Mechanical Hip Actuation Of A 2-D Passive-Dynamics Based Walker

TAM 492 – 3 Credits

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Introduction

Two primary philosophies have emerged in regards to how to best control a walking bipedal robot.

Perhaps most intuitive way of imitating how humans move might be described as brute-force mimicry. If one is to model a human as a collection of rigid line segments connecting point masses, and then record how the angles between these line segments change with time, an 'understanding' of walking can be found. This understanding may not provide much insight into *why or how* walking works, but it certainly shows to a degree *what happens*.

There are two primary problems with this kinematic approach. First, the robot thus created has no innate predisposition to walking; if we were to pick it up mid-stride and put it down again at almost any time, it would simply fall down. It isn't so much *walking* as it is kinematically *mimicking walking*.

The second problem with this type of walking is one of power consumption. Human legs do not power every joint in their bodies 100% of the time. Most of the time our legs are swinging freely, and not using much energy. It follows then that persistent joint angle control is not the most efficient means of walking in terms of energy consumption.

Another, non-kinematic approach to walking is to take advantage of the passive dynamical properties of the robot so as to reduce energy used. By using slight downhill slopes to provide energy, we now know that it is possible to create working models of human gait that use no outside energy (aside from gravity) at all.[1]

Sadly, as we have all found out at one point or another, life is not constantly downhill, and it's probably important to have a walker that can actually walk on level surfaces. To do this one provides *slight* power to the model, not controlling ever angle in the walker, but instead lending small amounts of energy to the device through mechanical analogues to things such as hip flexors and ankles. This method requires more complicated physics knowledge and modeling, and often does not produce models that appear quite as robust as those created through joint angle control, but since this is the method by which human beings seem to move around, it is almost certainly the most promising method available. Robots have been designed using this method, and these robots have walked. They have generally failed, however, in terms of robustness. They often take many trials to produce a small number of short walks.[2]

We seek to build a simple, slightly powered passive dynamic based walker that can walk regularly and robustly. We will consider ourselves successful if the walker succeeds in walking the majority of trials, and if it can walk a substantial distance. This report deals primarily with the problem of actuating the hip of the robot, the significant problems encountered the solutions we have found, and the questions that are left unanswered.

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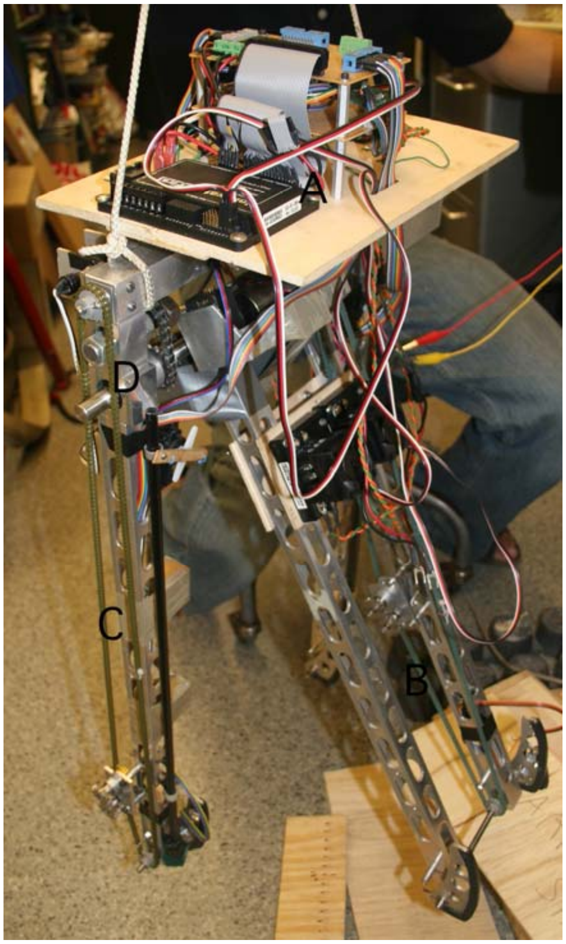
[1] *A Three-Dimensional Passive-Dynamic Walking Robot with Two Legs and Knees.* Collins, S. H., Wisse, M., Ruina, A.

[2] *A Bipedal Walking Robot with Efficient and Human-Like Gait.* Steve Collins, Andy Ruina

<u>Design and Construction</u>

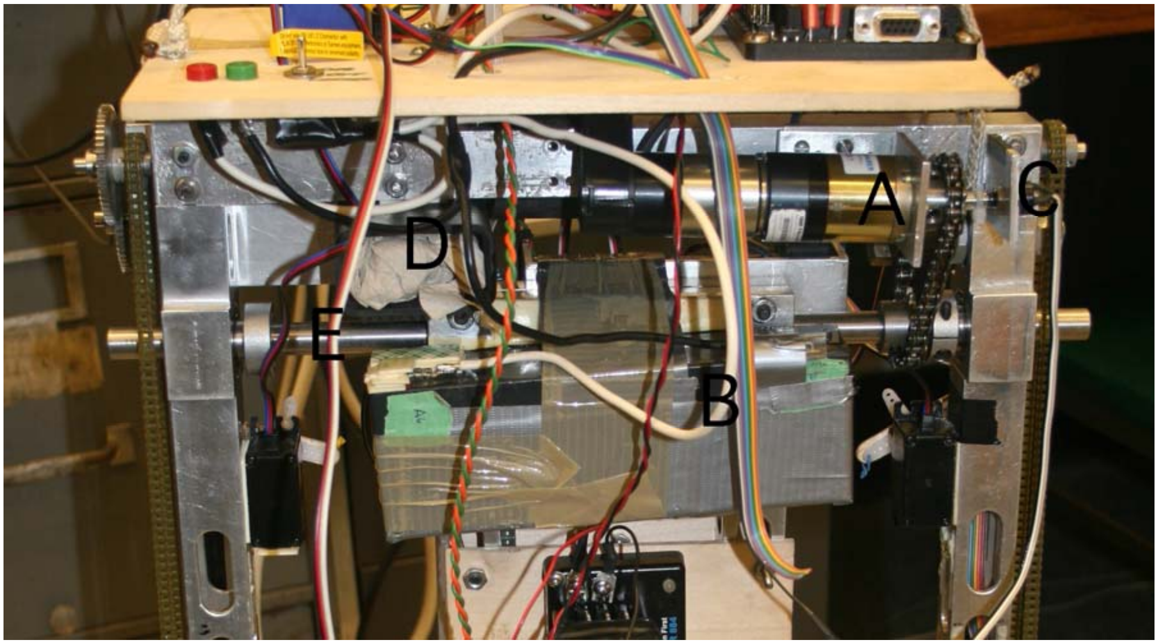
Mechanics



The Robot

The robot has two pairs of legs, an inner pair (B on the above photograph) and an outer pair (C on the above photograph); both sets are rigid, and have no knees. At the bottom of each leg there is an actuated foot, which serves to push off and give the robot kinetic energy. As the robot walks the inner and outer sets of legs swing back and forth relative to each other, and this process is assisted by the hip actuation system (D on the above photograph). The entire robot is controlled by the robot's CPU (A on the above photograph).

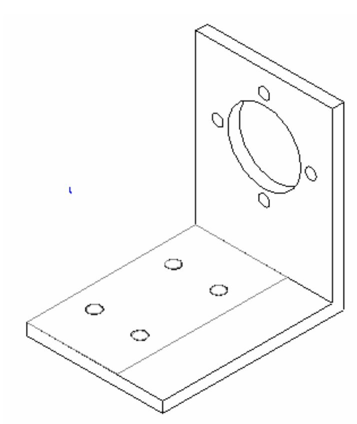
The task we were given was to actuate the hip of the robot. Previous iterations of this robot used powered ankles, and didn't walk. Part of the problem was that the feet were not striking far enough forward, and so we were asked to design and create a system by which power could be provided to the hip. This would allow us to manipulate exactly where foot strike occurred. To do so we had to select a motor and gearbox that would provide necessary power in a form factor that took into account the available space on the robot. The motor had to be capable of holding the legs stationary at a 45-degree angle with respect to vertical, and had to use a reasonable amount of energy without failing. The 45-degree figure was chosen because we could not envision a step that would necessitate any greater angle than this.



