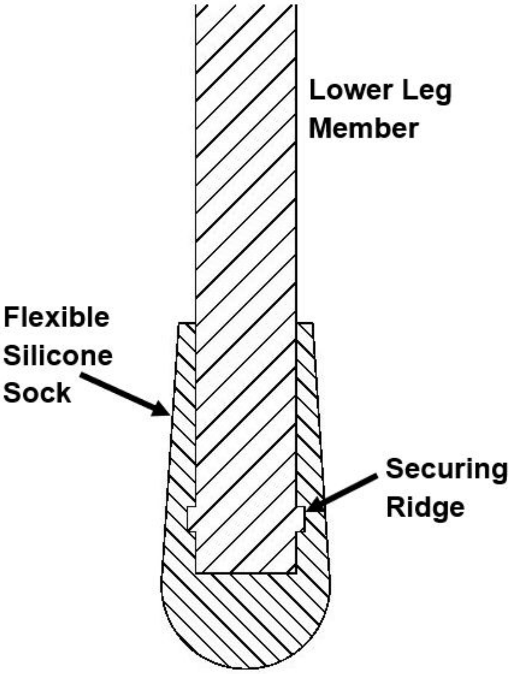


Figure 14: Crab Side View - Leg and Foot

A possible configuration for the weatherproofing and accessibility of the chassis is shown in Figure 15. A hinge is used on one side to facilitate access to the inside components for maintenance. A flange-type gasket is included all around the chassis to seal the ”lid”. It is secured by bolts.

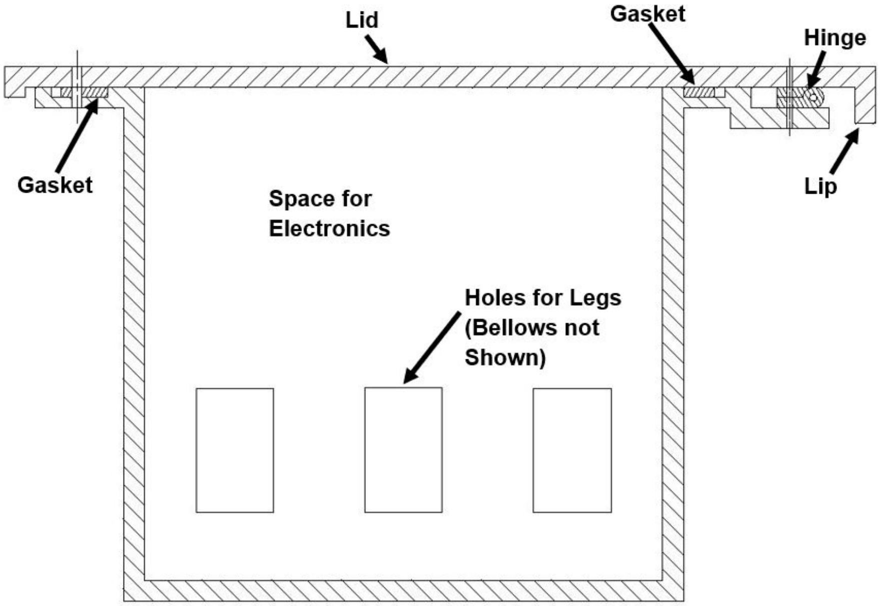


Figure 15: Crab Side View - Chassis

2.3 Concept 3 - Spider

The third concept, shown in Figure 16, is based on a spider-like leg morphology. Six legs provide superior stability to four; each leg has three degrees of freedom, allowing it to rotate and lift at the hip, as well as extend at the knee [3]. Round flange-mounted bellows are used to seal the joints from water, dust, amongst others. The leg linkages are made out of I-beams for structural rigidity. Figure 16 also shows the location of the various electrical components. These are positioned onto mounting plates inside the chassis. A front view of the chassis is also shown in Figure 17.

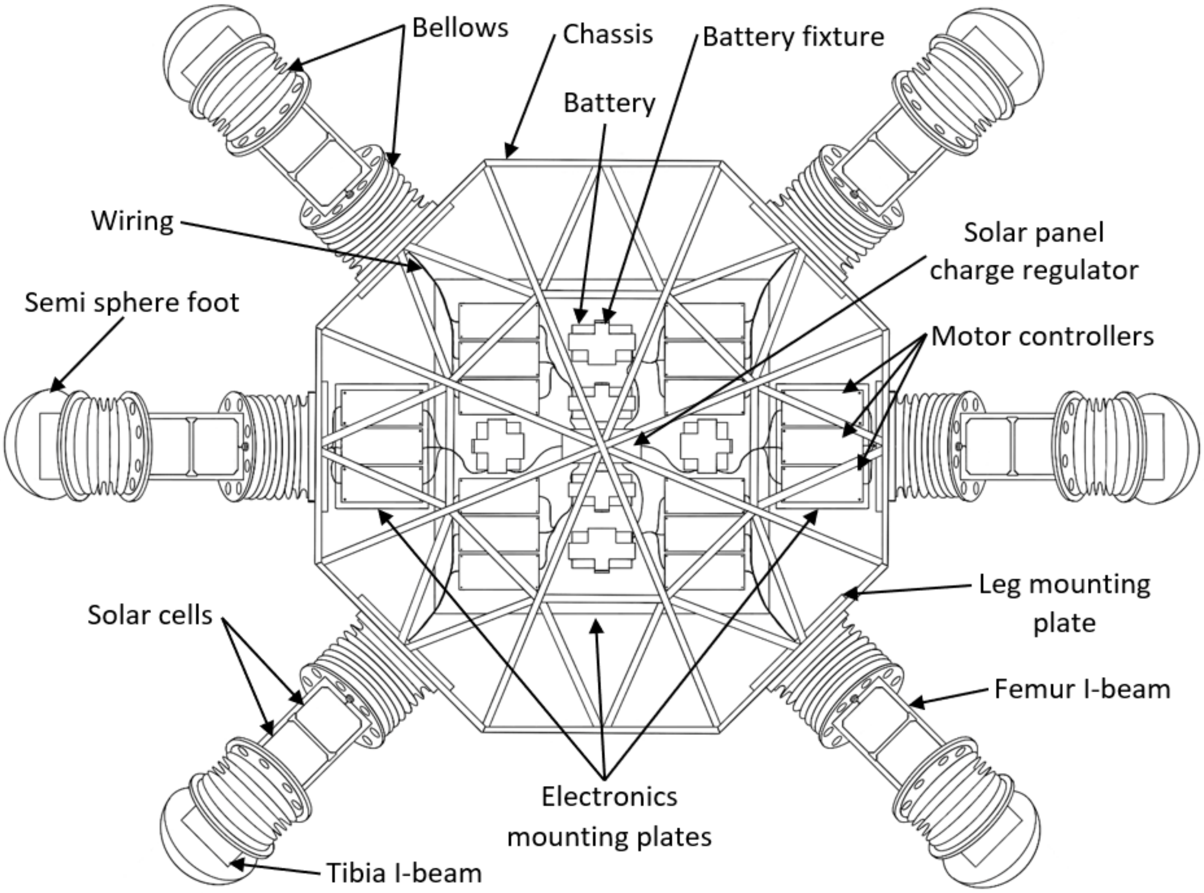


Figure 16: Spider Top View - Overview

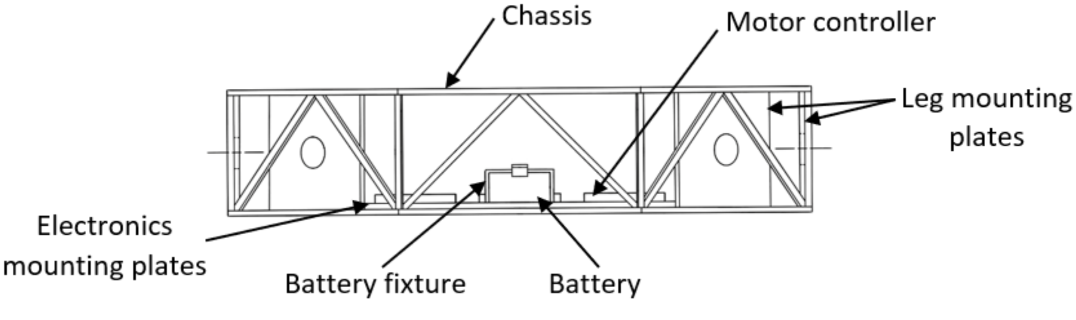


Figure 17: Spider Front View - Frame

A detailed drawing of the knee joint is shown in Figure 18. There are plate discs mounted onto the end of the I-beams to help in the mounting of components. They provide easy mounting points for the bellow flanges. Support plates for the motor are then added using

L-brackets. The motor has a shaft that extends on both other ends, which allows it to be supported on both sides and balances the forces acting on the motor. The motor then is face mounted onto the multi-stage planetary gearbox. Only one of the motor shafts is attached to the gearbox and fixed to the lower link to move it with a flange collar. The other side is simply floating in bearings.

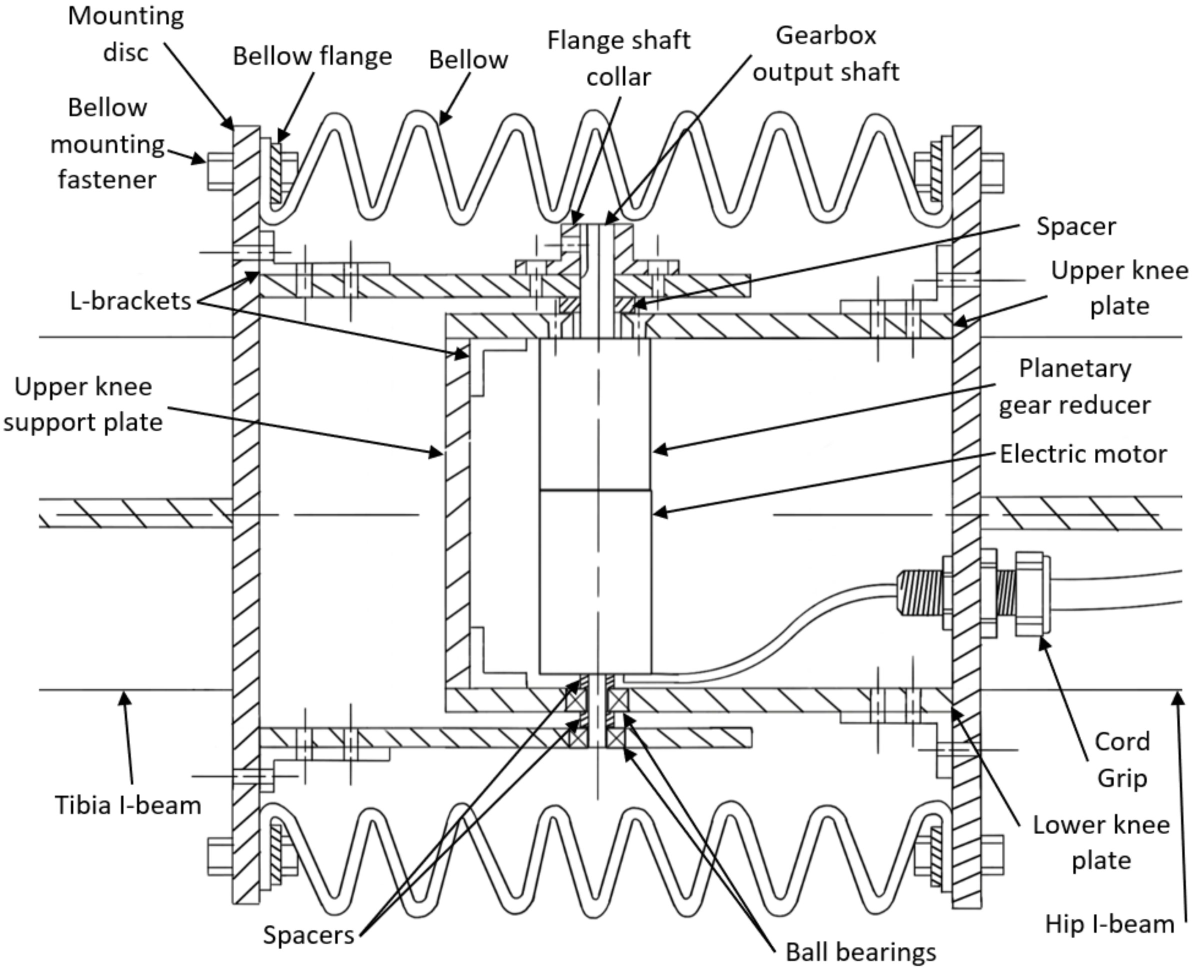


Figure 18: Spider Top View - Knee Joint

The hip joint, shown in Figure 19, uses similar principles to the knee joint. However, there are two motors positioned perpendicularly by U-shaped brackets, which allows for two degrees of freedom at the hip. Cord grips are used to feed the cables from the knee joints to the chassis for a waterproof design. The hip joint is mounted onto the chassis using longer bolts and a mounting plate positioned inside the chassis. A gasket is also used to seal the joint from the environment. Also, corner-mount draw latches are mounted at each edge of the octagon upper casing for a quick connection with the lower casing.

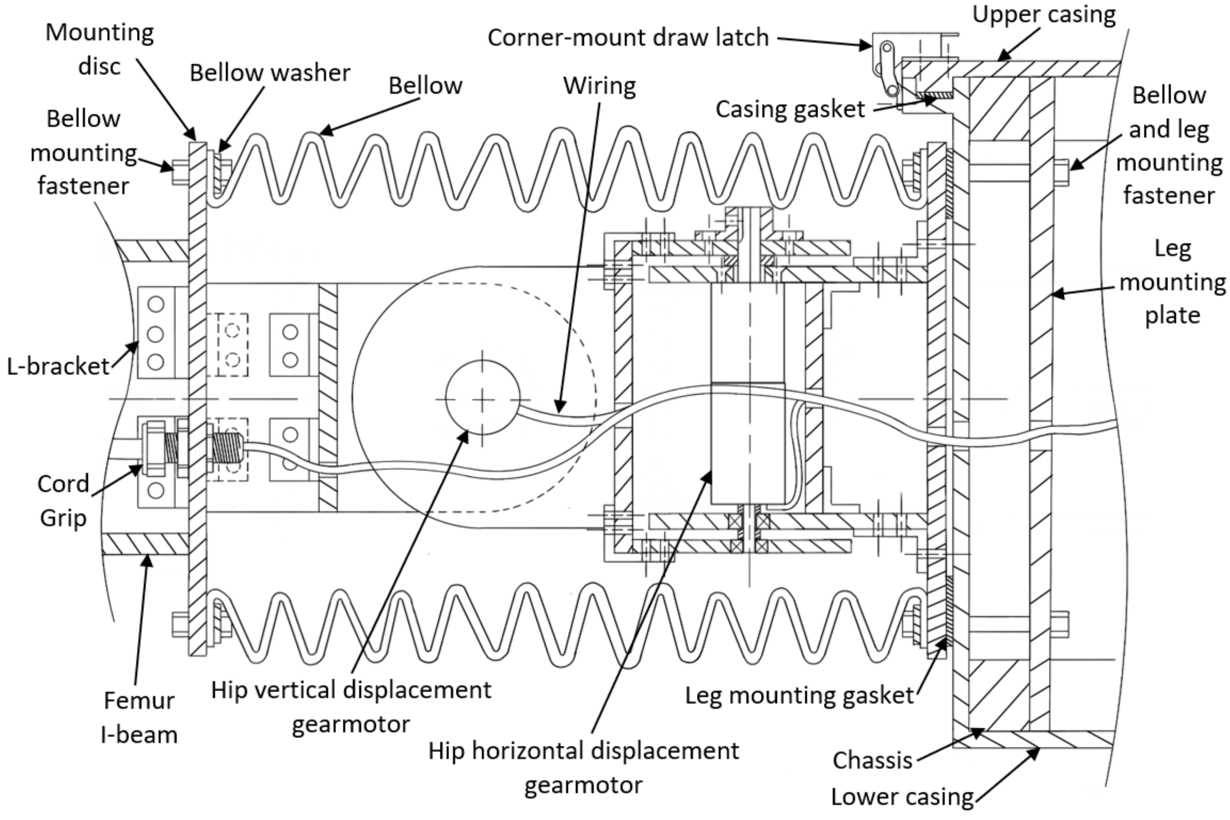


Figure 19: Spider Front View - Hip Joint

2.4 Solar Panel Concepts

Three solar panel concepts were created to explore various configurations. The concepts were not created based on any specific robot/locomotion concept as seen previously. Instead, they were made with the intention that they could be accommodated on those designs easily or with minor changes. The major goal was to explore options to maximize solar panel surface area, and consequently maximize power.

