Design and Assembly of a Super Treadmill

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This report describes the design and construction of an oversized, ruggedized treadmill built for testing heavy loads. The design permits for speed and slope control, as well as a safety tether and emergency stops. The design description is categorized by related systems. The walking belt is powered by an electric motor, which transfers the mechanical rotation via hubs, a linkage belt and rollers. The floor and surface base are sized and designed for proper operation and clearance. The electronics board provides electric power, speed control, and a powered braking system. Safety features are designed for user protection: guard rails, covers, a gantry crane and tether, and emergency stops. Operation is possible for an incline range of -30° to +30° at 22 increments from the horizontal, and speeds of up to 10 mph with a granularity of 0.01 mph. The larger than usual size and strength allows for extensive usability and testing, for a successful and well-functioning apparatus.

I. Introduction

Berkeley Bionics company, based out of Berkeley, California found highly desirable the design and construction of a custom treadmill for the use of exoskeleton testing. The company designed HULC or Human Universal Load Carrier as a powerful tool for dismounted soldiers, allowing the carry of heavy combat loads. The HULC is a completely un-tethered, hydraulic-powered anthropomorphic exoskeleton that provides users with the ability to carry loads of up to 200 lbs for extended periods of time and over all terrains. Its flexible design allows for deep squats, crawls and upper-body lifting. There is no joystick or other control mechanism. The exoskeleton senses what users want to do and where they want to go. It augments their ability, strength and endurance. An onboard micro-computer ensures the exoskeleton moves in concert with the individual. Its modularity allows for major components to be swapped out in the field. Additionally, its unique power-saving design allows the user to operate on battery power for extended missions. The HULC's load-carrying ability works even when power is not available.[1]

With a carried load of 200 lbs, in addition to the weight of the HULC and user, static forces on the treadmill are expected to exceed 450 lbs. With the addition impact loads of running, jumping, and even the possibility of multiple people on the treadmill simultaneously; it must be designed for strength, stability, and safety throughout all uses.

II. Apparatus and Procedure

The general shape and size of the treadmill is as follows: 50 in width, 140 in length, and a variable height ranging from 48 in to 96 in depending on the angle of elevation, with the guard rails in place. The SolidWorks model is shown as Figure 1. Note that the model is shown at the maximum height extension, with regular use expected at a horizontal or slightly inclined position.

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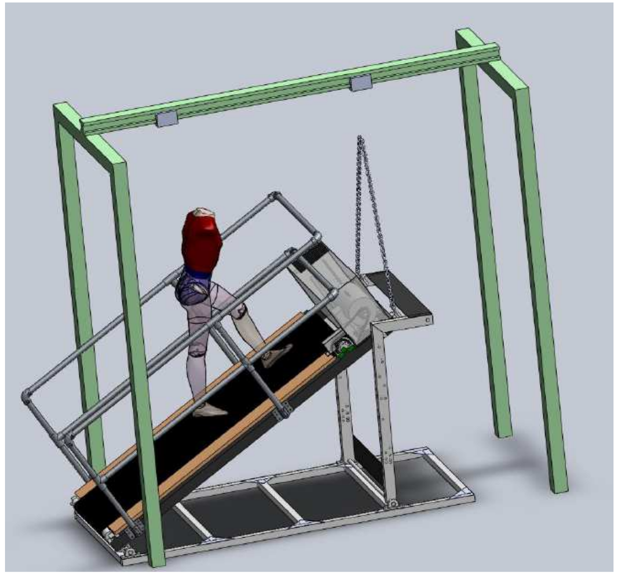

Figure 1. Complete treadmill model, with simulated user and gantry crane in position.

Whereas a complete list of all components and descriptions would be extensive, the major parts will be described as follows. The floor and surface bases were sized to allow ample walking and jogging space with the exoskeleton on. The overall length is extended to provide sufficient walking space in the most restrictive orientation: when fully inclined, and walking downhill at 30 degrees.

For the mechanical support a walking surface base and floor base were designed. Rectangular cross section steel of 1 in x 3 in and 2 in x 3 in and wall thickness of 0.120 in were selected for a conservative safety factor of over 4. Calculations and material sizing are shown in Figure 2. The bases allow for a stable platform and full mobility of the lifting arms through 22 incremented slope positions available. Pin locks are used to hold the treadmill at a fixed incline once it is selected. A detailed view of the lifting arm assembly is visible in Figure 3.