Final Placement of the Hip Motor

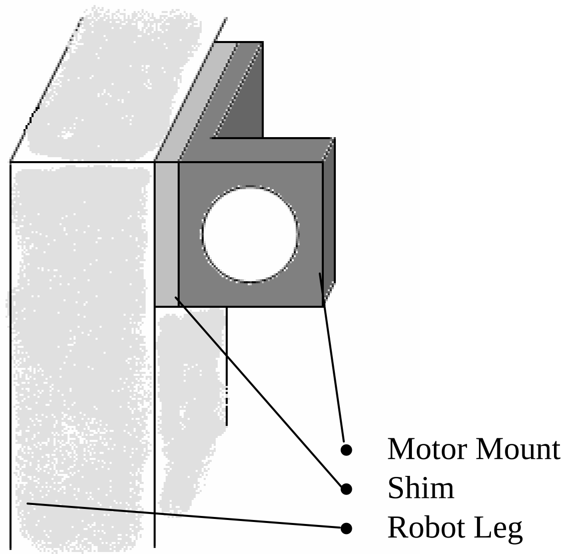
Once the choice of the motor was finalized, we proceeded to build in Solidworks a fairly in-depth CAD model that included all the parts that we did not consider to be mobile (i.e. everything except some of the electronics which were being replaced). We used this to find a place where the motor could be installed without interfering with leg swing. This proved difficult because the motor controlling the ankles of the inside leg, and also the battery (B in the above photograph) are inconveniently placed. When the leg swings they provide very little free space for the hip motor to occupy. We eventually placed the motor as shown above (A in the photograph) so that it could easily be configured to power the axle (E in the photograph). You can also see the potentiometer and mount (C in the photograph) which are both described in more detail later in the report.

We decided to use a sprocket and chain assembly to connect the motor and hip axle. We did this because it would allow more flexibility in placing the motor, since a chain can be lengthened and shortened easily whereas gears have fixed diameters.



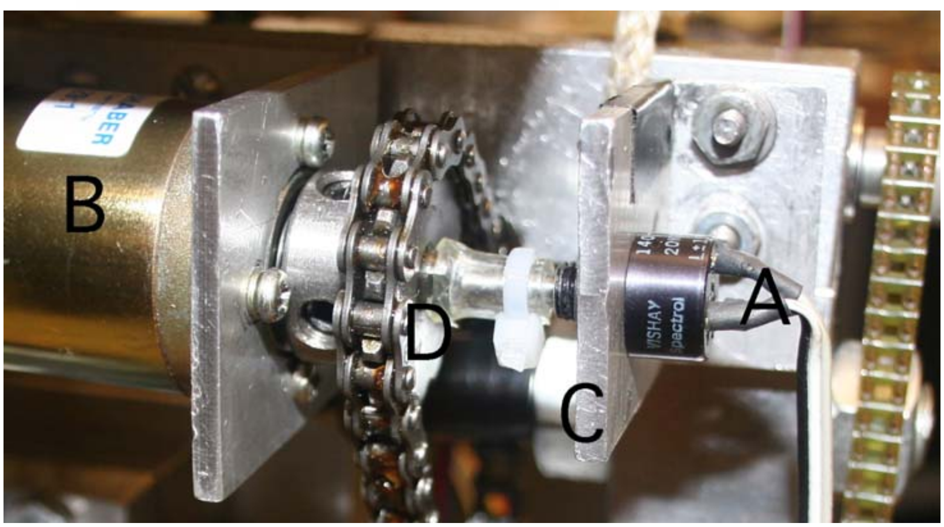
The Motor Rack

Once the motor was placed, we used CAD to design a motor rack to support it. After fabricating and mounting the motor rack we went about fixing a sprocket onto the hip axle. To do this we disassembled the robot and clamped the sprocket to the axle, then drilled through the axle using a mill, and then press-fit a spring pin into the hole. This solution keeps the sprocket extremely well fixed relative to the axle. In fixing the other sprocket to the motor shaft we used a 1/4" to 6mm bore reducer and a setscrew. We were skeptical of only using a setscrew to mount the sprocket on the motor shaft because of the typical ineffectiveness of setscrews. However, we screwed in the setscrew until it was flush with the flat surface that makes up one side of the motor shaft and have yet to see any evidence of slipping.



The Hip Motor Tensioner

After re-assembling the robot and mounting the chain on the sprockets we assessed its tightness and decided that we needed to increase the tension in the chain. We did this by simply manufacturing an aluminum shim and placing it between the robot and the bottom of the motor rack. This moved the motor rack slightly further away from the robot and therefore further away from the hip axle. This increased tension to a point we deemed sufficient.



The Potentiometer - Motor Couple

The Potentiometer Rack

Eventually it was decided that we were going to purchase and install potentiometers (A in the above photograph) instead of using the encoders we'd bought previously. This meant that the potentiometer had to be connected semi-rigidly (to avoid damage to the potentiometer) to the hip motor shaft. We designed and fabricated a potentiometer rack that mounts on the leg nearest the hip motor shaft and holds the potentiometer so that its shaft is facing the hip motor shaft. We then tried a variety of coupling methods, under the impression that each couple was slipping in some way. We eventually determined this slipping was not actually in the coupling, but was simply due to flexibility in system components. The final coupling solution involves 1/8th inch inner diameter tubing that is stretched over the shafts of the potentiometer and the motor (B in the above photograph) and tightened down using zip-ties. The potentiometer can remain in its rack (C in the above photograph). This simple solution (D in the above photograph) has worked well.

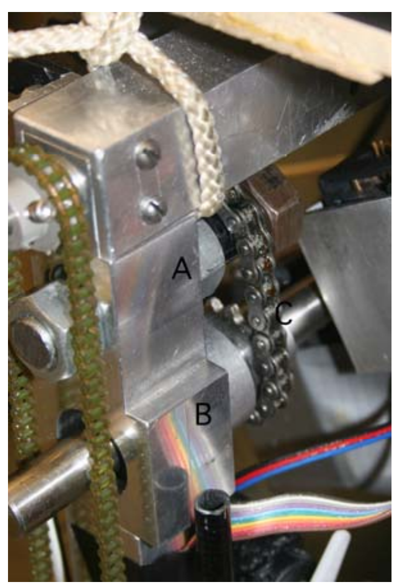
Axle Clamp

Another thing, however, that needs to be constantly examined is the tightness of the actual hip axel, as it's clamped to the inside leg. The clamp is simply created by having two semi-circular grooves that fit around the axel, and are tightened down using screws (see photograph to left). Initial tests showed the possibility of slipping, which would cause potentiometer drift. Tightening it down as well as possible yielded a situation where we could not physically move the leg relative to the hip axle.

The hip actuation system, as outlined above, stayed in place for some time until a more aggressive walking strategy was designed. This strategy calls for the motor to slam the leg against a stop on the forward side, and then accelerate it backwards and slam it against the other stop on the rear side. This process is repeated as long as the robot is walking, always running at maximum power. The short deceleration caused by the collisions involved put huge stresses on the chain, and caused failure.

Failed Sprockets and Chain

To increase the robustness of the hip actuation assembly we purchased a steel chain and steel sprockets with a larger diameter. This decreases the load on the chain, and increases the strength of the chain.



Hip Chain Tensioner

We also installed a variable tensioner (A in above photograph) for the hip chain that kept the new steel chain (C in above photograph) tight and therefore provided more precise angle control.

Electronics

Counters and Encoders

We ended up purchasing the same encoder as was used on the ankle actuating motors (see appendix for specs) and presumed that it would do fine. As for the counters, we looked into those extensively but were unable to find a bi-directional binary counter with sufficient resolution. Initially the leading plan was to use interrupts on the CPU itself to act as a counter.

After several weeks it was decided by the electronics section of the team that we would in fact not use the encoders that we had purchased, and that we would instead purchase a set of potentiometers to sense position. These needed to be mounted near every degree of freedom that needed sensing. This change was necessary because our CPU was unable to interpret encoder data at sufficient speeds.

The Motor

The motor was selected based on two criteria: adequate stall torque to hold the leg out at 45 degrees and efficiency. We found three motors with the appropriate stall torque, 2.1 Nm, given reasonable gear ratios and compared their relative efficiency. The chart below, provided by Mike Sherback, demonstrates, given motor constants, the effective watts per $(\text{oz-in})^2$ of torque. This quality of the motor, provided the motor is not run continuously, is a figure of merit for determining efficiency in regards to wasted heat. As demonstrated in the chart below, a larger motor can be used to decrease the wasted heat or the gear ratio (equivalent to mechanical efficiency as a result of friction). Ultimately we selected the 3042 with a gear ratio of 29:1 because it met our desired specifications and was the exact same motor used for ankle actuation, thus simplifying the control code.