2.4.1 Concept 1 - Solar Roof

The solar roof, as shown in Figure 20 consists in a light hollow tube structure with a curved sheet on top, on which a flexible solar panel is fastened using its grommets and some bolts. The curved surface that droops over the sides of the robot allows for maximum surface area. The solar panel is also elevated away from the robot, making it less likely to interfere with the waste collection system and legs. The structure consists of four side support beams (2 per side) bolted on the curved sheet and the side of the chassis. It also has two crossed beam structures bolted on top of the chassis, with the curved sheet simply resting on top.

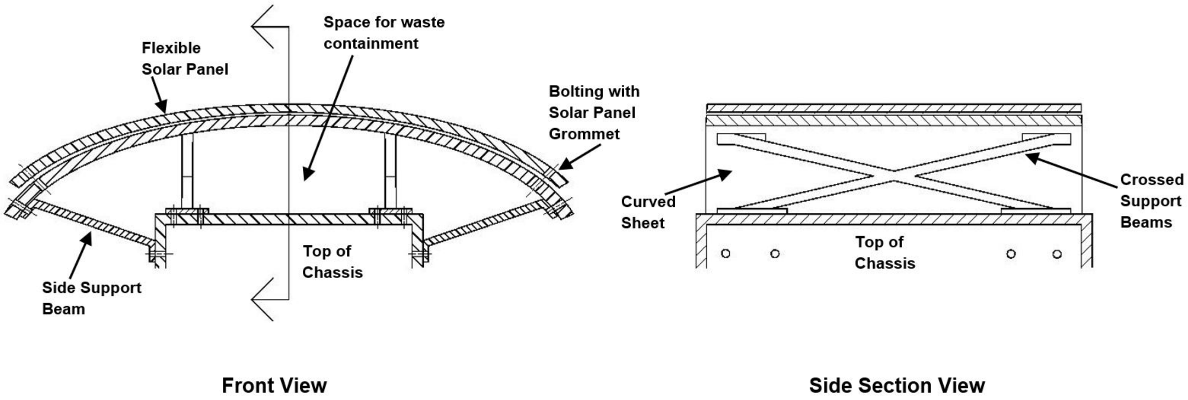


Figure 20: Solar roof concept

2.4.2 Concept 2 - Solar Awning

The solar awning, as shown in Figure 21, allows easy compatibility with any garbage picker concept requiring access to the roof of the robot. The concept uses typical metal stud tracks and wall angle channels as structural support for the solar panels. The metal studs are mounted using regular fasteners such as bolts on the side of the robot's chassis or casing/shell. The flexible solar panel is secured onto the studs using grommets and bolts.

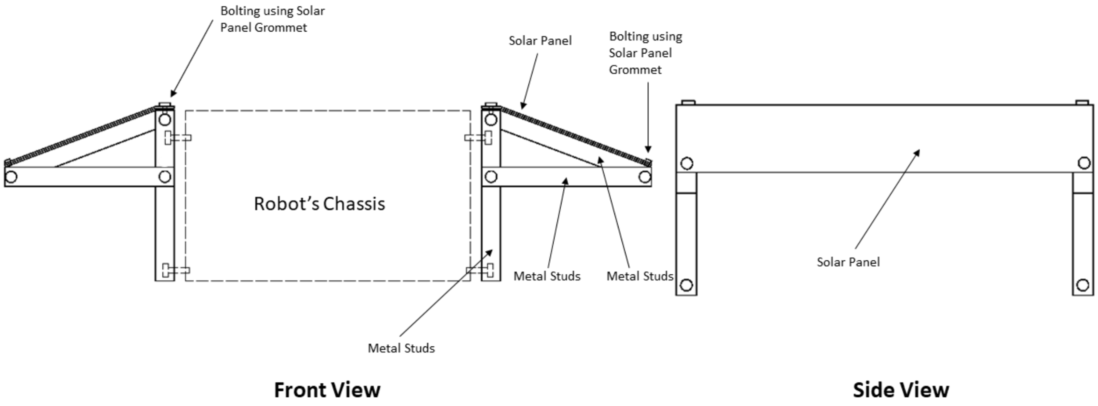


Figure 21: Solar awning concept

2.4.3 Concept 3 - Solar Cells

The third option is installing the solar cells onto the robot chassis and legs themselves with adhesive, as shown in Figure 22 [4] [5]. The useful area is whatever surfaces are exposed on the robot. A possible downside of this design is that depending on the form-factor of the litter collecting unit, the amount of space available for solar cells on the chassis may be limited. If the collector is in the form of a cube, then there is useful area on the top. Other shapes may provide less space for mounting solar cells. Additionally, increasing the width of leg linkages to accept solar cells will also increase the weight of the linkage, increasing the overall weight and power consumption.

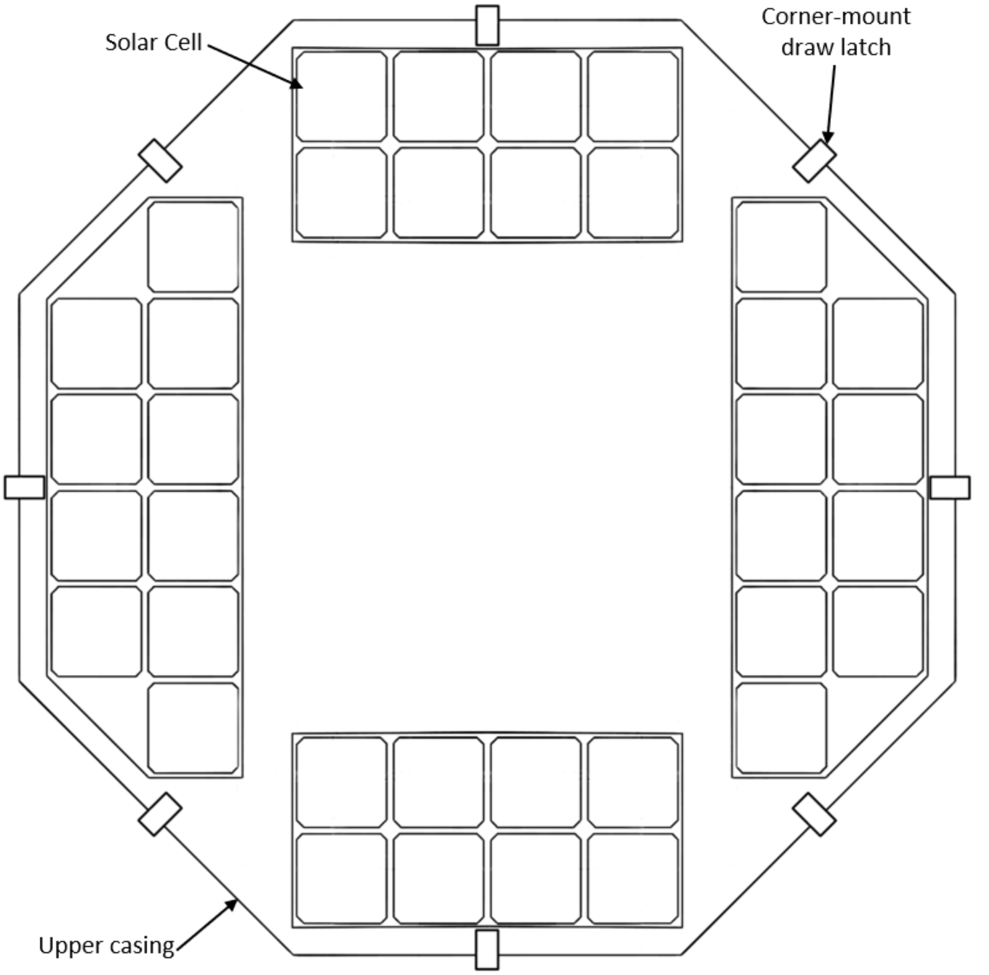


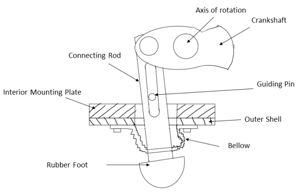
Figure 22: Custom solar cell positioning concept

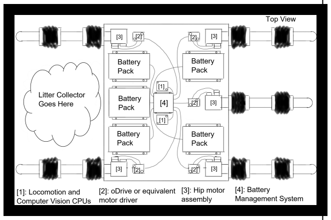
3 Cost Assessment

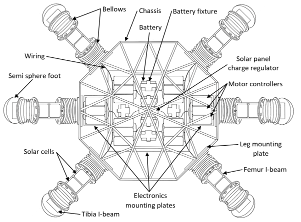
3.1 Concept Summary

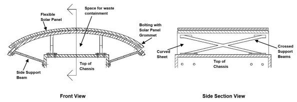
Table 1 summarizes the two primary subsystems identified for the WaterFront Robot; the robot leg topology and chassis, and solar panel mounting. The selected solution from each subsystem is framed by a rectangular form. Concept 2, the crab, was selected for the robot chassis and leg topology, and the Concept 3, the direct solar cell mounting, was selected for the solar panel mounting.

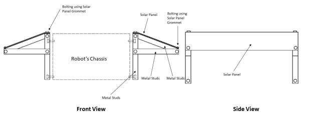
Table 1: Summary of concepts, broken down by subfunction

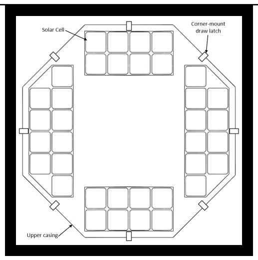
<table>
<tr><td></td><td colspan="3">Concepts</td></tr>
<tr><td></td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Robot and Legs</td><td>


</td><td>


</td><td>


</td></tr>
<tr><td>Solar Panels</td><td>


</td><td>


</td><td>


</td></tr>
</table>

3.2 Cost Assessment

A detailed cost assessment was conducted on all concepts and is shown in Appendix C. The summary of overall prices for each concept is shown in Table 2 for robot concepts and Table 3 for solar concepts. The robot concept 2 is the most expensive. This may be due to the fact that more pricey components were used, such as carbon fiber legs and harmonic drives. It would be determined with further analysis whether these pricier options are necessary, or if cheaper elements can be used, for example planetary gears and metal or plastic legs. Although the cost assessment result is higher for concept 2 compared to concept 3, it was determined that overall the concept 2 would be less expensive if similar graded components and parts as concept 3 were used. For the solar concepts, concept 3 is cheaper as it does not require additional material for a frame. Solar concept 1 is more expensive as it has a more complex frame as well as more solar panel surface area, and thus costs more in solar panels (albeit with higher power collection).

Table 2: Robot Concepts Cost Summary

Concept Number	Concept Name	Cost ($)
1	Linkage	17,035.56
2	Crab	27,804.74
3	Spider	24,785.87

Table 3: Solar Concepts Cost Summary

Concept Number	Concept Name	Cost ($)
1	Roof	1,645.22
2	Awning	589.51
3	Solar Cells	207.20

4 Discussion

The selected robot solution is concept 2, with the crab-like morphology. Various criteria were used to analyse all concepts and a decision analysis was performed, as detailed in Appendix B. The results for all concepts were close, however it is seen by observing the scoring that concept 2 is the better rounded solution. The feasibility and design complexity criteria is a driving factor in the decision, as the solution for concept 2 is believed to have a better balanced and simplistic approach. For example, although concept 1 seems relatively simple, it is likely to have a large force concentration at the guiding pin. It also has a smaller range of motion and stability. Concept 3 is inherently more complex due to the added motor for the third degree of freedom. It also has a motor on the exterior of the chassis, adding weight (inertia) to the leg and electronics on the outside.

A cost assessment was also performed, as summarized in Table 2, and is presented in detail in Appendix C. Concept 1 costed around \$16 000, Concept 2 costed around \$27 000 and Concept 3 costed around \$24 000, making Concept 2 the most expensive. For this design, however, cost has very little effect on the decision as the market is not competitive. Additionally, much of the cost putting it above Concepts 1 and 3 came from the use of carbon-fibre for the linkages (which could be substituted with the cheaper materials used in the other concepts) and Harmonic Drive gearboxes (whose zero-backdrive property may prove beneficial to improving battery life while individual legs are not active, as current will not be required to hold the motor in place). In the latter case, they could be replaced with the much less expensive planetary gearboxes used in Concept 3 if a power consumption analysis shows them to not be worth the additional price.

The chassis and sealing design for the selected concept 2 may be slightly modified and inspired by the chassis designed for the other concepts. It is dependant on further analysis and design of the legs as well as the final location of various components.

The solar panel concepts have also been analysed using a decision analysis table (Appendix B) and a cost assessment (Appendix C). The concept with the highest score is Concept 3, where custom solar panels or solar cells are positioned wherever possible on the top surface of the robot. This solution is retained as the best option for now, but may be changed depending on compatibility with the waste collection system solution and further analysis of power requirements and chassis surface area.