Length	95	In
Wt	600	lbs
A	45	In

250	steel yield strength (Mpa)			M	14211		M, from θ	9950.0
	Carbon Steel EW							
Manuf	Width	Height	Wall	I	c	Stress(σ, ksi)	Stress(σ, MPa)	SF, 2 bars
tubeservice	0.5	0.5	0.049	0.003	0.25	820.4	5656.6	0.1
	0.5	0.5	0.065	0.004	0.25	682.2	4703.3	0.1
	0.75	0.75	0.049	0.011	0.375	330.0	2275.1	0.2
	0.75	0.75	0.083	0.017	0.375	223.8	1542.9	0.3
	0.75	0.75	0.120	0.021	0.375	180.0	1241.0	0.4
	1	1	0.049	0.028	0.5	176.6	1217.6	0.4
	1	1	0.083	0.043	0.5	115.7	797.4	0.6
	1	1	0.120	0.056	0.5	89.6	617.7	0.8
	1.5	1.5	0.049	0.100	0.75	74.7	515.0	1.0
	1.5	1.5	0.095	0.176	0.75	42.3	291.6	1.7
	1.5	1.5	0.188	0.289	0.75	25.8	178.1	2.8
	1.5	1.5	0.250	0.339	0.75	22.0	152.0	3.3

1.75	1.75	0.065	0.208	0.875	41.9	289.1	1.7
1.75	1.75	0.095	0.288	0.875	30.2	208.4	2.4
1.75	1.75	0.120	0.348	0.875	25.0	172.3	2.9
1	2	0.090	0.255	1	39.1	269.3	1.9
1	2	0.120	0.321	1	31.0	213.5	2.3
1.5	2	0.095	0.353	1	28.2	194.5	2.6
1.5	2	0.120	0.428	1	23.3	160.5	3.1
2	2	0.095	0.439	1	22.7	156.3	3.2
2	2	0.188	0.754	1	13.2	91.0	5.5
2	2	0.250	0.911	1	10.9	75.3	6.6
2	3	0.120	1.416	1.5	10.5	72.7	6.9
2	3	0.188	2.055	1.5	7.3	50.1	10.0
2	3	0.250	2.547	1.5	5.9	40.4	12.4
2	4	0.083	2.053	2	9.7	66.8	7.5
2	4	0.188	4.225	2	4.7	32.5	15.4
2	4	0.250	5.307	2	3.7	25.9	19.3
3	3	0.065	1.096	1.5	13.6	93.9	5.3
3	3	0.120	1.914	1.5	7.8	53.8	9.3
3	3	0.188	2.799	1.5	5.3	36.8	13.6
3	3	0.250	3.495	1.5	4.3	29.4	17.0
3	3	0.313	4.103	1.5	3.6	25.1	19.9
3	3	0.375	4.614	1.5	3.2	22.3	22.4
1.5	3	0.060	0.628	1.5	23.8	163.9	3.1
1	3	0.120	0.918	1.5	16.3	112.0	4.5

Figure 2. Surface and Floor Base Material Sizing Calculations

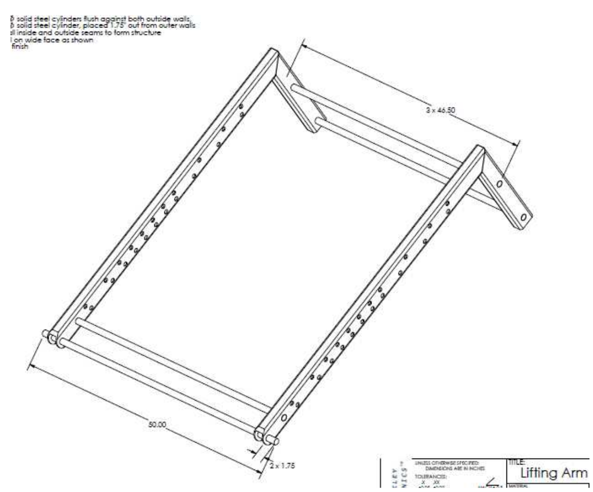

Figure 3. Lifting arm assembly detail

Power is transferred from the motor using a set of two hubs, and a power linkage belt. The rotational energy is directed to the front roller, which finally transfers the motion to the walking belt. On the opposite end, a free roller is placed to tension the belt and hold it in position. A detailed view of this power transfer assembly is shown as Figure 4.