Motor Selection Spreadsheet

Compare with minimum gear ratios						
Motor	A/oz-in	ohms	Stall torque	min gear ratio	W at stall/des. Oz-in	W/(oz-in)^2 at motor
2342	0.527	1.9	11.33	35.30	75.78	0.527
3042	0.338	1.7	20.68	19.34	84.70	0.194
3257	0.37	0.41	75	5.33	351.21	0.056
Compare motors with same gear ratios						
Motor	A/oz-in	ohms	stall torque	used gear ratio	W at des oz-in	W/(oz-in)^2 at motor
2342	0.527	1.9	11.33	36	65.14	0.528
3042	0.338	1.7	20.68	36	23.98	0.194
3257	0.37	0.41	75	36	6.93	0.056
Courtesy of Mike Sherback						

Another task we were given was to determine the amount of power (via) voltage and current that the engine draws at different RPMs. We started by partially disassembling the robot to remove one of the two motors already installed.

We then varied the voltage of the motor with no load on it and recorded the rate of rotation for each voltage, and also the amount of current being drawn. When given precise numbers for what kind of rate of rotation we're looking for, we can estimate the amount of voltage and amperage that is required.

Results

One point of interest for our group was to ascertain exactly how much energy it would take for the motor we chose to 'chase' at a certain angular velocity. That is, how much energy it takes for the motor to move at certain speeds with no load on it. This figure gives us a ballpark idea of how much energy is lost through electric-motor actuation without providing any additional force to the robot.

We varied the voltage and measured the current with no load on the motor, and at each voltage we measured the angular velocity by counting the number of rotations in a set amount of time and using this information to find the period of rotation.

It is clear that under no-load conditions the motor draws very little power. This means, that if the motor is 'chasing' the leg at approximately 60rpms, we're looking at less than one third watt power consumption. As long as the motor is merely chasing, power consumption is kept to a minimum. Thus, when the robot is in states of passive-dynamic motion we see very little energy usage.

Table of Current and Period Varying with Voltage with No Load on the Motor

Current (amps)	Voltage (volts)	Period (sec)	RPMs	Power (watts)
0.04	1	10.23	5.0	0.04
0.05	2	2.7	22.2	0.10
0.06	3	1.6	37.5	0.18
0.06	4	1.1	54.5	0.24
0.07	5	0.68	88.2	0.35
0.08	6	0.58	103.4	0.48
0.08	7	0.47	127.7	0.56
0.08	8	0.45	133.3	0.64
0.09	9	0.40	150	0.81

Conclusion

When actuating the hip of our robot, we saw great success using a robust chain and sprocket system. This system provides great flexibility and durability, as long as sprocket diameter and chain strength are sufficient. Hip actuation on this robot works properly and robustly.

Also, from a power consumption standpoint, it's very advantageous to have a robot that is designed with passive dynamics in mind. As long as the actuating motors are simply chasing, power consumption is minimal.

Acknowledgements

We would like to take this space to thank the concept of drilling holes in things and putting pins in them. This is just about the best way ever to prevent things from slipping.

Purchased Part List

Part Name	Description	Purchased From	Quantity	Price
25CCF	8.3” long Plastic Chain	www.wmberg.com	1	$8.55
25EM-B-10	1/4" bore sprocket, hip motor sprocket small	www.wmberg.com	1	$8.77
25CP68A-10	1/2" bore sprocket, hip axle sprocket small	www.wmberg.com	1	$18.30
6261K107	1/4 pitch steel chain	www.mcmaster.com	2ft	$6.38
2737T107	Chain Sprocket for #25 Chain, 1/4" Pitch, 14 Teeth, 1/2" Bore; hip motor Sprocket large	www.mcmaster.com	1	$5.78
2737T105	Chain Sprocket for #25 Chain, 1/4" Pitch, 14 Teeth, 1/4" Bore; hip axle sprocket large	www.mcmaster.com	1	$5.78
6051K15	Chain breaker	www.mcmaster.com	1	$19.63
	Tubing used for potentiometer couple	Clark Hall	1ft	$0.50
	Zip-ties	Clark Hall	1	$0.10
3042W012C+32PG 29:1+HEDS5540I06 +X0433B+X0460C	Motor, gearbox, encoder combo	www.micromo.com	1	$456.70

Lab Owned Part List

Part Name	Use
3” length of ½” threaded rod	Metal chain tensioner
3 x ½” nuts fitting on threaded rod	Metal chain tensioner
1” of ½” inner diam. Carbon fiber rod, 1/16” outer diam.	Metal chain tensioner
4 x 1 ½” long #6-32 screws	Attach motor rack to robot
1” long 1/8” spring (or roll) pin	Used to secure the hip axle sprocket

DC-Micromotors

Graphite Commutation

16 Watt

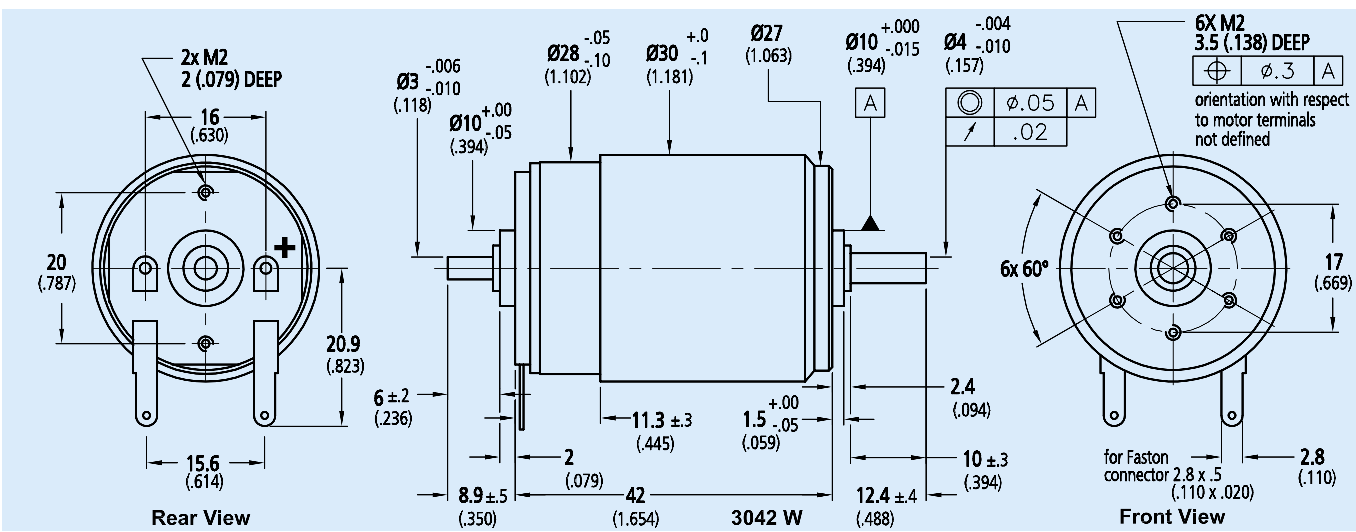
For combination with:
Gearheads: 30/1, 32PG, 38/1, 38/2
Encoders: HE, 5500, 5540