5 References

[1] N. Kau, A. Schultz, N. Ferrante, and P. Slade, "Stanford Doggo: An Open-Source, Quasi-Direct-Drive Quadruped," in *2019 International Conference on Robotics and Automation (ICRA)*. Montreal, QC, Canada: IEEE, May 2019, pp. 6309–6315. [Online]. Available: https://ieeexplore.ieee.org/document/8794436/

[2] Harmonic Drive, "CSD-2a Component Set | Harmonic Drive." [Online]. Available: https://www.harmonicdrive.net/products/component-sets/cup-type/csd-2a

[3] robot platform, "Robot Platform | Knowledge | Wheeled Robots." [Online]. Available: http://www.robotplatform.com/knowledge/Classification_of_Robots/legged_robots.html

[4] Gioco Solutions, "installation of flexible solar panel, fixing, accessories," Jan. 2018. [Online]. Available: http://www.giocosolutions.net/install-a-flexible-solar-panel/

[5] 3M, "3m VHB^{TM} Tapes | 3m." [Online]. Available: https://www.3m.com/3M/en_US/vhb-tapes-us/

[6] 3D Hubs, "3d Hubs." [Online]. Available: https://www.3dhubs.com/

[7] 18650 battery store, "18650 battery store." [Online]. Available: https://www.18650batterystore.com/

[8] Acklands-Grainger, "Acklands-Grainger." [Online]. Available: https://www.acklandsgrainger.com/en

[9] Alibaba, "Alibaba." [Online]. Available: https://www.alibaba.com

[10] Amazon, "Amazon." [Online]. Available: https://www.amazon.ca/

[11] Canadian Tire, "Canadian Tire." [Online]. Available: https://www.canadiantire.ca/en.html

[12] DigiKey, "DigiKey." [Online]. Available: https://www.digikey.com/

[13] Electric Motor Wholesale, "Electric Motor Wholesale." [Online]. Available: http://www.electricmotorwholesale.com/

[14] Electromate, "Electromate." [Online]. Available: https://www.electromate.com/

[15] ePlastics, “ePlastics.” [Online]. Available: https://www.eplastics.com/

[16] Speed-Talk, “Finding a custom crank maker - Don Terrill’s Speed-Talk.” [Online]. Available: https://www.speed-talk.com/forum/viewtopic.php?t=40581;

[17] Global Industrial Canada, “Global Industrial Canada.” [Online]. Available: https://www.globalindustrial.ca/

[18] H. Depot, “Home Depot.” [Online]. Available: https://www.homedepot.com/

[19] Hot Rod Network, “Hot Rod Network.” [Online]. Available: https://www.hotrod.com/

[20] Indeed, “Indeed.” [Online]. Available: https://ca.indeed.com/

[21] Lowe’s Canada, “Lowe’s Canada.” [Online]. Available: https://www.lowes.ca/

[22] Maxon Motor, “Maxon.” [Online]. Available: https://www.maxongroup.com/maxon/view/content/index

[23] McMaster-Carr, “McMaster-Carr.” [Online]. Available: https://www.mcmaster.com/

[24] METAL SUPERMARKETS, “METAL SUPERMARKETS.” [Online]. Available: https://ecommerce.metalsupermarkets.com/MSC-Home.aspx

[25] Metals Depot, “Metals Depot.” [Online]. Available: https://www.metalsdepot.com/

[26] PayScale, “PayScale.” [Online]. Available: https://www.payscale.com

[27] REDARC Electronics, “REDARC.” [Online]. Available: https://www.redarc.com.au/

[28] Robots Shop, “RobotShop.” [Online]. Available: https://www.robotshop.com/

[29] Rock West Composites, “Rock West Composites.” [Online]. Available: https://www.rockwestcomposites.com/

[30] Summit Racing, “Summit Racing.” [Online]. Available: https://www.summitracing.com/

[31] TAP Plastics, “TAP Plastics.” [Online]. Available: https://www.tapplastics.com/

[32] The Big Bearing Store, “The Big Bearing Store.” [Online]. Available: https://www.thebigbearingstore.com/

[33] Webo Solar, "Webo Solar." [Online]. Available: https://webosolar.com/store/en/

[34] Gadget Makers' Blog, "Arduino Power Consumption," Sep. 2013. [Online]. Available: https://www.gadgetmakersblog.com/arduino-power-consumption/

[35] RasPi.TV, "How much power does the Pi4b use? Power Measurements," Jun. 2019. [Online]. Available: https://raspi.tv/2019/how-much-power-does-the-pi4b-use-power-measurements

[36] NVIDIA, "JETSON TX2 AND TX2i DATASHEET," 2018. [Online]. Available: http://static6.arrow.com/aropdfconversion/766a44ea9100e05d6acca62618622b4380fe242b/jetson_tx2_tx2i_module_datasheet_v01.pdf

[37] maxon motor, "EC60 flat 60mm, brushless, 100 W, with Hall sensors." [Online]. Available: https://www.maxongroup.com/maxon/view/catalog?etcc_med=ID+Teaser&etcc_cmp=ID-Teaser-Rebrush-Homepage&etcc_cu=onsite&etcc_var=%5bcom%5d%23en%23_d_&etcc_plc=home

[38] ANYbotics, "ANYmal C – Autonomous Legged Robot." [Online]. Available: https://www.anybotics.com/anymal-legged-robot/

[39] Boston Dynamics, "Spot® | Boston Dynamics," Sep. 2019. [Online]. Available: https://www.bostondynamics.com/spot

[40] F. Lambert, "Tear down of 85 kWh Tesla battery pack shows it could actually only be a 81 kWh pack [Updated]," Feb. 2016. [Online]. Available: https://electrek.co/2016/02/03/tesla-battery-tear-down-85-kwh/

[41] Panasonic Industrial Devices, "Specifications for NCR18650bd." [Online]. Available: https://b2b-api.panasonic.eu/file_stream/pids/fileversion/3445

A Additional Material

No detailed additional literature review material was required for the creation of the concepts.

B Decision Analysis Tables

Decision analysis' are shown in the following tables. Concepts are scored (S) from 1 (worst) to 3 (best). This is then multiplied by the weight to get the weighed score (WS) and a total sum is calculated for each solution. The concept with the highest total is the winner.

Table 4 shows the decision analysis for the robot locomotion concepts. The highest weight of 30/100 is attributed to power consumption, as the solution must be solar powered, making power a limiting factor. The scores are attributed based on the number of electric motors on each solution.

The next criteria, weighed at 20/100, is mobility and terrain operation. This includes ability to turn, navigate on slopes and walk in various difficult terrains such as sand, pebbles, shallow water, mud and small plants.

The next criteria weighs 20/100 as well and consists of feasibility and design complexity. This relates to the the simplicity of the design as well as the complexities that may arise in further analysis of the design (force concentrations on parts, number of components to consider, etc).

Furthermore, maintainability and longevity is added with a weight of 15/100. This is included due to the fact that the robot should be self-reliant. It takes into account frequency and ease of maintenance.

The last two criteria are: aesthetics (10/100) as the robot operates in public areas, and cost (5/100) which is a minor consideration due to the fact that this solution has very little existing competition. It is still considered in order to ensure the designs' feasibility.

Table 4: Decision analysis table for robot and leg concepts

Criteria	Weight	Concept 1		Concept 2		Concept 3	
		S	WS	S	WS	S	WS
Power Consumption	30	3	90	2	60	1	30
Mobility and Terrain Operation	20	1	20	2	40	3	60
Feasibility and Design Complexity	20	1	20	3	60	2	40
Maintainability and Longevity	15	3	45	1	15	2	30
Aesthetics	10	1	10	2	20	3	30
Cost	5	3	15	2	10	1	5
Total	100		200		205		195

Table 5 shows the decision analysis for the solar panel solutions.

The most critical criteria, weighed at 35/100 is to maximise the sun exposure surface. This includes maximising the surface area of the solar panels as well as orienting them in a favourable manner towards the sun. It determines the amount of power output from the solar panels.

The second highest weighed criteria, with 30/100, is compatibility and integration. This includes whether the solar panels could impede with the movement of the robots' legs or other moving parts. It also takes into account whether it could potentially interfere with the integration of the waste collecting system designed by group 2B. It was discussed that a garbage container might be positioned on top of the robot, with an arm moving to deposit waste in the container.

Stability, weighed at 20/100, takes into account the effects of the solar panels on the center of mass of he robot and whether they could get caught in the wind. Lastly, cost is included as a measure of complexity of the solutions, and weighs 15/100.

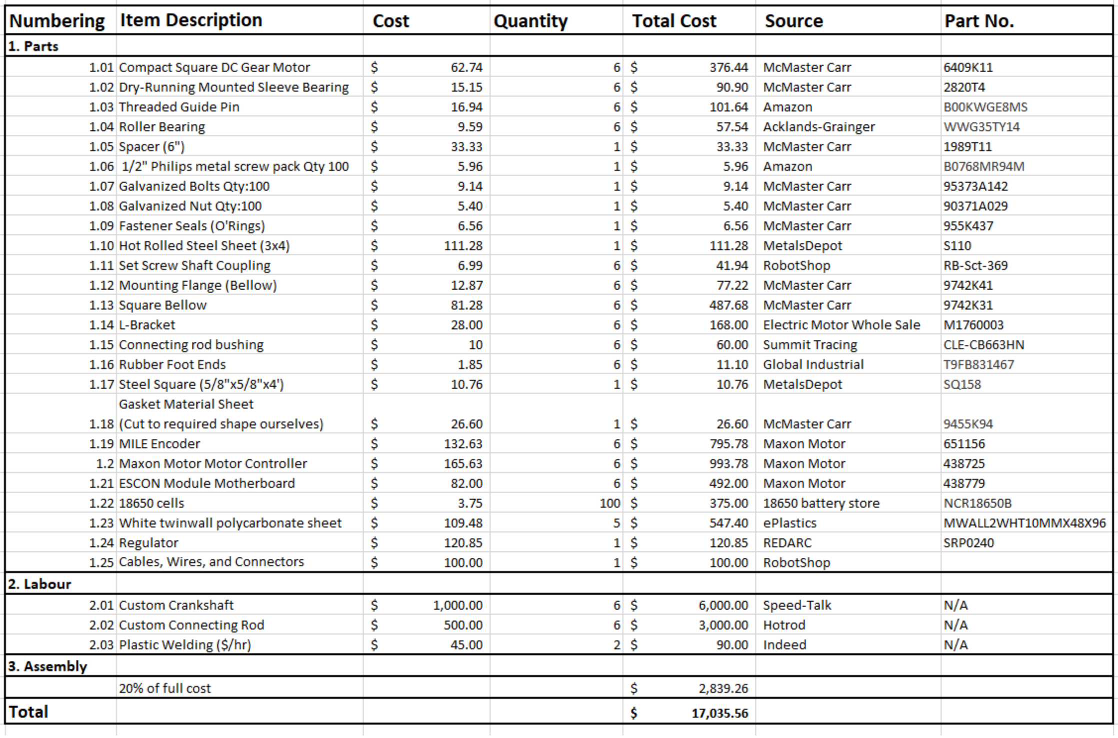
Table 5: Decision analysis table for solar panel concepts

Criteria	Weight	Concept 1		Concept 2		Concept 3	
		S	WS	S	WS	S	WS
Maximise Sun Exposed Surface Area	35	3	105	1	35	2	70
Cost	15	1	15	2	30	3	45
Compatibility and Integration	30	2	60	1	30	3	90
Stability	20	1	20	2	40	3	60
Total	100		200		135		265

C Detailed Cost Assessment

The references to all sources used in the cost assessment tables can be found in Table 12. The quote for Harmonic Drives provided by Electromate was given in CAD; this number was converted to USD for a fair comparison with other expensive components such as motors and gearboxes.

Table 6: Cost Analysis for Concept 1 - Linkage

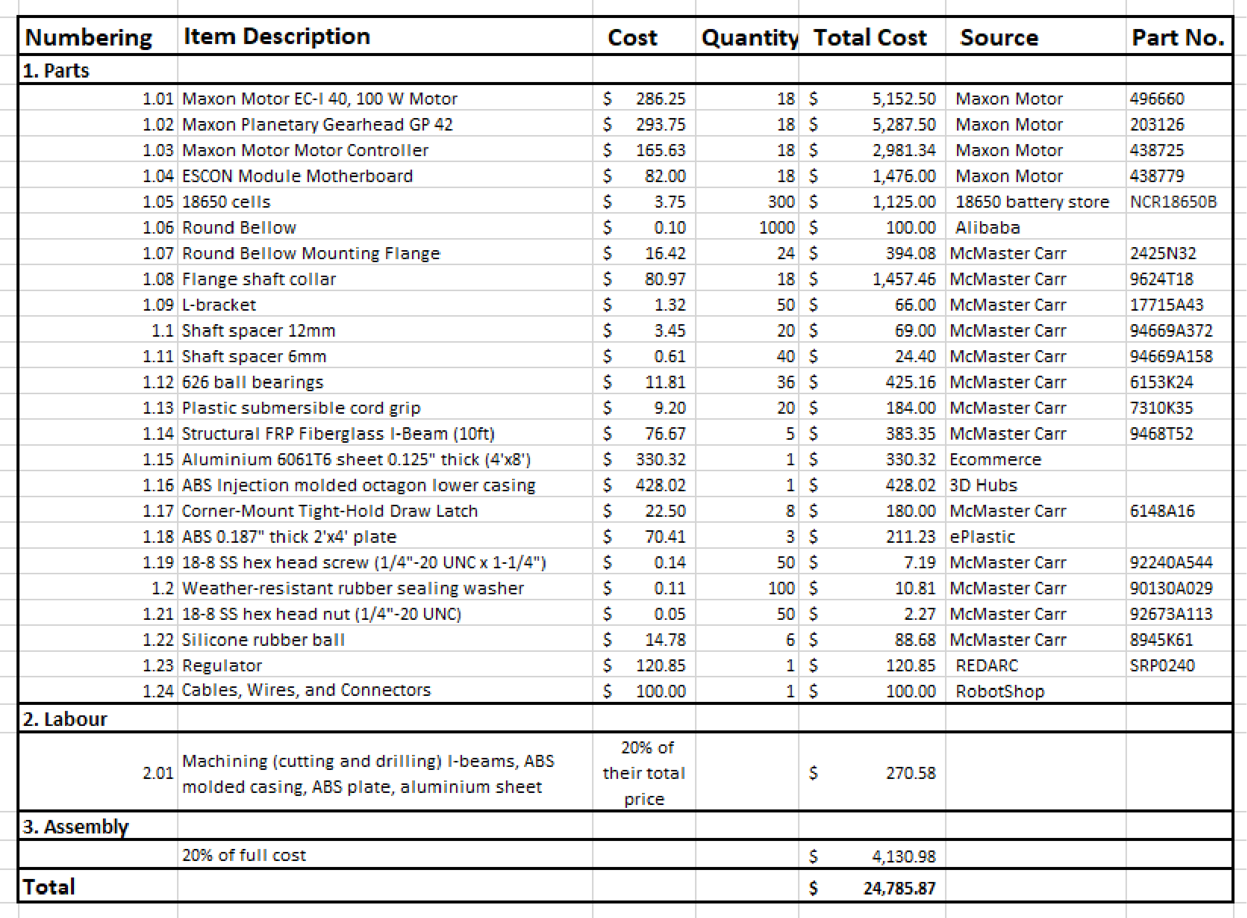


Numbering	Item Description	Cost	Quantity	Total Cost	Source	Part No.
1. Parts						
1.01	Compact Square DC Gear Motor	$ 62.74	6	$ 376.44	McMaster Carr	6409K11
1.02	Dry-Running Mounted Sleeve Bearing	$ 15.15	6	$ 90.90	McMaster Carr	2820T4
1.03	Threaded Guide Pin	$ 16.94	6	$ 101.64	Amazon	B00KWGE8MS
1.04	Roller Bearing	$ 9.59	6	$ 57.54	Acklands-Grainger	WWG35TY14
1.05	Spacer (6")	$ 33.33	1	$ 33.33	McMaster Carr	1989T11
1.06	1/2" Philips metal screw pack Qty 100	$ 5.96	1	$ 5.96	Amazon	B0768MR94M
1.07	Galvanized Bolts Qty:100	$ 9.14	1	$ 9.14	McMaster Carr	95373A142
1.08	Galvanized Nut Qty:100	$ 5.40	1	$ 5.40	McMaster Carr	90371A029
1.09	Fastener Seals (O'Rings)	$ 6.56	1	$ 6.56	McMaster Carr	955K437
1.10	Hot Rolled Steel Sheet (3x4)	$ 111.28	1	$ 111.28	MetalsDepot	S110
1.11	Set Screw Shaft Coupling	$ 6.99	6	$ 41.94	RobotShop	RB-Sct-369
1.12	Mounting Flange (Bellow)	$ 12.87	6	$ 77.22	McMaster Carr	9742K41
1.13	Square Bellow	$ 81.28	6	$ 487.68	McMaster Carr	9742K31
1.14	L-Bracket	$ 28.00	6	$ 168.00	Electric Motor Whole Sale	M1760003
1.15	Connecting rod bushing	$ 10	6	$ 60.00	Summit Tracing	CLE-CB663HN
1.16	Rubber Foot Ends	$ 1.85	6	$ 11.10	Global Industrial	T9FB831467
1.17	Steel Square (5/8"x5/8"x4')	$ 10.76	1	$ 10.76	MetalsDepot	SQ158
1.18	Gasket Material Sheet (Cut to required shape ourselves)	$ 26.60	1	$ 26.60	McMaster Carr	9455K94
1.19	MILE Encoder	$ 132.63	6	$ 795.78	Maxon Motor	651156
1.2	Maxon Motor Motor Controller	$ 165.63	6	$ 993.78	Maxon Motor	438725
1.21	ESCON Module Motherboard	$ 82.00	6	$ 492.00	Maxon Motor	438779
1.22	18650 cells	$ 3.75	100	$ 375.00	18650 battery store	NCR18650B
1.23	White twinwall polycarbonate sheet	$ 109.48	5	$ 547.40	ePlastics	MWALL2WHT10MMX48X96
1.24	Regulator	$ 120.85	1	$ 120.85	REDARC	SRP0240
1.25	Cables, Wires, and Connectors	$ 100.00	1	$ 100.00	RobotShop	
2. Labour						
2.01	Custom Crankshaft	$ 1,000.00	6	$ 6,000.00	Speed-Talk	N/A
2.02	Custom Connecting Rod	$ 500.00	6	$ 3,000.00	Hotrod	N/A
2.03	Plastic Welding ($/hr)	$ 45.00	2	$ 90.00	Indeed	N/A
3. Assembly						
	20% of full cost			$ 2,839.26		
Total				**$ 17,035.56**		