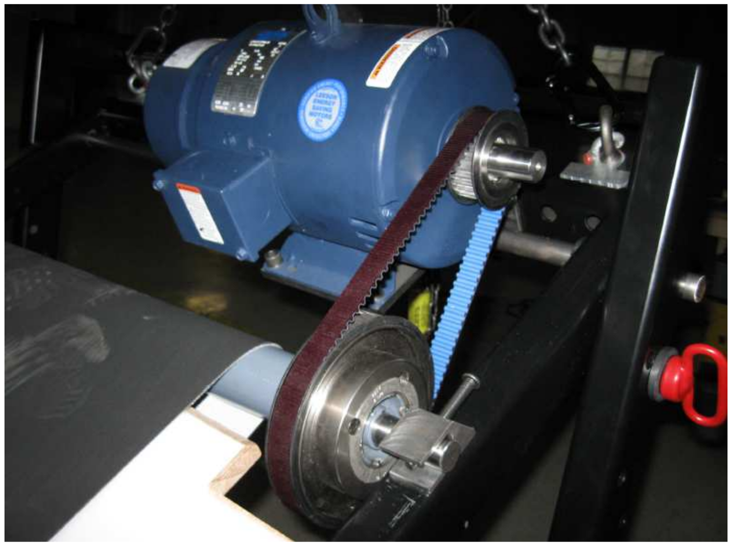

Figure 4. Motor, linkage belt, hubs, and power roller are shown in position.

The electronics board was designed with several considerations in mind. First, the motor should be protected against power surges. Three emergency stops were desired for safe operation. Additionally, variable speed control was desirable. The electronics schematic is shown as Figure 5.

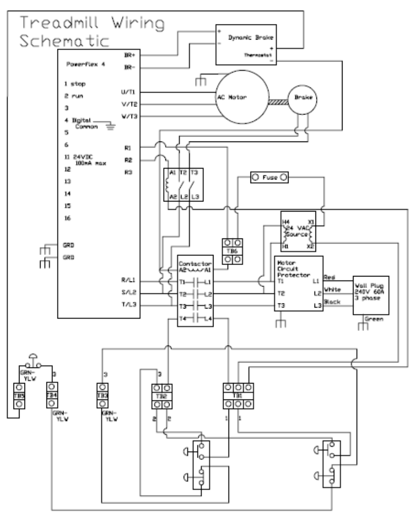

Figure 5. Treadmill wiring and electronics components schematic.

Overall usability and safety features are important concerns in the design and build. Guard hand rails were placed to prevent falls, and allow for a guided walking surface. They were found to be very useful for new users, and for assistance during inclined use. Covers were placed below and above the motor and powered drive assembly, as well as to enclose the electronics components. The covers greatly reduced safety hazards associated with use of the treadmill, and reduced the possible pinch points at the geared hubs. A large overhead gantry crane was placed for the use of a tether, which connects to the exoskeleton. The tether catches a user in the case of a fall, which can be a risk when using an exoskeleton. Additionally, three emergency stops were placed: one accessible to the user, one accessible to a nearby observer, and a third attached to an easy to use pull-rope. The nearly complete assembly is shown in Figure 6.

Figure 6. Assembled treadmill with safety covers removed.

III. Conclusion

The report describes the design and assembly of an oversized and ruggedized test treadmill. The important components can be summarized and grouped into special systems. The motor, drive linkage belt, and power transfer hubs operate to direct rotational motion to the walking surface belt. The floor and surface bases in junction with the lifting arm assembly permit for a stable platform with fine incline control for both uphill and downhill use. The electronics board provides regulated power to the motor, with safety features such as power surge protection, powered brake, and emergency stops. The rails, covers, gantry crane and tether provide for the necessary safety and support equipment for extended walking and running. Operation is possible for an incline range of -30° to +30° at 22 increments from the horizontal, and speeds of up to 10 mph with a granularity of 0.01 mph. Possible future improvements include live slope and banking control. These added attributes would allow for pre-programmed courses of incline and speed settings.