Series 3042 ... C

See beginning of the Motor Section for Ordering Information

		3042 W		006 C	012 C	018 C	024 C	036 C	
1	Nominal voltage	U_N		6	12	18	24	36	Volt
2	Terminal resistance	R	± 12%	0.6	1.7	3.8	6.8	14.0	Ω
3	Output power	$P_{2\ max.}$		14.5	20.6	20.7	20.6	22.5	W
4	Efficiency	$\eta_{max.}$		76	80	78	79	79	%
5	No-load speed	n_o	± 12%	5,100	5,400	5,600	5,700	5,500	rpm
6	No-load current (with shaft ø 0.16 in)	I_o	± 50%	0.180	0.093	0.070	0.050	0.035	A
7	Stall torque	M_H		15.29	20.68	19.97	19.54	22.09	oz-in
8	Friction torque	M_R		0.283	0.269	0.297	0.283	0.312	oz-in
9	Speed constant	k_n		866	456	316	241	155	rpm/V
10	Back-EMF constant	k_E		1.16	2.19	3.17	4.15	6.46	mV/rpm
11	Torque constant	k_M		1.558	2.960	4.277	5.608	8.737	oz-in/A
12	Current constant	k_I		0.642	0.338	0.234	0.178	0.114	A/oz-in
13	Slope of n-M curve	$\Delta n/\Delta M$		334	261	280	292	249	rpm/oz-in
14	Rotor inductance	L		44	165	360	620	1,450	µH
15	Mechanical time constant	τ_m		7	7	7	7	7	ms
16	Rotor inertia	J		$1.983 \cdot 10^{-4}$	$2.549 \cdot 10^{-4}$	$2.407 \cdot 10^{-4}$	$2.266 \cdot 10^{-4}$	$2.691 \cdot 10^{-4}$	oz-in-sec²
17	Angular acceleration	$\alpha_{max.}$		76	81	84	85	82	$\cdot 10^3 rad/s^2$
18	Thermal resistance	$R_{th\ 1} / R_{th\ 2}$	3 / 14						°C/W
19	Thermal time constant	τ_{w1} / τ_{w2}	17.6 / 832						s
20	Operating temperature range:								
	– motor		– 30 to +125 (– 22 to +257)						°C (°F)
	– rotor, max. permissible		+125 (+257)						°C (°F)
21	Shaft bearings		ball bearings, preloaded						
22	Shaft load max.:								
	– with shaft diameter		0.157						in
	– radial at 3,000 rpm (0.12 in from bearing)		72						oz
	– axial at 3,000 rpm		7.2						oz
	– axial at standstill		72						oz
23	Shaft play:								
	– radial	≤	0.0006						in
	– axial	=	0						in
24	Housing material		steel, zinc galvanized and passivated						
25	Weight		5.51						oz
26	Direction of rotation		clockwise, viewed from the front face						
	Recommended values								
27	Speed up to	$n_{e\ max.}$		5,000	5,000	5,000	5,000	5,000	rpm
28	Torque up to [1]	$M_{e\ max.}$		4.248	4.248	4.248	4.248	4.248	oz-in
29	Current up to (thermal limits)	$I_{e\ max.}$		2.650	1.550	1.050	0.790	0.550	A

[1] thermal resistance $R_{th\ 2}$ by 40% reduced



For notes on technical data refer to "Technical Information". Specifications subject to change without notice. MME0402

Planetary Gearheads

637 oz-in

For combination with:
DC-Micromotors: 2338, 2842, 3042, 3557, 2342CR
DC-Motor-Tacho Combinations: 3557 ... CR

Series 32PG

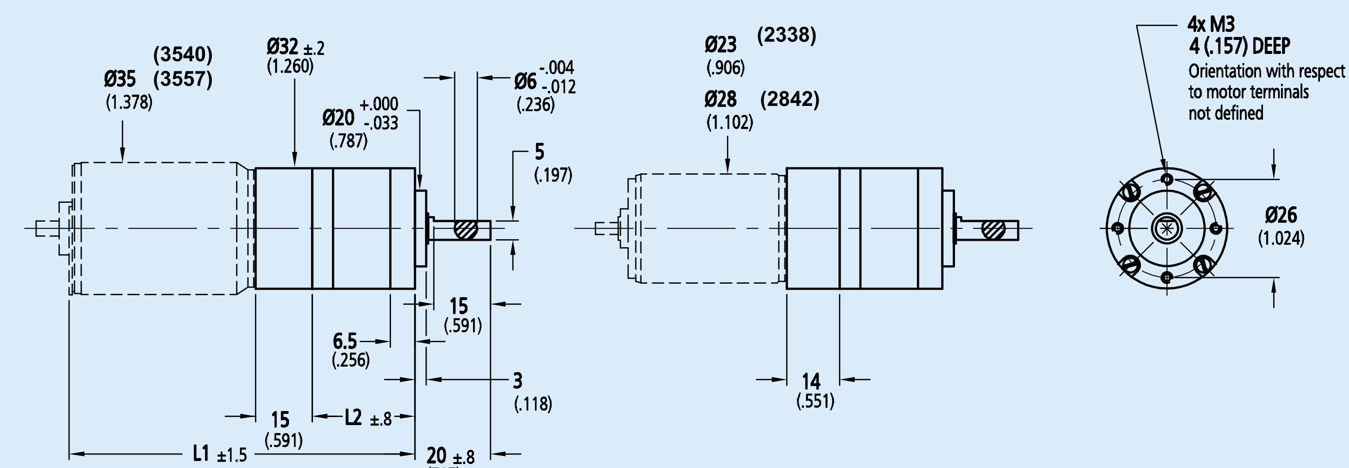
See beginning of the Gearhead Section for Ordering Information

	32PG		
Housing material		metal	
Recommended max. input speed for:			
– continuous operation		3,000 rpm	
Backlash, at no-load		≤ 2.5°	
Bearings on output shaft		ball bearings	
Ratios	4:1 - 7:1	14:1 - 46:1	93:1 and higher
Shaft load, max.:			
– radial (10 mm (0.394 in) from mounting face)	≤ 108 oz	≤ 144 oz	≤ 288 oz
– axial	≤ 23.4 oz	≤ 32.4 oz	≤ 61.2 oz
Maximum shaft press fit force	≤100N (360 oz-in) all ratios		
Shaft play (on bearing output):			
– radial		≤ 0.0012 in	
– axial		≤ 0.012 in	
Operating temperature range		– 20 to +80 °C (– 4 to +176 °F)	

Specifications

reduction ratio (nominal)	weight without motor	length without motor L2		length with motor 2338 S L1		length with motor 2342 S 2842 S 3042 W L1		length with motor 3557 K L1		output torque continuous operation M max.	output torque intermittent operation M max.	direction of rotation (reversible)	efficiency
	oz	mm	(in)	mm	(in)	mm	(in)	mm	(in)	oz-in	oz-in		%
4 : 1	5.6	28.2	(1.11)	79.8	(3.14)	84.2	(3.32)	100.2	(3.95)	106.2	142	=	80
7 : 1	5.6	28.2	(1.11)	79.8	(3.14)	84.2	(3.32)	100.2	(3.95)	106.2	142	=	80
14 : 1	7.4	37.7	(1.48)	89.3	(3.52)	93.7	(3.69)	109.7	(4.32)	318.6	425	=	75
25 : 1	7.4	37.7	(1.48)	89.3	(3.52)	93.7	(3.69)	109.7	(4.32)	318.6	425	=	75
29 : 1	7.4	37.7	(1.48)	89.3	(3.52)	93.7	(3.69)	109.7	(4.32)	318.6	425	=	75
46 : 1	7.4	37.7	(1.48)	89.3	(3.52)	93.7	(3.69)	109.7	(4.32)	318.6	425	=	75
93 : 1	9.2	47.2	(1.86)	98.8	(3.89)	103.2	(4.06)	119.2	(4.69)	637.3	850	=	70
124 : 1	9.2	47.2	(1.86)	98.8	(3.89)	103.2	(4.06)	119.2	(4.69)	637.3	850	=	70
169 : 1	9.2	47.2	(1.86)	98.8	(3.89)	103.2	(4.06)	119.2	(4.69)	637.3	850	=	70
308 : 1	9.2	47.2	(1.86)	98.8	(3.89)	103.2	(4.06)	119.2	(4.69)	637.3	850	=	70
344 : 1	10.9	56.7	(2.23)	108.3	(4.26)	112.7	(4.44)	128.7	(5.07)	637.3	850	=	60
626 : 1	10.9	56.7	(2.23)	108.3	(4.26)	112.7	(4.44)	128.7	(5.07)	637.3	850	=	60
1,140 : 1	10.9	56.7	(2.23)	108.3	(4.26)	112.7	(4.44)	128.7	(5.07)	637.3	850	=	60
2,076 : 1	10.9	56.7	(2.23)	108.3	(4.26)	112.7	(4.44)	128.7	(5.07)	637.3	850	=	60

Note: Reduction ratios have been rounded off.
Exact values are available upon request.