Table 7: Cost Analysis for Concept 2 - Crab

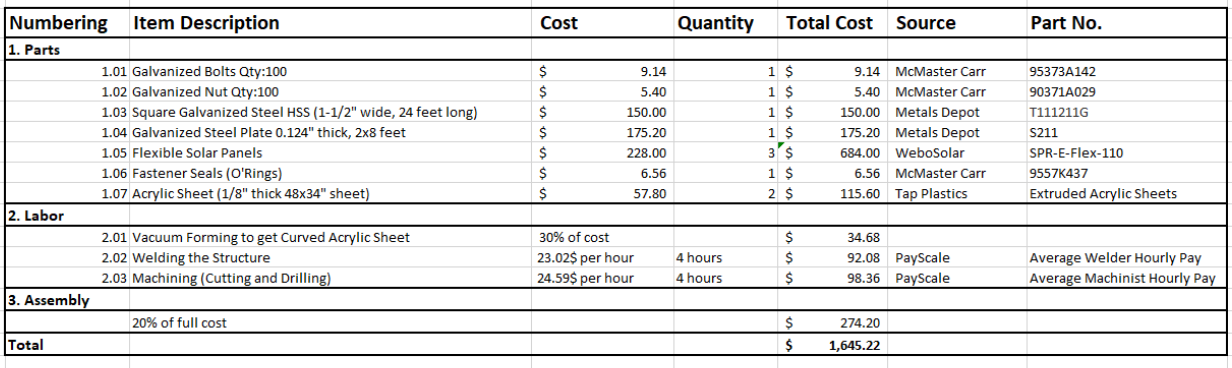
Numbering	Item Description	Cost	Quantity	Total Cost	Source	Part No.
1. Parts						
1.01	Harmonic Drive Component Set	$ 1,350.00	10	$ 10,169.87	Electromate	
1.02	Maxon Motor EC 60, 100 W Motor	$ 103.63	10	$ 1,036.30	Maxon Motor	645604
1.03	MILE Encoder	$ 132.63	10	$ 1,326.30	Maxon Motor	651156
1.04	Maxon Motor Motor Controller	$ 165.63	10	$ 1,656.30	Maxon Motor	438725
1.05	ESCON Module Motherboard	$ 82.00	10	$ 820.00	Maxon Motor	438779
1.06	18650 cells	$ 3.75	300	$ 1,125.00	18650 battery store	NCR18650B
1.07	Silicone Rubber for Feet (3D printed mold, make ourselves)	$ 40.00	1	$ 40.00		
1.08	Square Flange Bellow	$ 91.09	10	$ 910.90	McMaster Carr	9742K32
1.09	Mounting Flange (Bellow)	$ 15.42	10	$ 154.20	McMaster Carr	9742K42
1.10	1/2" Philips metal screw pack Qty 100	$ 5.96	1	$ 5.96	Amazon	B0768MR94M
1.11	Galvanized Bolts Qty: 100	$ 9.14	1	$ 9.14	McMaster Carr	95373A142
1.12	Galvanized Nut Qty: 100	$ 5.40	1	$ 5.40	McMaster Carr	90371A029
1.13	Fastener Seals (O'Rings)	$ 6.56	1	$ 6.56	McMaster Carr	9557k437
1.14	Gasket Material Sheet (Cut to required shape ourselves)	$ 26.60	1	$ 26.60	McMaster Carr	9455K94
1.15	Lower Shin Square Rod	$ 241.99	1	$ 241.99	RockWest Composites	25497
1.16	Upper Thigh Square Tube (Carbon Fiber)	$ 1,179.99	1	$ 1,179.99	RockWest Composites	25516
1.17	Leg Side Plate Material (Aluminum 6061, 3/8" thick, 4x8 feet sheet)	$ 894.40	1	$ 894.40	Metals Depot	P338T6
1.18	Flange Mounted Bearings	$ 43.64	15	$ 654.60	McMaster Carr	5968K71
1.19	Drive Pulley	$ 47.28	5	$ 236.40	McMaster Carr	6495K412
1.20	Hub for Pulleys (1/2" Shaft)	$ 14.02	10	$ 140.20	McMaster Carr	6086k111
1.21	Shafts (1/2" diameter)	$ 30.16	1	$ 66.71	McMaster Carr	5936k75
1.22	Driven Pulley	$ 51.39	5	$ 256.95	McMaster Carr	6495K415
1.23	Belt (36.7" circle, 1" wide, 0.375" pitch, trapezoidal)	$ 37.87	5	$ 189.35	McMaster Carr	1679k289
1.24	Spacers (3/4" long LDPE)	$ 9.09	1	$ 9.09	McMaster Carr	92825A243
1.25	Pillow Bearing Block	$ 10.20	5	$ 51.00	TheBigBearingStore	SBSP201-08
1.26	Shaft Coupler	$ 31.19	5	$ 155.95	McMaster Carr	61005k331
1.27	Motor Face Mount L-Bracket	$ 10.99	2	$ 21.98	Amazon	
1.28	U-Bracket 1	$ 6.07	5	$ 30.35	McMaster Carr	18725a62
1.29	U-Bracket 2	$ 4.00	5	$ 20.00	McMAster Carr	Based on 18725a62
1.30	Material for Chassis (Acrylic 3/8" thick, 48x35" sheets)	$ 175.00	2	$ 350.00	Tap Plastics	
1.31	Regulator	$ 120.85	1	$ 120.85	REDARC	SRP0240
1.32	Cables, Wires, and Connectors	$ 100.00	1	$ 100.00	RobotShop	
2. Labour						
2.01	Machining Leg Links and Plates (cutting into segments, shaping top of shin piece, making holes, etc)	20% of their total price		$ 463.28		
2.02	Custom Chassis Vacuum Forming and Machining	30% of material price		$ 70.00		
2.03	Custom Shaft/Face Plate	5 hours per shaft, 5 shafts per robot, $25/hour		$ 625.00		
3. Assembly						
	20% of full cost			$ 4,634.12		
Total				**$ 27,804.74**		

Table 8: Cost Analysis for Concept 3 - Spider



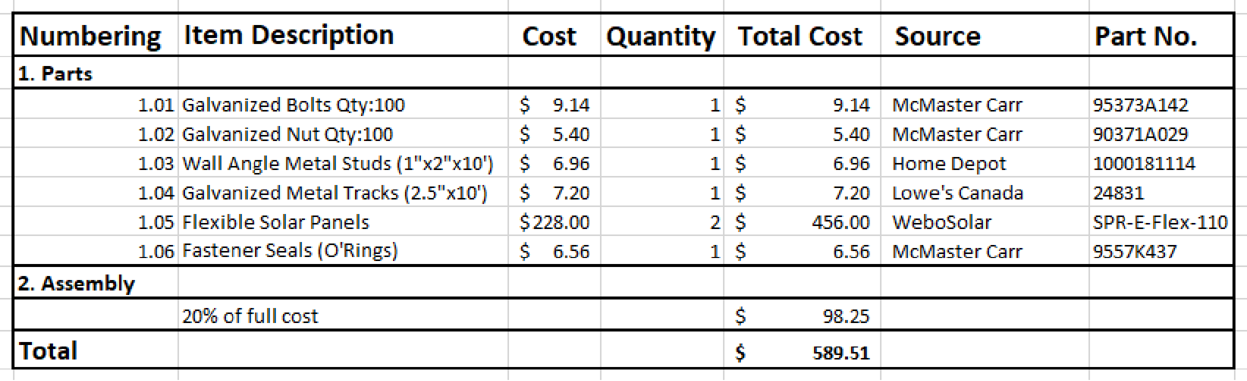
Numbering	Item Description	Cost	Quantity	Total Cost	Source	Part No.
1. Parts						
1.01	Maxon Motor EC-I 40, 100 W Motor	$ 286.25	18	$ 5,152.50	Maxon Motor	496660
1.02	Maxon Planetary Gearhead GP 42	$ 293.75	18	$ 5,287.50	Maxon Motor	203126
1.03	Maxon Motor Motor Controller	$ 165.63	18	$ 2,981.34	Maxon Motor	438725
1.04	ESCON Module Motherboard	$ 82.00	18	$ 1,476.00	Maxon Motor	438779
1.05	18650 cells	$ 3.75	300	$ 1,125.00	18650 battery store	NCR18650B
1.06	Round Bellow	$ 0.10	1000	$ 100.00	Alibaba	
1.07	Round Bellow Mounting Flange	$ 16.42	24	$ 394.08	McMaster Carr	2425N32
1.08	Flange shaft collar	$ 80.97	18	$ 1,457.46	McMaster Carr	9624T18
1.09	L-bracket	$ 1.32	50	$ 66.00	McMaster Carr	17715A43
1.1	Shaft spacer 12mm	$ 3.45	20	$ 69.00	McMaster Carr	94669A372
1.11	Shaft spacer 6mm	$ 0.61	40	$ 24.40	McMaster Carr	94669A158
1.12	626 ball bearings	$ 11.81	36	$ 425.16	McMaster Carr	6153K24
1.13	Plastic submersible cord grip	$ 9.20	20	$ 184.00	McMaster Carr	7310K35
1.14	Structural FRP Fiberglass I-Beam (10ft)	$ 76.67	5	$ 383.35	McMaster Carr	9468T52
1.15	Aluminium 6061T6 sheet 0.125" thick (4'x8')	$ 330.32	1	$ 330.32	Ecommerce	
1.16	ABS Injection molded octagon lower casing	$ 428.02	1	$ 428.02	3D Hubs	
1.17	Corner-Mount Tight-Hold Draw Latch	$ 22.50	8	$ 180.00	McMaster Carr	6148A16
1.18	ABS 0.187" thick 2'x4' plate	$ 70.41	3	$ 211.23	ePlastic	
1.19	18-8 SS hex head screw (1/4"-20 UNC x 1-1/4")	$ 0.14	50	$ 7.19	McMaster Carr	92240A544
1.2	Weather-resistant rubber sealing washer	$ 0.11	100	$ 10.81	McMaster Carr	90130A029
1.21	18-8 SS hex head nut (1/4"-20 UNC)	$ 0.05	50	$ 2.27	McMaster Carr	92673A113
1.22	Silicone rubber ball	$ 14.78	6	$ 88.68	McMaster Carr	8945K61
1.23	Regulator	$ 120.85	1	$ 120.85	REDARC	SRP0240
1.24	Cables, Wires, and Connectors	$ 100.00	1	$ 100.00	RobotShop	
2. Labour						
2.01	Machining (cutting and drilling) I-beams, ABS molded casing, ABS plate, aluminium sheet	20% of their total price		$ 270.58		
3. Assembly						
	20% of full cost			$ 4,130.98		
Total				**$ 24,785.87**		

Table 9: Cost Analysis for Solar Concept 1 - Roof



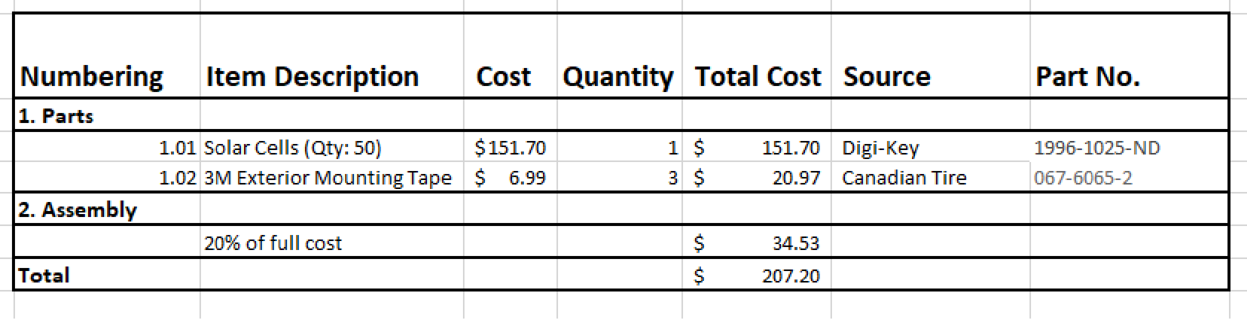
Numbering	Item Description	Cost	Quantity	Total Cost	Source	Part No.
1. Parts						
1.01	Galvanized Bolts Qty:100	$ 9.14	1	$ 9.14	McMaster Carr	95373A142
1.02	Galvanized Nut Qty:100	$ 5.40	1	$ 5.40	McMaster Carr	90371A029
1.03	Square Galvanized Steel HSS (1-1/2" wide, 24 feet long)	$ 150.00	1	$ 150.00	Metals Depot	T111211G
1.04	Galvanized Steel Plate 0.124" thick, 2x8 feet	$ 175.20	1	$ 175.20	Metals Depot	S211
1.05	Flexible Solar Panels	$ 228.00	3	$ 684.00	WeboSolar	SPR-E-Flex-110
1.06	Fastener Seals (O'Rings)	$ 6.56	1	$ 6.56	McMaster Carr	9557K437
1.07	Acrylic Sheet (1/8" thick 48x34" sheet)	$ 57.80	2	$ 115.60	Tap Plastics	Extruded Acrylic Sheets
2. Labor						
2.01	Vacuum Forming to get Curved Acrylic Sheet	30% of cost		$ 34.68		
2.02	Welding the Structure	23.02$ per hour	4 hours	$ 92.08	PayScale	Average Welder Hourly Pay
2.03	Machining (Cutting and Drilling)	24.59$ per hour	4 hours	$ 98.36	PayScale	Average Machinist Hourly Pay
3. Assembly						
	20% of full cost			$ 274.20		
Total				**$ 1,645.22**		