Appendix A: Complete Bill of Materials

1	New Super Treadmill for Exo Testing: BB									
2	Bill of Materials for 1 Super Treadmill - Simon Iacob									
3	Sub-Assembly	Bl	Vendor		Part No.		QTY	Cost Per $	Cost Ttl $	Subttls
4	Base		ProtekMfg	Surface Base Matl & Fab, holes, pc	2		1	954.85	954.85	
5			ProtekMfg	Floor Base Matl & Fab, holes, pow	1		1	1050.15	1050.15	
6			MacBeath	1" Hydro-Tek 4'x8' BS 1088 Philippi	Board		1	106.75	106.75	
7			Bob McGe	Bed Surface Fabrication, counterbor	4		1	300.00	300.00	
8			McMaster	Vibration Damping Mount 5/16-24 th	9376K61		20	2.59	51.80	
9			McMaster	Threaded Insert 5/16-18 Stl pack o	90975A036		1	7.07	7.07	
10			McMaster	Hex Nut 5/16-18 pack of 100	90498A030		1	3.06	3.06	
11			McMaster	U-Channel 2"x1"x6'	7779T22		1	37.29	37.29	
12			McMaster	Wood Screws #10 pack 100	91555A102		1	6.19	6.19	
13			McMaster	Heavy Duty Vibration-Damping Level	60855K55		6	7.24	43.44	2560.60
14										
15	Lift		ProtekMfg	Arm Matl and Assem (3"x2" 0.188" t	3		1	1023.61	1023.61	
16			Monterey	Eye Bolt Mounting Blocks (threaded	5		2	65.00	130.00	
17			McMaster	Cast Iron Base-Mounted Steel Ball E	6244K56		6	38.65	231.90	
18			McMaster	Pillow Block Mounting Sets	F2					
19			McMaster	Low-Carbon Steel Rod 1" Diameter,	8920K231		2	36.49	72.98	
20			McMaster	Shaft Collar Two-Piece Clamp-On 1"	6436K18		2	4.46	8.92	
21			McMaster	Forged Alloy Steel Lifting Eyebolt Sł	3049T92		2	16.27	32.54	
22			McMaster	Steel Hitch Pin W/Hairpin Cotter Pin	91594A315		2	6.66	13.32	
23			McMaster	Ceramic Ring Magnet 2.032" Od, .7(	5856K7		2	1.17	2.34	1515.61
24										
25	Conveyor		Watkins	Walking Belt	6		1	399.99	399.99	
26			Ensalco	Conveyor Roller	7		2	410.00	820.00	
27			Monterey	V-Block	8		4	72.00	288.00	
28			McMaster	V-Blocks fastening Sets	F3		4	7.00	28.00	1535.99
29										
30	Motor Mech		Monterey	5 X 3 X 1/4 Steel Angle (8" Length) &	9		1	150.00	150.00	
31			Monterey	Horizontal Sliding Plate & Fab (11x6	10		1	60.00	60.00	
32			ProtekMfg	Bottom Cover Matl & Fab	11		1	250.00	250.00	
33			ProtekMfg	Top Cover Matl & Fab	12		1	800.00	800.00	
34	Motion Ind		Leeson	Brake-Motor	131627		1	1100.00	1100.00	
35	Motion Ind		Gates	Motor Sprocket	8MX-30S-:	####	1	73.06	73.06	
36	Motion Ind		Gates	Roller Sprocket	8MX-67S-:	####	1	143.76	143.76	
37	Motion Ind		Gates	Motor Bushing 1 1/8"	1108	####	1	9.88	9.88	
38	Motion Ind		Gates	Roller Bushing Dodge 2.5"	2517	####	1	21.50	21.50	
39	Motion Ind		Gates	Timing Belt	8MGT-896	####	1	43.26	43.26	2651.46
40										
41	Electronics		McMaster	Electronics Boards Mounting DIN Rails			3	30.00	90.00	
42			ProtekMfg	Circuit Panel Matl & Fab	13		1	200.00	200.00	
43			McMaster	Cord Grip Al 1/2 (.25-.38") Cord Diar	7529K411		7	6.25	43.75	
44			McMaster	Cord Grip Al 1/2 (.38-.50") Cord Diar	7529K422		1	5.57	5.57	
45			McMaster	High-Amp Relay 3Pst-No,20 Amps,	70255K61		1	56.94	56.94	
46			McMaster	High-Inrush AC to AC Transformer 1:	6988K64		1	80.49	80.49	
47			McMaster	Fuse Block for 1 to 30 Amp Time-De	8078K31		1	10.42	10.42	
48			McMaster	Time-Delay Touch-Safe Fuse 600 V/	8078K14		1	29.02	29.02	
49			McMaster	Flexible Multiconductor Cable Unshi	9936K18		40	1.06	42.40	
50			McMaster	SBR Rubber Grommet 3/16" ID, 9/1(	9600K45		1	11.79	11.79	
51			McMaster	Modular Terminal Block	7641K52		25	1.65	41.25	