32PG 32PG Front View

FAULHABER

Encoders

Optical Encoders

Features:
96 to 1024 Pulses per revolution
2 or 3 Channels
Digital output

Series 5500, 5540

		HEDS 5500	HEDS 5540	HEDM 5500	
	N	96 - 512	100 - 512	1,000 -1,024	
		2	2+1	2	
	V_{CC}	4.5 to 5.5			V DC
	I_{CC}	17	57	57	mA
	P	180 ± 45	180 ± 35	180 ± 45	°e
	Φ	90 ± 20	90 ± 15	90 ± 15	°e
	S	90 ± 45	90 ± 35	90 ± 45	°e
	C	360 ± 5.5	360 ± 5.5	360 ± 7.5	°e
	tr/tf	0.20 / 0.05	0.18 / 0.04	0.18 / 0.04	µs
	f	up to 100	up to 100 [2)]	up to 10	kHz
	J	$8.497 \cdot 10^{-6}$			oz-in-sec²
		– 40 to +100 (– 40 to +212)		– 40 to +70 (– 40 to +158)	°C (°F)

		5500	5540		
HEDS 5500 K		2	–	96	
HEDS 5500 C	HEDS 5540 C	2	2+1	100	
HEDS 5500 D		2	–	192	
HEDS 5500 E	HEDS 5540 E	2	2+1	200	2036, 2444, 3056, 3564
HEDS 5500 F	HEDS 5540 F	2	2+1	256	2230, 2233, 2251
HEDS 5500 G	HEDS 5540 G	2	2+1	360	2338, 2342, 2356
HEDS 5500 H	HEDS 5540 H	2	2+1	400	2842, 3042
HEDS 5500 A	HEDS 5540 A	2	2+1	500	3557, 3863
HEDS 5500 I	HEDS 5540 I	2	2+1	512	
HEDM 5500 B		2	–	1,000	
HEDM 5500 J		2	–	1,024	

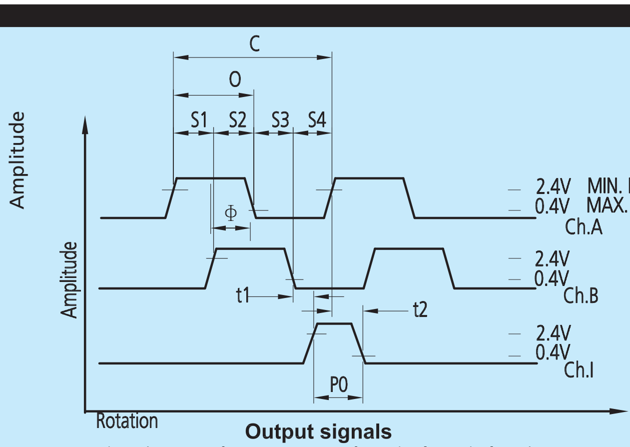
These incremental shaft encoders in combination with the FAULHABER DC-Micromotors are designed for indication and control of both, shaft velocity and direction of rotation as well as for positioning.

A LED source and lens system transmits collimated light through a low inertia metal disc to give two channels with 90° phase shift.

The single 5 volt supply and the two or three channel digital output signals are interfaced with a 5-pin connector.

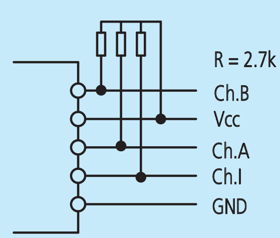
Ball bearings are recommended for continuous operation at low and high speeds and for elevated radial shaft load.

Details for the DC-Micromotors and suitable reduction gearheads are on separate catalog pages.



Output signals

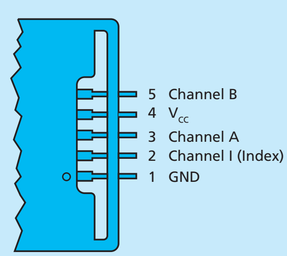
When direction of rotation as seen from the front shaft end
t1 is Channel I rise after Ch.A or Ch.B fall, .1µs typical.
t2 is Channel I fall after Ch.B or Ch.A rise, .15µs typical.



Connection diagram

HEDS 5540 requires pull-up resistors

Pin Function

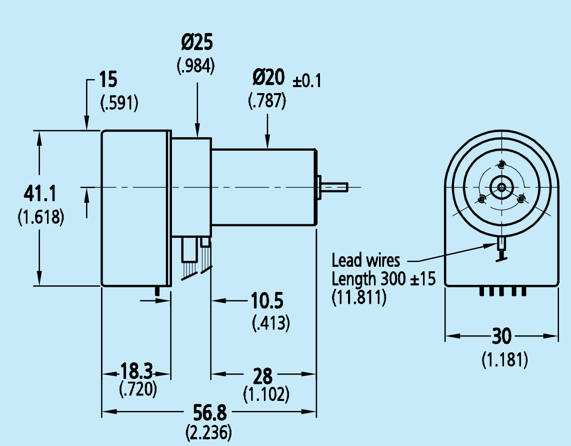


Connector
suggested connectors
AMP 103686-4/640442-5,
Molex 2695/2759
Berg 65039--032/4825X-000
HEDS 8903

For notes on technical data refer to "Technical Information". Specifications subject to change without notice. MME0304

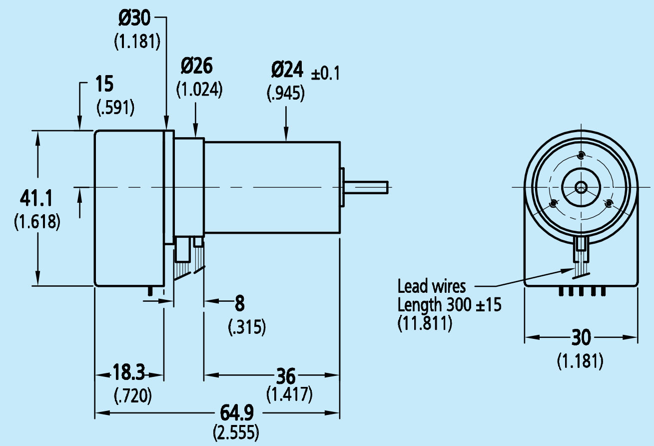
Series 5500, 5540

HEDS 5500, 5540 with Brushless Servomotor 2036 U ... B K312



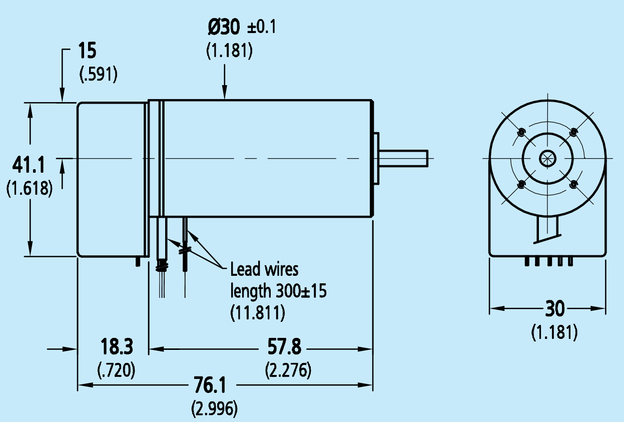
Encoders HEDS 5500, 5540
with Brushless DCServomotor- 2036 U ... B K312

HEDS 5500, 5540 with Brushless Servomotor 2444S ... B K312



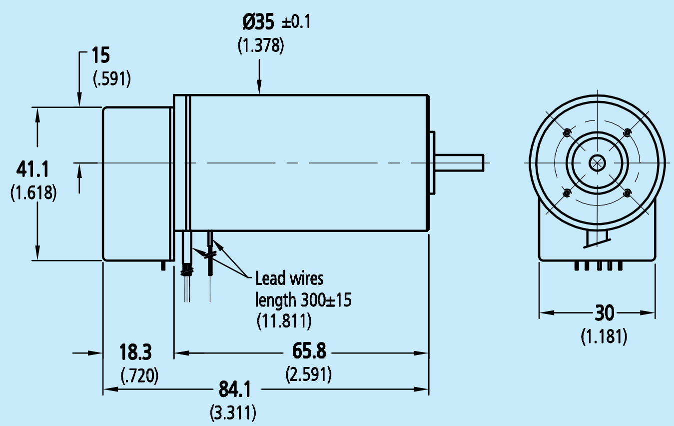
Encoders HEDS 5500, 5540
with Brushless DC-Servomotor 2444 S ... B K312