Table 10: Cost Analysis for Solar Concept 2 - Awning



Numbering	Item Description	Cost	Quantity	Total Cost	Source	Part No.
1. Parts						
1.01	Galvanized Bolts Qty:100	$ 9.14	1	$ 9.14	McMaster Carr	95373A142
1.02	Galvanized Nut Qty:100	$ 5.40	1	$ 5.40	McMaster Carr	90371A029
1.03	Wall Angle Metal Studs (1"x2"x10')	$ 6.96	1	$ 6.96	Home Depot	1000181114
1.04	Galvanized Metal Tracks (2.5"x10')	$ 7.20	1	$ 7.20	Lowe's Canada	24831
1.05	Flexible Solar Panels	$ 228.00	2	$ 456.00	WeboSolar	SPR-E-Flex-110
1.06	Fastener Seals (O'Rings)	$ 6.56	1	$ 6.56	McMaster Carr	9557K437
2. Assembly						
	20% of full cost			$ 98.25		
Total				**$ 589.51**		

Table 11: Cost Analysis for Solar Concept 3 - Solar Cells



Numbering	Item Description	Cost	Quantity	Total Cost	Source	Part No.
1. Parts						
1.01	Solar Cells (Qty: 50)	$ 151.70	1	$ 151.70	Digi-Key	1996-1025-ND
1.02	3M Exterior Mounting Tape	$ 6.99	3	$ 20.97	Canadian Tire	067-6065-2
2. Assembly						
	20% of full cost			$ 34.53		
Total				$ 207.20		

Table 12: Part Source References

3D Hubs	[6]
18650 battery store	[7]
Acklands-Grainger	[8]
Alibaba	[9]
Amazon	[10]
Canadian Tire	[11]
DigiKey	[12]
Electric Motor Wholesale	[13]
Electromate	[14]
ePlastics	[15]
Speed-Talk	[16]
Global Industrial Canada	[17]
Home Depot	[18]

Hot Rod Network	[19]
Indeed	[20]
Lowe's Canada	[21]
Maxon Motor	[22]
McMaster-Carr	[23]
Metal Supermarkets	[24]
Metals Depot	[25]
PayScale	[26]
REDARC	[27]
RobotShop	[28]
Rock West Composites	[29]
Summit Racing	[30]
TAP Plastics	[31]
The Big Bearing Store	[32]
Webo Solar	[33]

C.1 Battery Selection

Batteries were selected in the following manner:

1. Power consumption per motor was set at 50W; not all motors will be running at the same time, nor at full capacity, so 50% of total capacity was selected.

2. Power consumption for computers is set conservatively to the full power of NVIDIA Jetson TX2s; these consume more power than Raspberry Pis and Arduinos, giving a conservative approximation [34] [35] [36].

3. The battery voltage matches the highest voltage element in the robot. This is likely the motors, which in the given configuration need 24 V, compared to up to 15 V for the NVIDIA Jetson TX2 [36] [37].

4. A runtime of two hours was selected. This is in line with the two to four hours advertised by ANYbotics' ANYmal and hour-and-a-half advertised by Boston Dynamics' Spot [38] [39].

5. The Panasonic NCR18650B variant of 18650 cell were selected (same model as used in Tesla batteries), with 3.6 V and 3400mAh (12.58 Wh) [7] [40].
6. The number of cells required is equal to the number of cells required to achieve the desired voltage, times the number of cells required to achieve the two hour runtime. In the case of the crab model, it requires seven cells in series and 42 is parallel, or approximately 300 cells in total.

Table 13: Approximate Power consumption of Crab Model (see Figure 9) (does not include losses)

Device Name	Power Consumption (W)	No. of device	Total power consumption (W)
Computer	7.5	2	15
DC Motor	50	10	500
Total			530

D Data Sheets

Table 14 contains references for all data sheets beyond this point.

Table 14: Part Source References

Item	Source	Part Number (if applicable)
Harmonic Drive CSD	[2]	N/A
Maxon Motor GP42C	[22]	203126
Maxon Motor EC 60	[37]	645604
Maxon Motor ECi 40	[22]	496660
Panasonic 18650 Cell	[41]	NCR18650B
RockWest Composites Carbon Fibre	[29]	25516
McMaster-Carr DC Gearmotor	[23]	6409K11

Ordering Code

CSD - 20 - 100 - 2A - GR - SP

Table 063-1

Series	Size	Ratio*				Model	Special specification
CSD	14	50	80	100	—	2A-GR = component type (2A-R for Size 14, 17)	Blank= Standard product SP= Special specification code BB= Big Bore
	17	50	80	100	120		
	20	50	80	100	120		
	25	50	80	100	120		
	32	50	80	100	120		
	40	50	80	100	120		
	50	50	80	100	120		

* The reduction ratio value is based on the following configuration:
Input: wave generator, fixed: circular spline, output: flexspline

Technical Data

CSD-2A Component Set

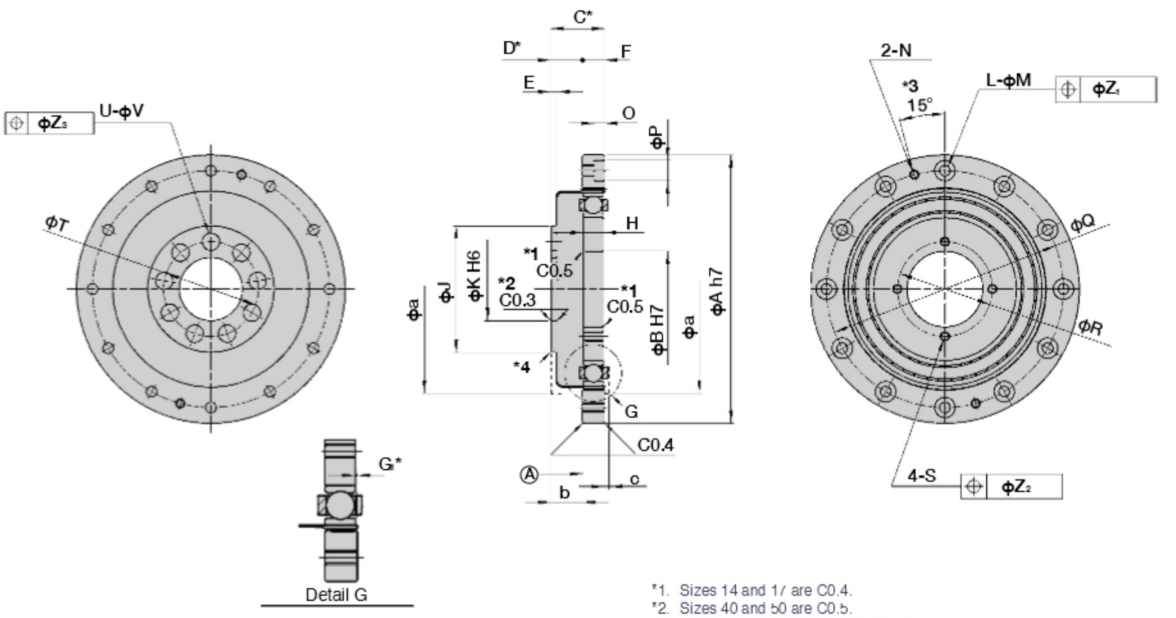
Size	Gear ratio	Rated torque at input speed 2000rpm		Limit for repeated peak torque		Limit for average torque		Limit for momentary peak torque		Maximum input speed (rpm)		Limit for average input speed (rpm)		Moment of inertia	
		Nm	kgfm	Nm	kgfm	Nm	kgfm	Nm	kgfm	Oil	Grease	Oil	Grease	$I \times 10^{-4} kgm^2$	$J \times 10^{-5} kgfms^2$
14	50	3.7	0.38	12	1.2	4.8	0.49	24	2.4	14000	8500	6500	3500	0.021	0.021
	80	5.4	0.55	16	1.6	7.7	0.79	31	3.2						
	100	5.4	0.55	19	1.9	7.7	0.79	31	3.2						
17	50	11	1.1	23	2.3	18	1.8	48	4.9	10000	7300	6500	3500	0.054	0.055
	80	15	1.5	29	3.0	19	1.9	55	5.6						
	100	16	1.6	37	3.8	27	2.8	55	5.6						
	120	16	1.6	37	3.8	27	2.8	55	5.6						
20	50	17	1.7	39	4.0	24	2.4	69	7.0	10000	6500	6500	3500	0.090	0.092
	80	24	2.4	51	5.2	33	3.4	76 (65)	7.7 (6.6)						
	100	28	2.9	57	5.8	34	3.5	76 (65)	7.7 (6.6)						
	120	28	2.9	60	6.1	34	3.5	76 (65)	7.7 (6.6)						
25	50	27	2.8	69	7.0	38	3.9	127	13	7500	5600	5600	3500	0.282	0.288
	80	44	4.5	96	9.8	60	6.1	152 (135)	15 (14)						
	100	47	4.8	110	11	75	7.6	152 (135)	15 (14)						
	120	47	4.8	117	12	75	7.6	152 (135)	15 (14)						
32	50	53	5.4	151	15	75	7.6	268	27	7000	4800	4600	3500	1.09	1.11
	80	83	8.5	213	22	117	12	359 (331)	37 (34)						
	100	96	9.8	233	24	151	15	359 (331)	37 (34)						
	120	96	9.8	247	25	151	15	359 (331)	37 (34)						
40	50	96	9.8	281	29	137	14	480	49	5600	4000	3600	3000	2.85	2.91
	80	144	15	364	37	198	20	685 (580)	70 (59)						
	100	185	19	398	41	260	27	694 (580)	71 (59)						
	120	205	21	432	44	315	32	694 (580)	71 (59)						
50	50	172	18	500	51	247	25	1000	102	4500	3500	3000	2500	8.61	8.78
	80	260	27	659	67	363	37	1300	133						
	100	329	34	686	70	466	48	1440 (1315)	147 (134)						
	120	370	38	756	77	569	58	1441	147 (134)						

1. Moment of inertia: $I = \frac{1}{4} GD^2$
2. *The maximum allowable momentary torque value marked by an asterisk(*) is restricted by the tightening torque of the flexspline.
3. The parenthesized value indicates the value when the bore of the flexspline has the maximum value (BB type).
4. See "Rating Table Definitions" on Page 12 for details of the terms.
5. When the max allowable momentary torque is expected to be applied, see "Bolt tightening of the flexspline" on p. 75.

Outline Dimensions

You can download the CAD files from our website: harmonicdrive.net

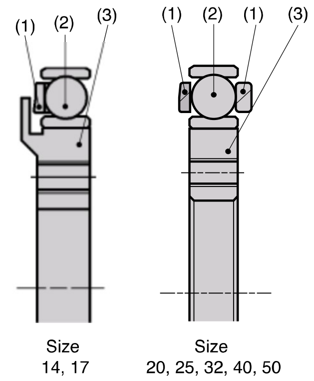
Fig. 064-1



*1. Sizes 14 and 17 are C0.4.
*2. Sizes 40 and 50 are C0.5.
*3. Size 14 is 30° and Size 17 is 22.5°.
*4: Sizes 14 to 32 are C0.3 and 40 and 50 are C0.5.
* Refer to confirmation drawing provided by Harmonic Drive LLC.

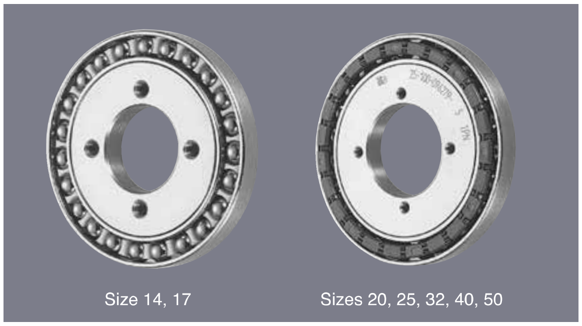
■ Structure and shape of the wave generator

Fig. 064-2



(1) Ball separator
(2) Wave generator bearing
(3) Wave generator plug

There is a difference in appearance of the the ball separator depending on the size.


Size 14, 17

Sizes 20, 25, 32, 40, 50

Dimensions

Table 065-1
Unit : mm

Symbol		14	17	20	25	32	40	50
φA h7		$50^{\ 0}_{-0.025}$	$60^{\ 0}_{-0.030}$	$70^{\ 0}_{-0.030}$	$85^{\ 0}_{-0.035}$	$110^{\ 0}_{-0.035}$	$135^{\ 0}_{-0.040}$	$170^{\ 0}_{-0.040}$
φB H7		$11^{+0.018}_{\ 0}$	$15^{+0.018}_{\ 0}$	$20^{+0.021}_{\ 0}$	$24^{+0.021}_{\ 0}$	$32^{+0.025}_{\ 0}$	$40^{+0.025}_{\ 0}$	$50^{+0.025}_{\ 0}$
C∗		11	12.5	14	17	22	27	33
D∗		$6.5^{+0.2}_{\ 0}$	$7.5^{+0.2}_{\ 0}$	$8^{+0.3}_{\ 0}$	$10^{+0.3}_{\ 0}$	$13^{+0.3}_{\ 0}$	$16^{+0.3}_{\ 0}$	$19.5^{+0.3}_{\ 0}$
E		1.4	1.7	2	2	2.5	3	3.5
F		4.5	5	6	7	9	11	13.5
G_1∗		$0.3^{+0.2}_{\ 0}$	$0.3^{+0.2}_{\ 0}$	$0.3^{+0.2}_{\ 0}$	$0.4^{+0.2}_{\ 0}$	$0.5^{+0.2}_{\ 0}$	$0.6^{+0.2}_{\ 0}$	$0.8^{+0.2}_{\ 0}$
H		$4^{\ 0}_{-0.1}$	$5^{\ 0}_{-0.1}$	$5.2^{\ 0}_{-0.1}$	$6.3^{\ 0}_{-0.1}$	$8.6^{\ 0}_{-0.1}$	$10.3^{\ 0}_{-0.1}$	$12.7^{\ 0}_{-0.1}$
φJ		23	27.2	32	40	52	64	80
φK H6	Standard	$11^{+0.011}_{\ 0}$	$11^{+0.011}_{\ 0}$	$16^{+0.011}_{\ 0}$	$20^{+0.013}_{\ 0}$	$30^{+0.013}_{\ 0}$	$32^{+0.016}_{\ 0}$	$44^{+0.016}_{\ 0}$
	BB spec.	$11^{+0.011}_{\ 0}$	$11^{+0.011}_{\ 0}$	$20^{+0.013}_{\ 0}$	$24^{+0.013}_{\ 0}$	$32^{+0.016}_{\ 0}$	$40^{+0.016}_{\ 0}$	$50^{+0.016}_{\ 0}$
L		6	8	12	12	12	12	12
φM		3.4	3.4	3.4	3.4	4.5	5.5	6.6
N		M3	M3	M3	M3	M4	M5	M6
O		—	—	3.3	3.3	4.4	5.4	6.5
φP		—	—	6.5	6.5	8	9.5	11
φQ		44	54	62	75	100	120	150
φR		17	21	26	30	40	50	60
S		M3	M3	M3	M3	M4	M5	M6
φT	Standard	17	19.5	24	30	41	48	62
	BB spec.	17	19.5	26	32	42	52	65
U	Standard	9	8	9	9	11	10	11
	BB spec.	9	8	12	12	14	14	14
φV	Standard	3.4	4.5	4.5	5.5	6.6	9	11
	BB spec.	3.4	4.5	3.4	4.5	5.5	6.6	9
φZ_1		0.2	0.2	0.2	0.2	0.25	0.25	0.3
φZ_2		0.25	0.25	0.2	0.2	0.25	0.25	0.3
φZ_3	Standard	0.2	0.25	0.25	0.25	0.3	0.5	0.5
	BB spec.	0.2	0.25	0.2	0.25	0.25	0.3	0.5
Minimum housing clearance	φa	38	45	53	66	86	106	133
	b	6.5	7.5	8	10	13	16	19.5
	c	1	1	1.5	1.5	2	2.5	3.5
Mass (kg)		0.06	0.10	0.13	0.24	0.51	0.92	1.9

(Note) Standard dimension for size 14 and 17 is the maximum bore.