52			McMaster	Modular Terminal Block DIN End Se	7641K33	4	0.40	1.60	
53			McMaster	Modular Terminal Block DIN End Stc	7641K35	8	0.95	7.60	
54			McMaster	Modular Terminal Block DIN Jumper:	7641K16	2	7.00	14.00	
55			McMaster	DIN-Rail Mount AC to DC Transform	7009K76	1	142.01	142.01	
56			McMaster	wire?		1	50.00	50.00	
57			McMaster	Indoor Enclosure-Mounted Switches	6748K37	2	54.71	109.42	
58			McMaster	Pull-Switch	7186K53	1	179.41	179.41	
59	Motion Ind		Allen-Bra	Powerflex 4 AC Drive	22A-B017N104	1	585.47	585.47	
60	Motion Ind		Allen-Bra	Dynamic Brake Module	AK-R2047P500	1	180.00	180.00	
61	Motion Ind		Allen-Bra	Branch Circuit Protector	140M-F8E-C25	1	338.75	338.75	
62	Motion Ind		Allen-Bra	Contactor	100-C23KJ400	1	122.40	122.40	
63	Motion Ind		Allen-Bra	Human Interface Module (HIM)	22-HIM-C2S	1	256.44	256.44	2598.73
64									
65	Rails	1	McMaster	Al Pipe 1-5/8" Pipe OD, 10' Length	4699T16	4	61.25	245.00	
66		2	McMaster	Al Pipe 1-5/8" Pipe OD, 5' Length	4699T23	2	32.67	65.34	
67		3	McMaster	Al Slip-On Struc. Fit., Mounting Re	4698T165	4	17.23	68.92	
68		5	McMaster	Al Slip-On Structural Fittings, 2-Ou	4698T22	2	12.66	25.32	
69		6	McMaster	Al Slip-On Structural Fittings, 3-Ou	4698T93	4	12.48	49.92	
70		7	McMaster	Al Slip-On Structural Fittings, 90 D	4698T33	6	11.17	67.02	
71		8	McMaster	Al Slip-On Structural Fittings, Extr	90289A618	1	12.63	12.63	
72		4	McMaster	Rect Flange Mount Fastening Sets	F1	16	8.00	128.00	662.15
73									
74	Hoist		McMaster	Hand Chain Hoist, Hook Mount	3094T2	2	251.14	502.28	
75			McMaster	SS 3.5x0.25x3 3/8 Trolley for Strut C	3626T23	1	121.60	121.60	
76			McMaster	Galvanized Steel Forged Anchor Sh	3559T45	3	5.59	16.77	
77			McMaster	Grade 100 Alloy Steel Chain for Lifti	3410T77	2	36.95	73.90	
78			McMaster	Grade 100 Alloy Steel Chain for Lifti	3410T77	1	103.46	103.46	818.01
79									
80						228	Total	12,342.55	12342.55
81									

Acknowledgements

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References

[1]"HULC" Lockheed Martin Company, Missiles and Fire control.
http://www.lockheedmartin.com/products/hulc/