HEDS 5500, 5540 with Brushless Servomotor 3056 K ... B K312



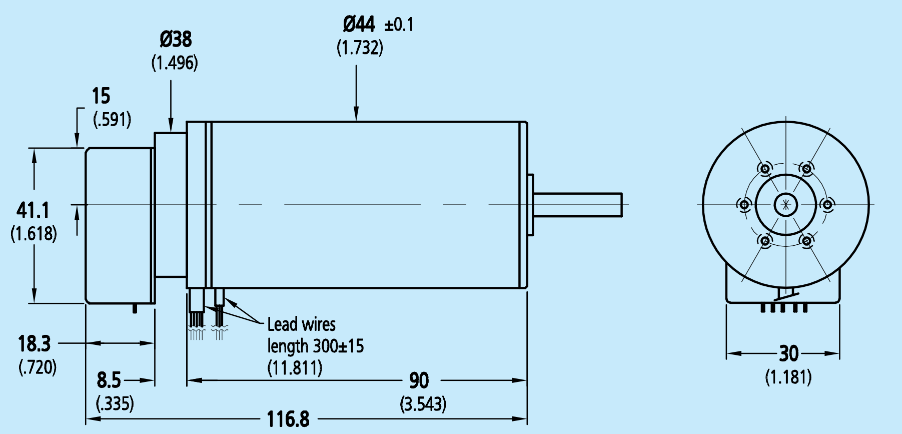
Encoders HEDS 5500, 5540
with Brushless DC-Servomotor 3056 K ... B K312

HEDS 5500, 5540 with Brushless Servomotor 3564 K ... B K312



Encoders HEDS 5500, 5540
with Brushless DC-Servomotor 3564 K ... B K312

HEDS 5500, 5540 with Brushless Servomotor 4490 K ... B K312

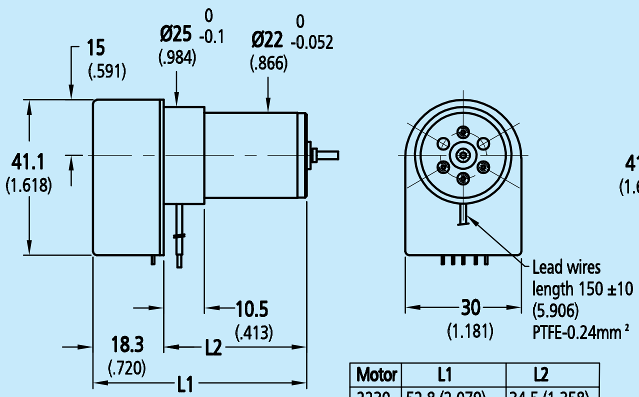


Encoder HEDS 5500, 5540
with Brushless DC-Servomotor 4490K ... B K312

For notes on technical data refer to "Technical Information". Specifications subject to change without notice. MME0304

Series 5500, 5540

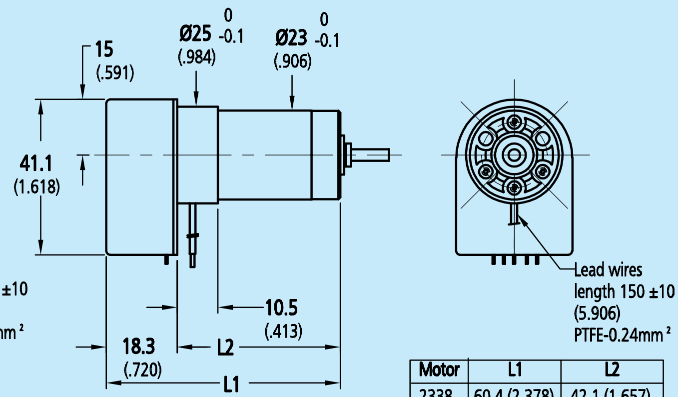
HEDS 5500, 5540 with motors 2230, 2233



Motor	L1	L2
2230	52.8 (2.079)	34.5 (1.358)
2233	55.6 (2.189)	37.3 (1.469)

Encoders HEDS 5500, 5540
DC-MICROMOTORS 2230, 2233

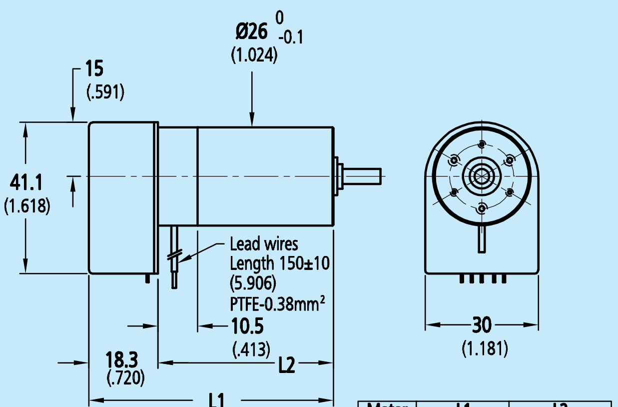
HEDS 5500, 5540 with motors 2338, 2342



Motor	L1	L2
2338	60.4 (2.378)	42.1 (1.657)
2342	64.8 (2.551)	46.5 (1.831)

Encoders HEDS 5500, 5540
DC-MICROMOTORS 2338, 2342

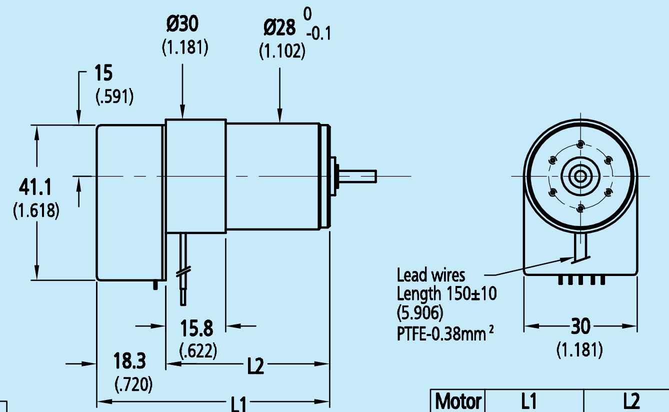
HEDS 5500, 5540 with motors 2642, 2657



Motor	L1	L2
2642	64.8 (2.551)	46.5 (1.831)
2657	79.8 (3.142)	61.5 (2.421)

Encoders HEDS 5500, 5540
with DC-Micromotor 2642, 2657

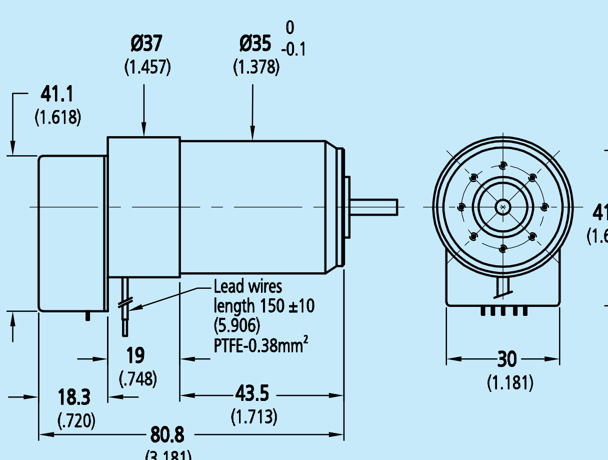
HEDS 5500, 5540 with motors 2842, 3042



Motor	L1	L2
2842	64.8(2.551)	27.5 (1.083)
3042	64.8(2.551)	30.7 (1.209)

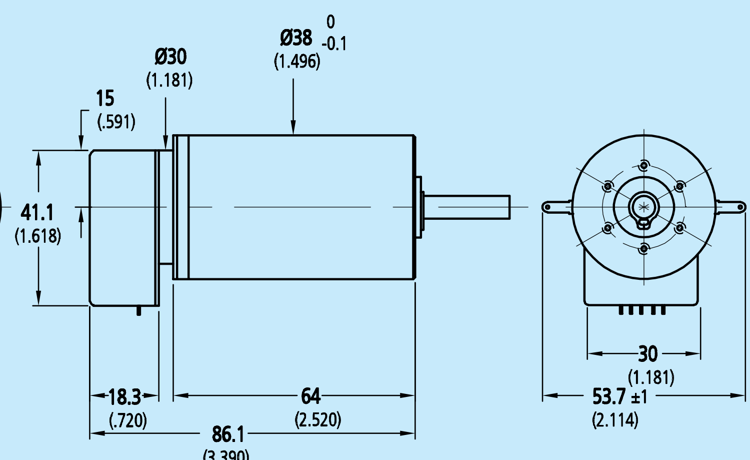
Encoders HEDS 5500, 5540
with DC-Micromotor 2842, 3042