- Surface A is the recommended mounting surface.
- The following dimensions can be modified to accommodate customer-specific requirements.

Wave Generator:	B
Flexspline:	U and V
Circular Spline:	L and M

- *C, D and G_1 values indicate relative position of individual gearing components (wave generator, flexspline, circular spline). Please strictly adhere to these values when designing your housing and mating parts.
- Due to the deformation of the Flexspline during operation, it is necessary to provide a minimum housing clearance, dimensions φa, b, c

The wave generator, flexspline, and circular spline are not assembled when delivered.

Positional accuracy

See "Engineering data" for a description of terms.

Table 066-1

Ratio		14	17	20	25	32	40	50
Positional Accuracy	$\times10^{-4}$rad	4.4	4.4	2.9	2.9	2.9	2.9	2.9
	arc min	1.5	1.5	1.0	1.0	1.0	1.0	1.0

Hysteresis loss

See "Engineering data" for a description of terms.

Table 066-2

Ratio \ Size		14	17	20	25	32	40	50
50	$\times10^{-4}$rad	7.3	5.8	5.8	5.8	5.8	5.8	5.8
	arc min	2.5	2.0	2.0	2.0	2.0	2.0	2.0
80 or more	$\times10^{-4}$rad	5.8	2.9	2.9	2.9	2.9	2.9	2.9
	arc min	2.0	1.0	1.0	1.0	1.0	1.0	1.0

Torsional stiffness

See "Engineering data" for a description of terms.

Table 066-3

Symbol \ Size			14	17	20	25	32	40	50
	T_1	Nm	2.0	3.9	7.0	14	29	54	108
		kgfm	0.2	0.4	0.7	1.4	3.0	5.5	11
	T_2	Nm	6.9	12	25	48	108	196	382
		kgfm	0.7	1.2	2.5	4.9	11	20	39
Reduction ratio 50	K_1	$\times10^4$Nm/rad	0.29	0.67	1.1	2.0	4.7	8.8	17
		kgfm/arc min	0.085	0.2	0.32	0.6	1.4	2.6	5.0
	K_2	$\times10^4$Nm/rad	0.37	0.88	1.3	2.7	6.1	11	21
		kgfm/arc min	0.11	0.26	0.4	0.8	1.8	3.4	6.3
	K_3	$\times10^4$Nm/rad	0.47	1.2	2.0	3.7	8.4	15	30
		kgfm/arc min	0.14	0.34	0.6	1.1	2.5	4.5	9
	θ_1	$\times10^{-4}$rad	6.9	5.8	6.4	7.0	6.2	6.1	6.4
		arc min	2.4	2.0	2.2	2.4	2.1	2.1	2.2
	θ_2	$\times10^{-4}$rad	19	14	19	18	18	18	18
		arc min	6.4	4.6	6.6	6.1	6.1	5.9	6.2
Reduction ratio 80 or more	K_1	$\times10^4$Nm/rad	0.4	0.84	1.3	2.7	6.1	11	21
		kgfm/arc min	0.12	0.25	0.4	0.8	1.8	3.2	6.3
	K_2	$\times10^4$Nm/rad	0.44	0.94	1.7	3.7	7.8	14	29
		kgfm/arc min	0.13	0.28	0.5	1.1	2.3	4.2	8.5
	K_3	$\times10^4$Nm/rad	0.61	1.3	2.5	4.7	11	20	37
		kgfm/arc min	0.18	0.39	0.75	1.4	3.3	5.8	11
	θ_1	$\times10^{-4}$rad	5.0	4.6	5.4	5.2	4.8	4.9	5.1
		arc min	1.7	1.6	1.8	1.8	1.7	1.7	1.7
	θ_2	$\times10^{-4}$rad	16	13	15	13	14	14	13
		arc min	5.4	4.3	5.0	4.5	4.8	4.8	4.6

* The values in this table are reference values. The minimum value is approximately 80% of the displayed value.

Starting torque

See "Engineering data" for a description of terms. Please use as reference values; the values vary based on use conditions.

Table 067-1
Unit: Ncm

Ratio \ Size	14	17	20	25	32	40	50
50	3.7	5.7	7.3	14	28	50	94
80	2.7	3.8	4.8	8.8	19	32	63
100	2.4	3.3	4.3	7.9	18	29	56
120	—	3.1	3.8	7.2	16	27	53

Backdriving torque

See "Engineering data" for a description of terms. Please use as reference values; the values vary based on use conditions.

Table 067-2
Unit: Nm

Ratio \ Size	14	17	20	25	32	40	50
50	2.5	3.8	4.4	8.3	17	30	57
80	2.6	3.7	4.9	8.8	19	32	62
100	3.1	4.1	5.2	9.6	21	35	67
120	—	4.5	5.7	11	22	38	74

Ratcheting torque

See "Engineering data" for a description of terms.

Table 067-3
Unit: Nm

Ratio \ Size	14	17	20	25	32	40	50
50	60	105	150	315	685	1260	2590
80	75	140	245	475	980	1960	3780
100	55	110	180	350	700	1470	2870
120	—	80	165	325	685	1330	2660

Buckling torque

See "Engineering data" for a description of terms.

Table 067-4
Unit: Nm

Size	14	17	20	25	32	40	50
All ratios	190	330	560	1000	2200	4300	8000

No-load running torque

No-load running torque is the torque which is required to rotate the input side (high speed side), when there is no load on the output side (low speed side).

Measurement condition

Table 068-1

Ratio 100:1			
Lubricant	Grease lubrication	Name	Harmonic Grease SK-1A (size 20 or larger) Harmonic Grease SK-2 (size 14, 17)
		Quantity	Recommended quantity (See page 71)
Torque value is measured after 2 hours at 2000rpm input.			

* Contact us for oil lubrication.

■ Compensation value in each ratio

No load running torque of the gear varies with ratio.
The graphs indicate a value for ratio 100.
For other gear ratios, add the compensation values from table on the right.

Compensation coefficient for no-load running torque

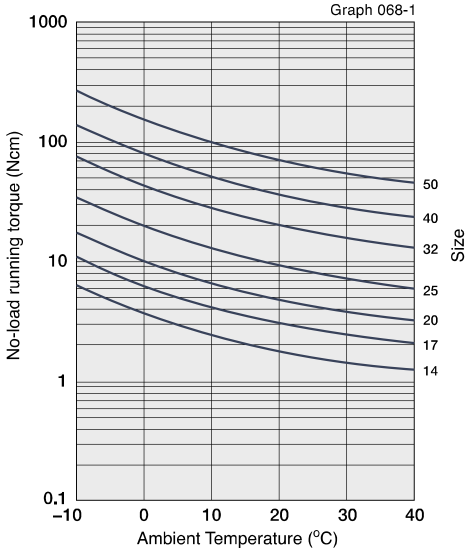
Table 068-2
Unit: Ncm

Ratio / Size	50
14	+0.56
17	+0.95
20	+1.4
25	+2.6
32	+5.4
40	+9.6
50	+18

■ No-load running torque for a reduction ratio of 100

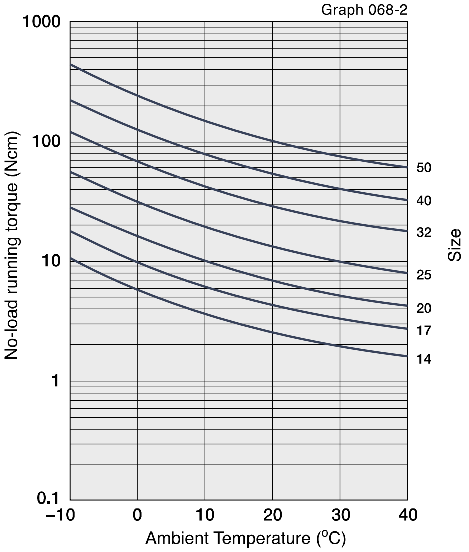
Input rotational speed: 500rpm

Graph 068-1



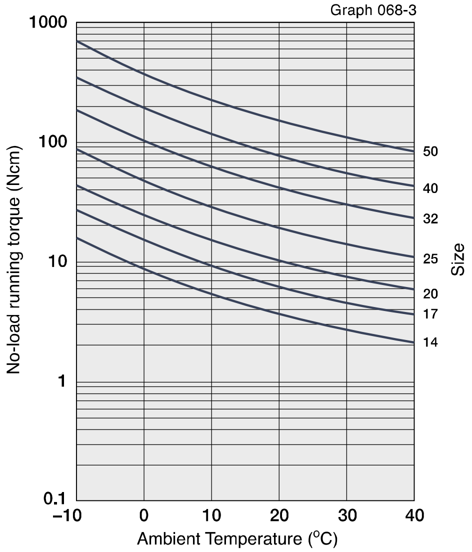
Input rotational speed: 1000rpm

Graph 068-2



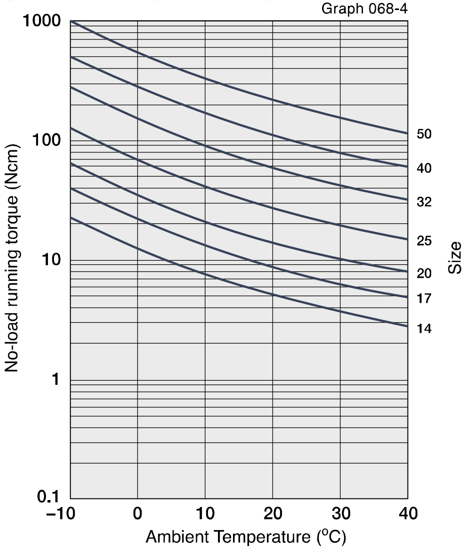
Input rotational speed: 2000rpm

Graph 068-3



Input rotational speed: 3500rpm

Graph 068-4



* The values in this graph are average value "$\overline{X}$".

Efficiency

The efficiency varies depending on the following conditions.

- Reduction ratio
- Input rotational speed
- Load torque
- Temperature
- Lubrication (Type and quantity)

Measurement condition

Table 069-1

Installation	Based on recommended tolerance		
Load torque	The rated torque shown in the rating table (see page 63)		
* When load torque is smaller than rated torque, the efficiency value is lowered. See efficiency compensation coefficient below.			
Lubricant	Grease lubrication	Name	Harmonic Grease SK-1A (size 20 or larger)
			Harmonic Grease SK-2 (size 14, 17)
		Quantity	Recommended quantity (see page 71)

* Contact us for oil lubrication.

Efficiency compensation coefficient

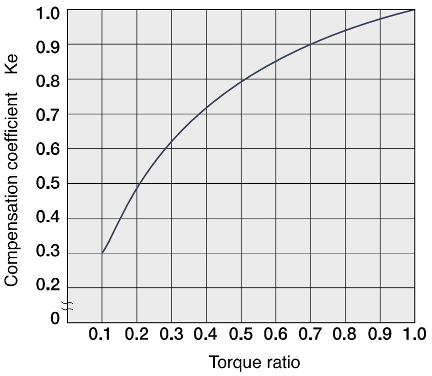
If the load torque is lower than the rated torque, the efficiency value decreases. Calculate the compensation coefficient Ke from Graph 069-1 to calculate the efficiency using the following calculation example.

* Efficiency Compensation coefficient Ke=1 holds when the load torque is greater than the rated torque.

Efficiency compensation coefficient

Graph 069-1

Torque ratio α is the value of load torque/rated torque (Rating table: page 063).

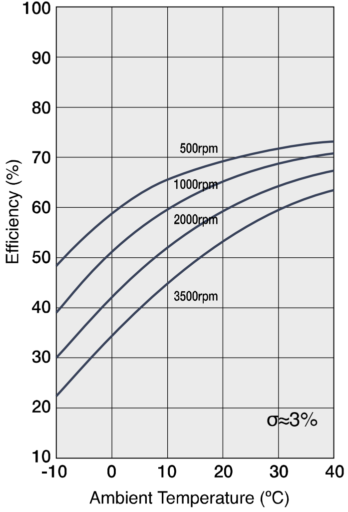


■ Efficiency at rated torque

Reduction ratio 50:1

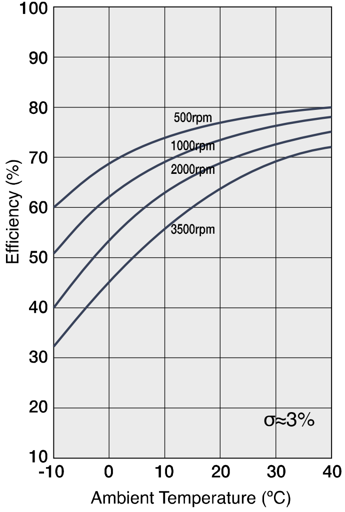
Size 14

Graph 070-1



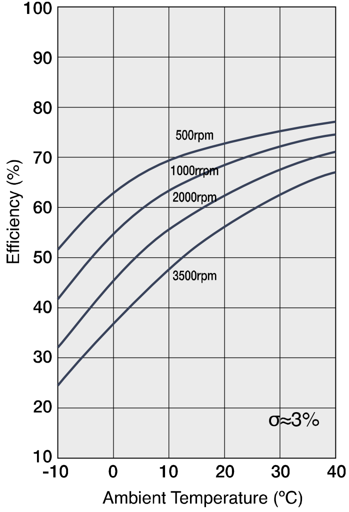
Size 17, 20

Graph 070-2



Size 25, 32, 40, 50

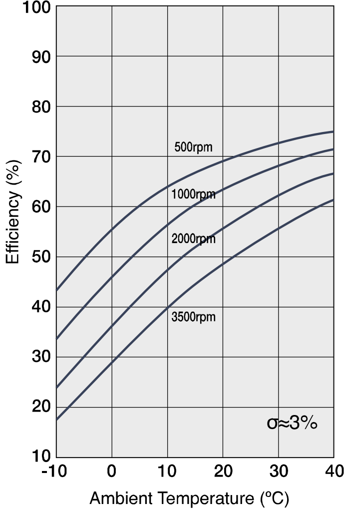
Graph 070-3



Reduction ratio 80, 100, 120:1

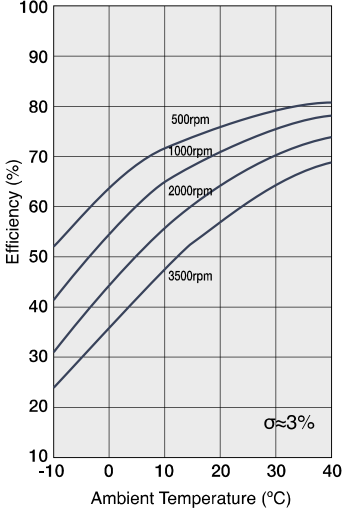
Size 14

Graph 070-4



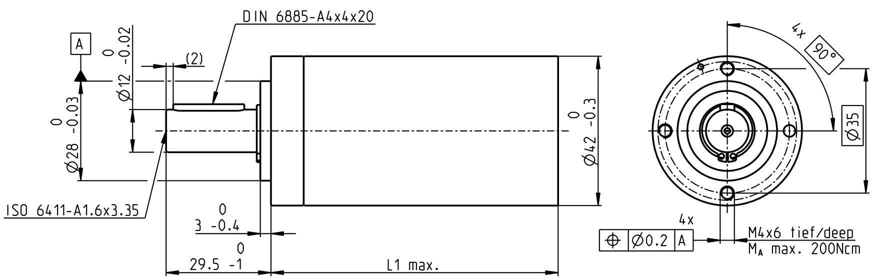
Size 17, 20, 25, 32, 40, 50

Graph 070-5



Planetary Gearhead GP 42 C ∅42 mm, 3.0–15.0 Nm

Ceramic Version



M 1:2

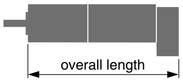
Technical Data

Planetary Gearhead	straight teeth
Output shaft	stainless steel
Bearing at output	preloaded ball bearings
Radial play, 12 mm from flange	max. 0.06 mm
Axial play at axial load < 5 N	0 mm
> 5 N	max. 0.3 mm
Max. axial load (dynamic)	150 N
Max. force for press fits	300 N
Direction of rotation, drive to output	=
Max. continuous input speed	8000 rpm
Recommended temperature range	-40…+100°C
Number of stages	1 2 3 4
Max. radial load, 12 mm from flange	120 N 240 N 360 N 360 N

🟥 Stock program
☐ Standard program
▨ Special program (on request)

			Part Numbers									
			203113	203115	**203119**	**203120**	203124	**203129**	203128	203133	203137	203141
Gearhead Data												
1	Reduction		3.5 : 1	12 : 1	26 : 1	43 : 1	81 : 1	156 : 1	150 : 1	285 : 1	441 : 1	756 : 1
2	Absolute reduction		7/2	49/4	26	343/8	2197/27	156	2401/16	15379/54	441	756
10	Mass inertia	gcm²	14	15	9.1	15	9.4	9.1	15	15	14	14
3	Max. motor shaft diameter	mm	10	10	8	10	8	8	10	10	10	10
	Part Numbers		**203114**	**203116**	260552*	203121	203125	260553*	203130	203134	203138	203142
1	Reduction		4.3 : 1	15 : 1	36 : 1	53 : 1	91 : 1	216 : 1	186 : 1	319 : 1	488 : 1	936 : 1
2	Absolute reduction		13/3	91/6	36/1	637/12	91	216/1	4459/24	637/2	4394/9	936
10	Mass inertia	gcm²	9.1	15	5.0	15	15	5.0	15	15	9.4	9.1
3	Max. motor shaft diameter	mm	8	10	4	10	10	4	10	10	8	8
	Part Numbers		260551*	203117		203122	203126		203131	203135	203139	260554*
1	Reduction		6 : 1	19 : 1		66 : 1	113 : 1		230 : 1	353 :1	546 : 1	1296 : 1
2	Absolute reduction		6/1	169/9		1183/18	338/3		8281/36	28561/81	546	1296/1
10	Mass inertia	gcm²	4.9	9.4		15	9.4		15	9.4	14	5.0
3	Max. motor shaft diameter	mm	4	8		10	8		10	8	10	4
	Part Numbers			203118		203123	203127		203132	203136	203140	
1	Reduction			21 : 1		74 : 1	126 : 1		257 : 1	394 : 1	676 : 1	
2	Absolute reduction			21		147/2	126		1029/4	1183/3	676	
10	Mass inertia	gcm²		14		15	14		15	15	9.1	
3	Max. motor shaft diameter	mm		10		10	10		10	10	8	
4	Number of stages		1	2	2	3	3	3	4	4	4	4
5	Max. continuous torque	Nm	3.0	7.5	7.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0
6	Max. intermittent torque at gear output	Nm	4.5	11.3	11.3	22.5	22.5	22.5	22.5	22.5	22.5	22.5
7	Max. efficiency	%	90	81	81	72	72	72	64	64	64	64
8	Weight	g	260	360	360	460	460	460	560	560	560	560
9	Average backlash no load	°	0.6	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11	Gearhead length L1**	mm	41.0	55.5	55.5	70.0	70.0	70.0	84.5	84.5	84.5	84.5

*no combination with EC 45 (150/250 W) and EC-i 40
**for EC 45 flat L1 is -3.6 mm

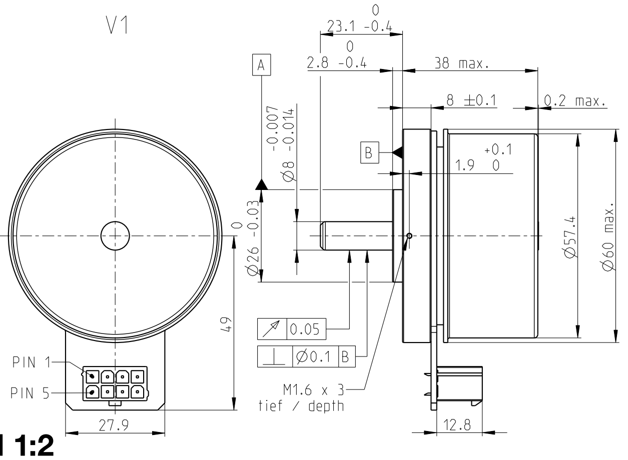


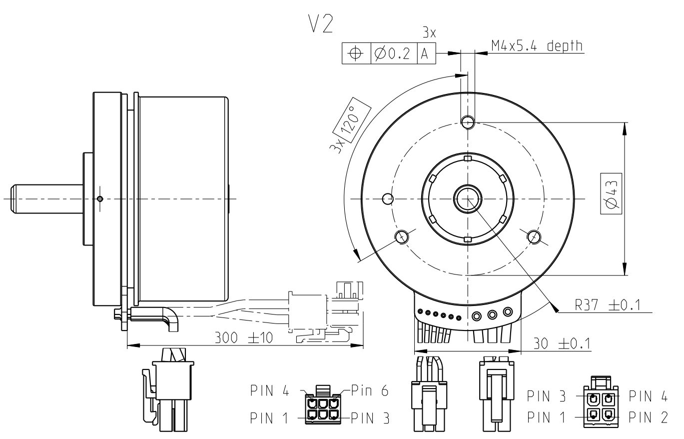
maxon Modular System

+ Motor	Page	**+ Sensor**	Page	**Brake**	Page	**Overall length [mm]** = Motor length + gearhead length + (sensor/brake) + assembly parts									
RE 35, 90 W	130					112.1	126.6	126.6	141.1	141.1	141.1	155.6	155.6	155.6	155.6
RE 35, 90 W	130	MR	420			123.5	138.0	138.0	152.5	152.5	152.5	167.0	167.0	167.0	167.0
RE 35, 90 W	130	HED_5540	429/431			132.8	147.3	147.3	161.8	161.8	161.8	176.3	176.3	176.3	176.3
RE 35, 90 W	130	DCT 22	438			130.2	144.7	144.7	159.2	159.2	159.2	173.7	173.7	173.7	173.7
RE 35, 90 W	130			AB 28	480	148.2	162.7	162.7	177.2	177.2	177.2	191.7	191.7	191.7	191.7
RE 35, 90 W	130	HED_5540	429/431	AB 28	480	165.4	179.9	179.9	194.4	194.4	194.4	208.9	208.9	208.9	208.9
RE 40, 150 W	132					112.1	126.6	126.6	141.1	141.1	141.1	155.6	155.6	155.6	155.6
RE 40, 150 W	132	MR	420			123.5	138.0	138.0	152.5	152.5	152.5	167.0	167.0	167.0	167.0
RE 40, 150 W	132	HED_5540	429/432			132.8	147.3	147.3	161.8	161.8	161.8	176.3	176.3	176.3	176.3
RE 40, 150 W	132	HEDL 9140	436			166.2	180.7	180.7	195.2	195.2	195.2	209.7	209.7	209.7	209.7
RE 40, 150 W	132			AB 28	480	148.2	162.7	162.7	177.2	177.2	177.2	191.7	191.7	191.7	191.7
RE 40, 150 W	132			AB 28	481	156.2	170.7	170.7	185.2	185.2	185.2	199.7	199.7	199.7	199.7
RE 40, 150 W	132	HED_ 5540	429/432	AB 28	480	165.4	179.9	179.9	194.4	194.4	194.4	208.9	208.9	208.9	208.9
RE 40, 150 W	132	HEDL 9140	436	AB 28	481	176.7	191.2	191.2	205.7	205.7	205.7	220.2	220.2	220.2	220.2
EC 40, 170 W	213					121.1	135.6	135.6	150.1	150.1	150.1	164.6	164.6	164.6	164.6
EC 40, 170 W	213	HED_5540	430/432			144.5	159.0	159.0	173.5	173.5	173.5	188.0	188.0	188.0	188.0
EC 40, 170 W	213	Res 26	439			148.3	162.8	162.8	177.3	177.3	177.3	191.8	191.8	191.8	191.8
EC 40, 170 W	213			AB 32	482	163.8	178.3	178.3	192.8	192.8	192.8	207.3	207.3	207.3	207.3
EC 40, 170 W	213	HED_5540	430/432	AB 32	482	182.2	196.7	196.7	211.2	211.2	211.2	225.7	225.7	225.7	225.7
EC 45, 150 W	214					152.3	166.8	166.8	181.3	181.3	181.3	195.8	195.8	195.8	195.8
EC 45, 150 W	214	HEDL 9140	436			167.9	182.4	182.4	196.9	196.9	196.9	211.4	211.4	211.4	211.4
EC 45, 150 W	214	Res 26	439			152.3	166.8	166.8	181.3	181.3	181.3	195.8	195.8	195.8	195.8
EC 45, 150 W	214			AB 28	481	159.7	174.2	174.2	188.7	188.7	188.7	203.2	203.2	203.2	203.2
EC 45, 150 W	214	HEDL 9140	436	AB 28	481	176.7	191.2	191.2	205.7	205.7	205.7	220.2	220.2	220.2	220.2
EC 45, 250 W	215					185.1	199.6	199.6	214.1	214.1	214.1	228.6	228.6	228.6	228.6
EC 45, 250 W	215	HEDL 9140	436			200.7	215.2	215.2	229.7	229.7	229.7	244.2	244.2	244.2	244.2
EC 45, 250 W	215	Res 26	439			185.1	199.6	199.6	214.1	214.1	214.1	228.6	228.6	228.6	228.6
EC 45, 250 W	215			AB 28	481	192.5	207.0	207.0	221.5	221.5	221.5	236.0	236.0	236.0	236.0
EC 45, 250 W	215	HEDL 9140	436	AB 28	481	209.5	224.0	224.0	238.5	238.5	238.5	253.0	253.0	253.0	253.0

EC 60 flat ∅60 mm, brushless, 100 Watt

NEW





M 1:2

🟥	Stock program
☐	Standard program
▨	Special program (on request)

Part Numbers

V1 with Hall sensors	625854	625855	625856
V2 with Hall sensors and cables	647691	645604	647692

Motor Data

Values at nominal voltage				
1 Nominal voltage	V	12	24	48
2 No load speed	rpm	3760	4300	4020
3 No load current	mA	797	493	221
4 Nominal speed	rpm	3210	3730	3460
5 Nominal torque (max. continuous torque)	mNm	261	269	298
6 Nominal current (max. continuous current)	A	8.72	5.14	2.61
7 Stall torque[1]	mNm	3340	4300	4870
8 Stall current	A	111	81.9	43.2
9 Max. efficiency	%	84.1	85.3	86.4
Characteristics				
10 Terminal resistance phase to phase	Ω	0.108	0.293	1.11
11 Terminal inductance phase to phase	mH	0.0911	0.279	1.28
12 Torque constant	mNm/A	30	52.5	113
13 Speed constant	rpm/V	318	182	84.8
14 Speed/torque gradient	rpm/mNm	1.14	1.01	0.837
15 Mechanical time constant	ms	9.99	8.86	7.32
16 Rotor inertia	gcm^2	835	835	835

Specifications

Thermal data	
17 Thermal resistance housing-ambient	2.5 K/W
18 Thermal resistance winding-housing	3.8 K/W
19 Thermal time constant winding	41.4 s
20 Thermal time constant motor	90 s
21 Ambient temperature	-40…+100°C
22 Max. winding temperature	+125°C
Mechanical data (preloaded ball bearings)	
23 Max. speed	6000 rpm
24 Axial play at axial load < 12.0 N	0 mm
> 12.0 N	0.14 mm
25 Radial play	preloaded
26 Max. axial load (dynamic)	12 N
27 Max. force for press fits (static)	170 N
(static, shaft supported)	8000 N
28 Max. radial load, 5 mm from flange	112 N
Other specifications	
29 Number of pole pairs	7
30 Number of phases	3
31 Weight of motor	355 g

Values listed in the table are nominal.

Connection V1		**V2** (sensors, AWG 24)
Pin 1	Hall sensor1	Hall sensor1
Pin 2	Hall sensor 2	Hall sensor 2
Pin 3	V_{Hall} 4.5…24 VDC	Hall sensor 3
Pin 4	Motor winding 3	GND
Pin 5	Hall sensor 3	V_{Hall} 4.5…24 VDC
Pin 6	GND	N.C.
Pin 7	Motor winding 1	
Pin 8	Motor winding 2	
		V2 (Motor, AWG 16)
Pin 1		Motor winding 1
Pin 2		Motor winding 2
Pin 3		Motor winding 3
Pin 4		N.C.

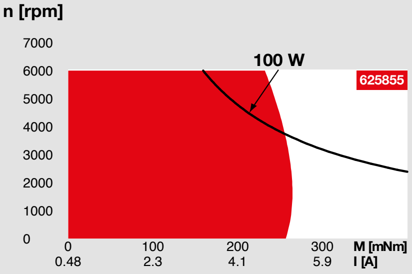
Wiring diagram for Hall sensors see p. 47

Connector	**Part number**	
Molex	46015-0806	43025-0600
Molex		39-01-2040

Connection cable for V1

Connection cable Universal, L = 500 mm	**339380**
Connection cable zu EPOS4, L = 500 mm	**354045**

Operating Range



Comments

🟥 **Continuous operation**
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

☐ **Short term operation**
The motor may be briefly overloaded (recurring).