HEDS 5500, 5540 with motor 3557



Encoders HEDS 5500, 5540
with DC-Micromotor 3557

HEDS 5500, 5540 with motor 3863



Encoders HEDS 5500, 5540
with DC-Micromotor 3863

FAULHABER

Encoders

Optical Encoders with Line Driver

Features:
500 Pulses per revolution
3 Channels + complementary outputs
Digital output
Line driver

Series 5540

		HEDL 5540	
Pulses per revolution	N	500	
Signal output, (quadrature)		2+1 index and complementary outputs	channels
Supply voltage	V_{CC}	4.5 to 5.5	V DC
Current consumption, typical (V_{CC} = 5 V DC)	I_{CC}	57	mA
Pulse width	P	180 ± 35	°e
Index pulse width	Po	90 ± 35	°e
Phase shift, channel A to B	Φ	90 ± 15	°e
Logic state width	S	90 ± 35	°e
Cycle	C	360 ± 5.5	°e
Signal rise/fall time, typical	tr/tf	0.25 / 0.25	µs
Frequency range [1)]	f	up to 100	kHz
Inertia of code disc	J	$8.497 \cdot 10^{-6}$	oz-in-sec²
Operating temperature range		0 to 70 (32 to 158)	°C (°F)

[1)] Velocity (rpm) = f (Hz) x 60/N

Ordering information

Encoder type	number of channels	pulses per revolution	For combination with:
HEDL 5540 A	2+1	500	**DC-Micromotors and DC-Motor-Tachos series** 2230, 2233, 2251 2338, 2342 2642, 2657, 2842 3042, 3557, 3863 **Brushless DC-Servomotors series** 2036, 2444, 3564

The housing dimensions of the HEDL encoder are the same as the HEDS/HEDM encoders, but there is a ribbon cable instead of plain connector pins

Suggested Line Receivers: LT-1

Features

These incremental shaft encoders in combination with the FAULHABER DC-Micromotors and brushless DC-Servomotors are designed for indication and control of both, shaft velocity and direction of rotation as well as for positioning.

A LED source and lens system transmits collimated light through a low inertia metal disc to give two channels with 90° phase shift.

The index pulse is synchronized with the channel B.
Each encoder channel provides complementary output signals.

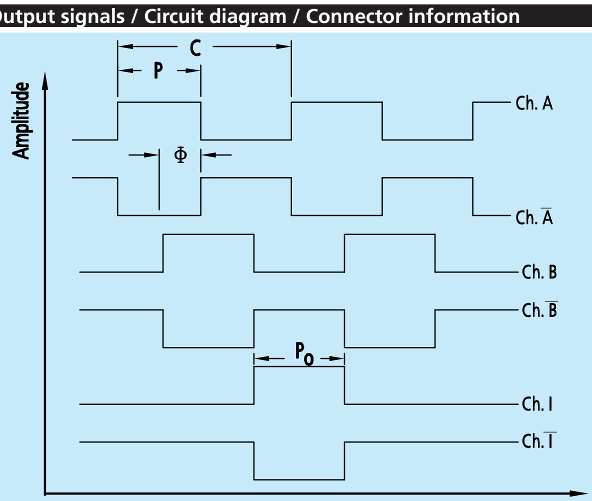
The single 5 volt supply and the digital output signals are interfaced with a connector.

The line driver offers enhanced performance when the encoder is used in noisy environments, or when it is required to drive long distances.

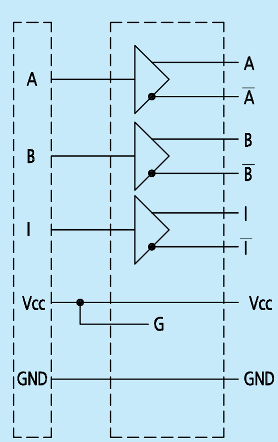
Motor with ball bearings are recommended for continuous operation at low and high speeds and for elevated radial shaft load.

Details for the motors and suitable reduction gearheads are on separate catalog pages.

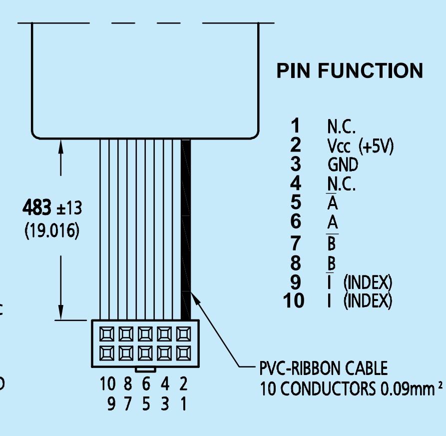
Output signals / Circuit diagram / Connector information



Output signals HEDL 5540
with clockwise rotation as seen from the shaft end



Connection diagram



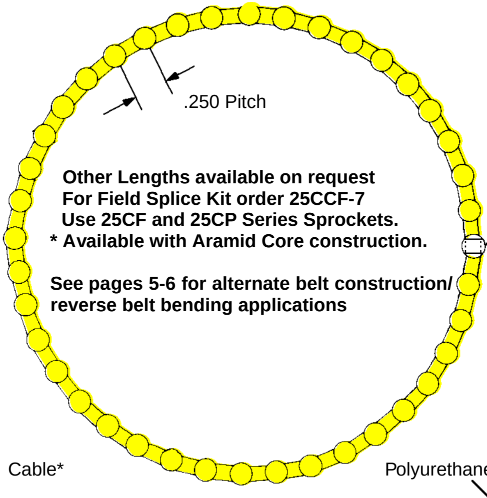
Connector
DIN-41651
GRID 2.54mm

FLEX-E-PITCH®

Cable Chain

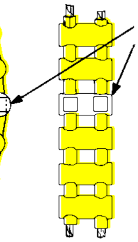
.250 Circular Pitch

Designed To Replace Standard Metal Roller Chain Systems:
- No Multiple Link Joints To Bind.
- Lubrication is Never Required.
- Easily Modified To Any Length.
- Large Selection of Mating Sprockets.

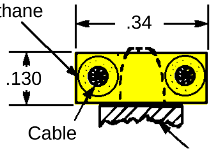


Other Lengths available on request
For Field Splice Kit order 25CCF-7
Use 25CF and 25CP Series Sprockets.
*** Available with Aramid Core construction.**

See pages 5-6 for alternate belt construction/ reverse belt bending applications



- Infinite Lengths
- Rust Proof
- Non Magnetic
- Zero Backlash
- Silent Drive
- No Lubrication Required
- Positive Drive
- Weight .30 oz./ft.
- 1/32" Dia.Stainless Steel Cable*
- 90A Durometer
- Polyurethane (Yellow)
- Ultimate Tensile Strength 100 lbs. (22 lbs./Pin)
- Temp Range + 180°F to -15°F
- Recommended Operating Load 20-25 lbs
- Recommended Operating Speed 376 ft./min.



Cable Chain FLEX-E-PITCH® 25CCF Series.

STOCK NUMBER	NO. OF PITCHES	LENGTH (Ref.)
25CCF-40-E	40	10.000
25CCF-50-E	50	12.500
25CCF-60-E	60	15.000
25CCF-70-E	70	17.500
25CCF-80-E	80	20.000
25CCF-90-E	90	22.500
25CCF-100-E	100	25.000
25CCF-110-E	110	27.500
25CCF-120-E	120	30.000
25CCF-130-E	130	32.500
25CCF-140-E	140	35.000
25CCF-150-E	150	37.500
25CCF-160-E	160	40.000
25CCF-170-E	170	42.500
25CCF-180-E	180	45.000
25CCF-190-E	190	47.500
25CCF-200-E	200	50.000
25CCF-210-E	210	52.500
25CCF-220-E	220	55.000
25CCF-230-E	230	57.500

STOCK NUMBER	NO. OF PITCHES	LENGTH (Ref.)
25CCF-240-E	240	60.000
25CCF-250-E	250	62.500
25CCF-260-E	260	65.000
25CCF-270-E	270	67.500
25CCF-280-E	280	70.000
25CCF-290-E	290	72.500
25CCF-300-E	300	75.000
25CCF-310-E	310	77.500
25CCF-320-E	320	80.000
25CCF-330-E	330	82.500
25CCF-370-E	370	92.500
25CCF-380-E	380	95.000
25CCF-390-E	390	97.500
BULK FOOTAGE-NOT SPLICED		
25CCF-5FT	5 FT LENGTH	
25CCF-10FT	10FT LENGTH	
25CCF-25FT	25FT LENGTH	
25CCF-50FT	50 FT LENGTH	
25CCF-100FT	100FT LENGTH	

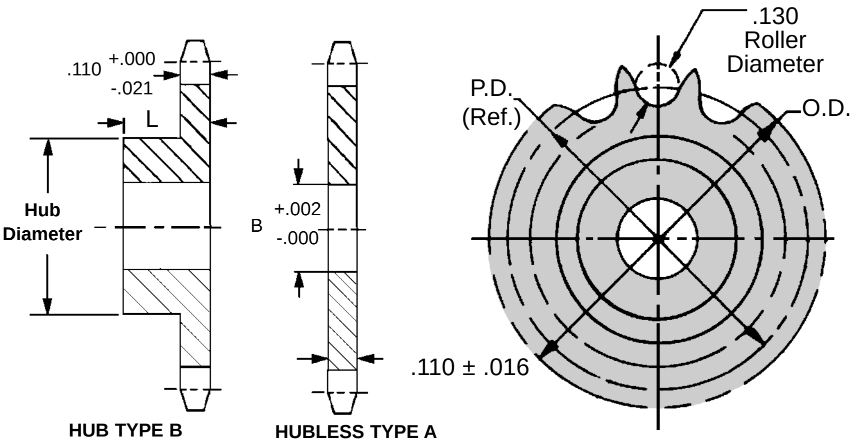
ROW-L-ER®
Mild Steel

.250 Pitch Sprockets

Circular Pitch

1/4", 3/8" and 1/2" Bore   Finish: Black Oxide

For American Standard No.25 Roller Chain



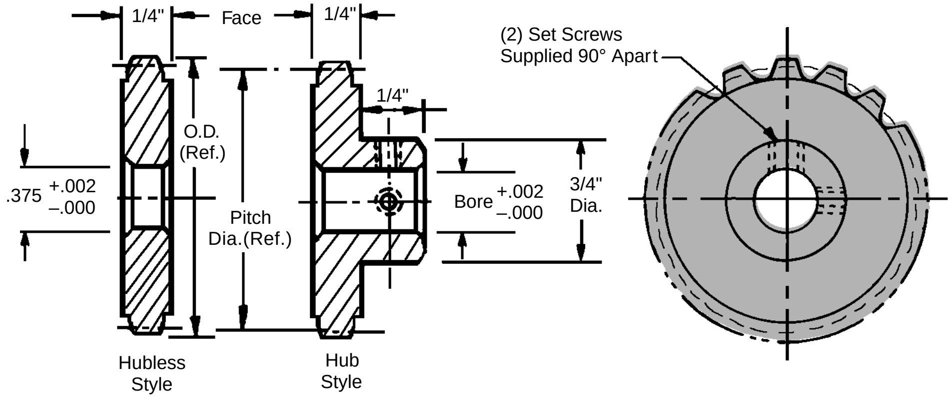
HUB TYPE B							HUBLESS TYPE A	
STOCK NUMBER	BORE	HUB DIA.	L	NO. OF TEETH	PITCH DIAMETER	OUTSIDE DIAMETER	STOCK NUMBER	BORE
25EM-B-9	.250	.43	.50	9	.7310	.836	--	--
25EM-B-10	.250	.50	.50	10	.8090	.919	--	--
25EM-B-11	.250	.57	.50	11	.8874	1.001	--	--
25EM-B-12	.250	.62	.50	12	.9659	1.083	--	--
25EM-B-13	.250	.72	.50	13	1.0446	1.164	--	--
25EM-B-14	.250	.81	.50	14	1.1235	1.245	--	--
25EM-B-15	.250	.89	.50	15	1.2024	1.326	--	--
25EM-B-16	.250	.96	.50	16	1.2815	1.406	--	--
25EM-B-18	.250	1.12	.50	18	1.4397	1.567	25SP-A-18	.250
25EM-B-20	.250	1.28	.62	20	1.5980	1.728	25SP-A-20	.250
25EM-B-21	.250	1.37	.62	21	1.6774	1.808	--	--
25EM-B-22	.250	1.43	.62	22	1.7567	1.888	25SP-A-22	.375
25EM-B-24	.375	1.50	.62	24	1.9153	2.048	25SP-A-24	.375
25EM-B-25	.375	1.50	.62	25	1.9947	2.128	25SP-A-25	.375
25EM-B-26	.375	1.50	.62	26	2.0741	2.208	25SP-A-26	.375
25EM-B-28	.375	1.50	.62	28	2.2329	2.368	25SP-A-28	.375
25EM-B-30	.375	1.50	.62	30	2.3917	2.528	25SP-A-30	.375
25EM-B-32	.375	1.50	.62	32	2.5506	2.688	25SP-A-32	.375
—	–	–	–	35	2.7890	2.927	25SP-A-35	.375
25EM-B-36	.375	1.50	.75	36	2.8684	3.007	25SP-A-36	.375
25EM-B-40	.500	2.00	.75	40	3.1864	3.326	25SP-A-40	.500
25EM-B-45	.500	2.00	.75	45	3.5839	3.725	25SP-A-45	.500
25EM-B-48	.500	2.00	.75	48	3.8224	3.964	25SP-A-48	.500
25EM-B-54	.500	2.00	.75	54	4.2996	4.442	25SP-A-54	.500
25EM-B-60	.500	2.00	.75	60	4.7768	4.920	25SP-A-60	.500
25EM-B-70	.500	2.00	.75	70	5.5723	5.716	--	--
25EM-B-72	.500	2.00	.75	72	5.7314	5.875	25SP-A-72	.500

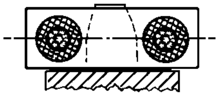
Other numbers of teeth, keyways. modified bores and set screws available an request.

Flex-E-Pitch®
Pin Style Hub

Chain Sprockets

.250 Circular Pitch





Material:
Aluminum 2024T4
Red Anodized

Operates with Flex-E-Pitch® Chain 25CCF Series

HUBLESS STYLE	HUB STYLE					
.375 BORE STOCK NO.	.250 BORE STOCK NO.	.375 BORE STOCK NO.	.500 BORE STOCK NO.	NO. OF TEETH	PITCH DIAMETER	OUTSIDE DIAMETER
25CF77A-9	25CP66A-9	25CP67A-9	25CP68A-9	9	.7161 ▲	.836
25CF77A-10	25CP66A-10	25CP67A-10	25CP68A-10	10	.7957	.915
25CF77A-12	25CP66A-12	25CP67A-12	25CP68A-12	12	.9549	1.074
25CF77A-13	25CP66A-13	25CP67A-13	25CP68A-13	13	1.0345	1.154
25CF77A-14	25CP66A-14	25CP67A-14	25CP68A-14	14	1.1140	1.234
25CF77A-15	25CP66A-15	25CP67A-15	25CP68A-15	15	1.1936	1.313
25CF77A-16	25CP66A-16	25CP67A-16	25CP68A-16	16	1.2732	1.393
25CF77A-18	25CP66A-18	25CP67A-18	25CP68A-18	18	1.4323	1.552
25CF77A-20	25CP66A-20	25CP67A-20	25CP68A-20	20	1.5915	1.711
25CF77A-24	25CP66A-24	25CP67A-24	25CP68A-24	24	1.9098	2.029
25CF77A-25	25CP66A-25	25CP67A-25	25CP68A-25	25	1.9894	2.109
25CF77A-28	25CP66A-28	25CP67A-28	25CP68A-28	28	2.2281	2.348
25CF77A-30	25CP66A-30	25CP67A-30	25CP68A-30	30	2.3873	2.507
25CF77A-36	25CP66A-36	25CP67A-36	25CP68A-36	36	2.8647	2.984
25CF77A-40	25CP66A-40	25CP67A-40	25CP68A-40	40	3.1830	3.303
25CF77A-48	25CP66A-48	25CP67A-48	25CP68A-48	48	3.8197	3.939
25CF77A-60	25CP66A-60	25CP67A-60	25CP68A-60	60	4.7746	4.894
25CF77A-72	25CP66A-72	25CP67A-72	25CP68A-72	72	5.7295	5.849

▲ Sprockets .750 and smaller are recommended for idler use only.