— **Assigned power rating**

maxon Modular System

Details on catalog page 36

Planetary Gearhead
∅52 mm
4 - 30 Nm
Page 367

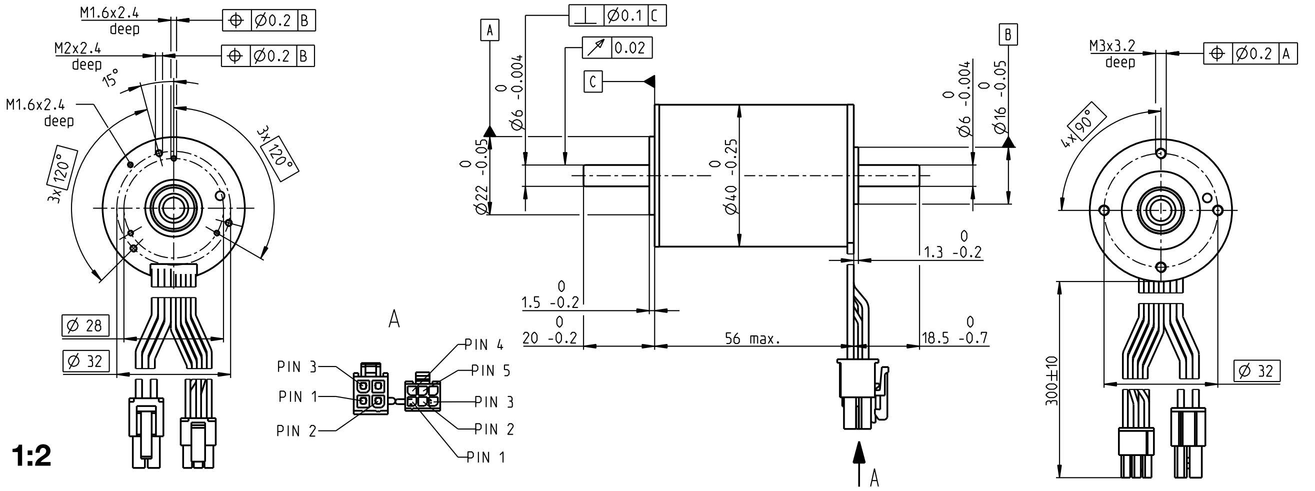
Encoder MILE
512 - 4096 CPT,
2 channels
Page 413

Recommended Electronics:	
Notes	Page **36**
ESCON Module 50/5	455
ESCON Mod. 50/8 (HE)	456
ESCON 50/5	457
ESCON 70/10	457
DEC Module 50/5	459
EPOS4 50/5	463
EPOS4 Mod./Comp. 50/5	463
EPOS4 Mod./Comp. 50/8	465
EPOS4 Mod./Comp. 50/15	466
EPOS4 70/15	467
EPOS2 P 24/5	470
MAXPOS 50/5	473

[1] Calculation does not include saturation effect (p. 57/162)

EC-i 40 ∅40 mm, brushless, 100 Watt

High Torque



M 1:2

🟥 Stock program
☐ Standard program
▨ Special program (on request)

Part Numbers

		with Hall sensors	496660	496661	488607
Motor Data					
	Values at nominal voltage				
1	Nominal voltage	V	18	36	48
2	No load speed	rpm	4540	4550	5000
3	No load current	mA	352	176	150
4	Nominal speed	rpm	3920	3950	4390
5	Nominal torque (max. continuous torque)	mNm	207	207	222
6	Nominal current (max. continuous current)	A	5.46	2.72	2.39
7	Stall torque[1]	mNm	2860	3160	4330
8	Stall current	A	76.3	42.2	47.5
9	Max. efficiency	%	87	87	89
	Characteristics				
10	Terminal resistance phase to phase	Ω	0.236	0.853	1.01
11	Terminal inductance phase to phase	mH	0.169	0.675	0.995
12	Torque constant	mNm/A	37.5	74.9	91
13	Speed constant	rpm/V	255	127	105
14	Speed/torque gradient	rpm/mNm	1.6	1.45	1.16
15	Mechanical time constant	ms	0.739	0.669	0.537
16	Rotor inertia	gcm²	44	44	44

Specifications

	Thermal data		
17	Thermal resistance housing-ambient		7.17 K/W
18	Thermal resistance winding-housing		1.35 K/W
19	Thermal time constant winding		20.7 s
20	Thermal time constant motor		1400 s
21	Ambient temperature		-40…+100°C
22	Max. winding temperature		+155°C
	Mechanical data (preloaded ball bearings)		
23	Max. speed		8000 rpm
24	Axial play at axial load	< 9.0 N	0 mm
		> 9.0 N	0.15 mm
25	Radial play		preloaded
26	Max. axial load (dynamic)		7 N
27	Max. force for press fits (static)		87 N
	(static, shaft supported)		3000 N
28	Max. radial load, 5 mm from flange		29.9 N
	Other specifications		
29	Number of pole pairs		7
30	Number of phases		3
31	Weight of motor		390 g

Values listed in the table are nominal.

Connection motor (Cable AWG 20)

red	Motor winding 1	Pin 1
black	Motor winding 2	Pin 2
white	Motor winding 3	Pin 3
	N.C.	Pin 4
Connector	**Article number**	
Molex	39-01-2040	

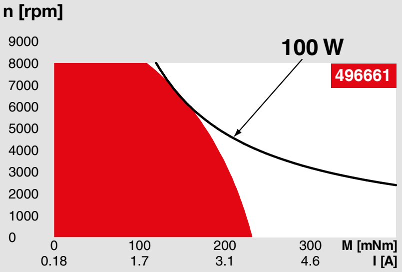
Connection sensor (Cable AWG 26)

yellow	Hall sensor 1	Pin 1
brown	Hall sensor 2	Pin 2
grey	Hall sensor 3	Pin 3
blue	GND	Pin 4
green	V_{Hall} 4.5…24 VDC	Pin 5
	N.C.	Pin 6
Connector	**Article number**	
Molex	430-25-0600	

Wiring diagram for Hall sensors see p. 47

[1] Calculation does not include saturation effect (p. 57/162)

Operating Range



Comments

🟥 **Continuous operation**
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

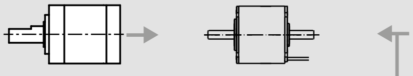
☐ **Short term operation**
The motor may be briefly overloaded (recurring).

— **Assigned power rating**

maxon Modular System

Details on catalog page 34

Planetary Gearhead
∅42 mm
3 - 15 Nm
Page 362



Recommended Electronics:	
Notes	Page **34**
ESCON 36/3 EC	455
ESCON Mod. 50/4 EC-S	455
ESCON Module 50/5	455
ESCON Mod. 50/8 (HE)	456
ESCON 50/5	457
ESCON 70/10	457
DEC Module 50/5	459
EPOS4 50/5	463
EPOS4 Mod./Comp. 50/5	463
EPOS4 Mod./Comp. 50/8	465
EPOS4 70/15	467
EPOS2 P 24/5	470
MAXPOS 50/5	473

Encoder 16 EASY
128 - 1024 CPT, 3 channels
Page 418
Encoder 16 EASY Absolute
4096 steps
Page 422
Encoder 16 RIO
1024 - 32 768 CPT, 3 channels
Page 436
Encoder AEDL 5810
1024 - 5000 CPT, 3 channels
Page 438
Encoder HEDL 5540
500 CPT, 3 channels
Page 446

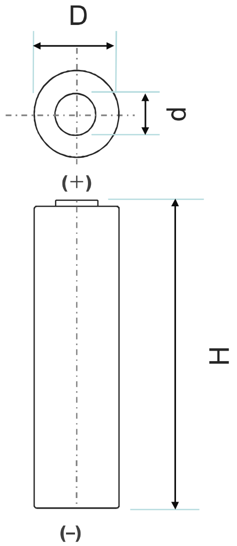
Specifications for NCR18650BD

Specifications

Rated capacity(1)		2980mAh	2910mAh
Capacity(2)	Minimum	3030mAh	2935mAh
	Typical	3180mAh	3080mAh
Nominal voltage		3.6V	
Charging	Method	CC-CV	
	Voltage	4.20V	4.15V
	Current	Std. 0.3CA	
Weight (max.) Without tube		49.5g	
Temperature	Charge	10 to +45° C	
	Discharge	-20 to +60° C	
	Storage	-20 to +50° C	
Energy density(3)	Volumetric	630 Wh/l	615 Wh/l
	Gravimetric	217 Wh/kg	212 Wh/kg

(1) At 20° C (2) At 25° C
(3) Energy density is calculated using bare cell dimensions (without tube).

Dimensions



Without tube	H	Max. 65.10mm
	D	Max. 18.25mm
	d	Max. 6.6mm

When designing a pack, refer to the cell's mechanical drawing for precise dimensions.

GRAFIL INC.

PYROFIL™ TR50S 12K

Typical Fiber Properties

Tow Tensile	Strength	710 4,900	ksi MPa	JISR 7601
	Modulus	35 240	msi GPa	
Typical Density		0.066 1.82	lb.in^3 g/cm^3	JISR 7601
Typical Yield	12K	620 800	yds/lb mg/m	JISR 7601

Typical Mechanical Properties

Tensile Properties	0º	Strength*	430 2950	ksi MPa	ASTM D3039 / Vf=60.0%
		Modulus*	20.6 142	msi GPa	ASTM D3039 / Vf=60.0%
	90º	Strength	11 79	ksi MPa	ASTM D3039 / Vf=56.0%
		Modulus	1.3 9	msi GPa	ASTM D3039 / Vf=56.0%
Compressive Properties	0º	Strength*	230 1600	ksi MPa	SRM 1-88 / Vf=60.0%
		Modulus*	18.7 130	msi GPa	SRM 1-88 / Vf=60.0%
Flexural Properties	0º	Strength	430 3000	ksi MPa	ASTM D790 / L/d=40 / Vf=60.0%
		Modulus	19 130	msi GPa	ASTM D790 / L/d=40 / Vf=60.0%
	90º	Strength	20 140	ksi MPa	ASTM D790 / L/d=16 / Vf=56.0%
		Modulus	1.3 9	msi GPa	ASTM D790 / L/d=16 / Vf=56.0%
Short-Beam Shear	Strength		13 90	ksi MPa	ASTM D2344 / L/d=4 / Vf=56.0%

- 250F Epoxy Prepregs
- Resin: Mitsubishi Rayon #340 resin system
- Tensile and compressive properties are normalized to 60% fiber volume

5900 88th Street
Sacramento, CA
95828, USA
Tel: 916.386.1733
Fax: 916.383.7668
Web: www.grafil.com

ISO 9001:2000
FM 56416

07/2008

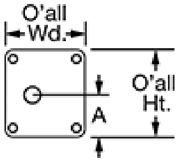
6, Orchard Court
Binley Business Park
Harry Weston Road
Binley, Coventry CV3 2TQ UK
Tel: +44 (0) 2476 447272
Fax: +44 (0) 2476 449565

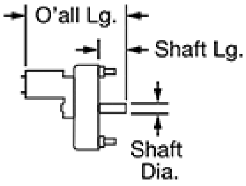
McMASTER-CARR®

Compact Square-Face DC Gearmotor

12V DC,0.6 rpm At 50 in.-lbs. Torque

$62.74 Each
6409K11



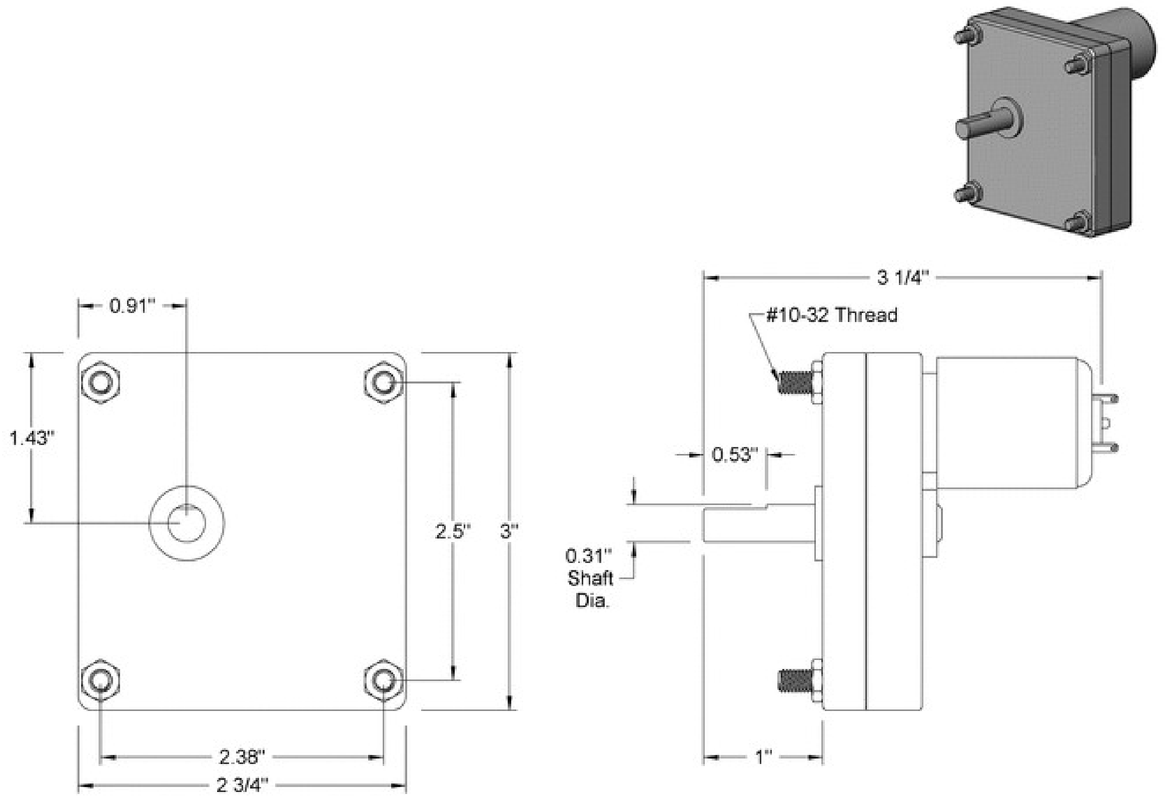


Maximum rpm	1
rpm @ Continuous Operating Torque	0.6 rpm @ 800 in.-oz.
Starting Torque	800 in.-oz.
hp	0.0003
Amps @ Full Load	0.1
Electrical Connection	Terminal Lugs
Overall	
Length	3 1/4"
Width	2 3/4"
Height	3"
Shaft	
Diameter	5/16"
Length	1"
Center to Base (A)	1.43"
Shaft Rotation	Clockwise or Counterclockwise
Shaft Type	D-Profile
Shaft Orientation	Parallel
Performance Rating	Continuous Duty
Motor Type	Brushed, Permanent Magnet
Service Factor	1
Enclosure Material	Die Cast Zinc
Gear	
Type	Spur
Material	Acetal, Metal
Bearing Type	Sleeve
Insulation	
Class	B
Maximum Temperature	266° F
Mounting Orientation	Horizontal, Vertical, Inverted, Any Angle
Mounting Location	Face
RoHS	RoHS 3 (2015/863/EU) compliant

Drive low-speed, high-torque applications in small spaces. Gearmotors combine a motor and speed reducer to lower speed and increase torque. Wire for clockwise or counterclockwise rotation.

Use amotor speed control(notincluded) to adjust the motor speed.

To convert AC power to DC power, see AC to DC transformers.



McMASTER-CARR® CAD

http://www.mcmaster.com

PART NUMBER **6409K11**

Compact Square-Face
DC Gearmotor