2023 Bearcat Baja Front Drivetrain

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By

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ABSTRACT

Several options were researched when creating a four wheel drive system on a low speed vehicle. These include a traditional system that utilizes a driveshaft and differential, a hydraulically driven system that utilizes a pump that powers two motors, one on each wheel, and a hydraulically driven system that utilizes a pump with a differential and a single motor. The hydraulically driven system that included two pumps was chosen as the 4WD system. Calculations were performed to prove the system's viability.

INTRODUCTION

The Baja Society of Automotive Engineers (Baja SAE) objective is to challenge collegiate groups to build an off-road vehicle that will endure rough terrain, obstacles, and water. The goal is to design, build, and test a prototype with the intention to meet mass production requirements for the intended sale to nonprofessional enthusiasts.

MAIN SECTION

PROBLEM STATEMENT - Design a 4WD that operates from a restricted 10 hp Kohler engine to power the front wheels of a Baja SAE compliant vehicle. This design must be easy to acquire or manufacture parts, maintain ground clearance without alteration of other sub-systems, ensure reliability, meet SAE rules, ensure safety of the driver and surroundings.

SAE RULES AND GUIDELINES - The competition has implemented rules to ensure safety of the drivers and fair competition. The rules listed below were considered during the design and build process of this system.

B.2.6.1 - Hydraulic

Hydraulic accumulators are the only type of stored energy device that may be incorporated into the vehicle for propulsion purposes. Hydraulic power systems must be properly shielded and documentation of the shielding made available for review. Teams shall provide a hydraulic power specification sheet at the time of technical inspection. The hydraulic power specification sheet is available at BajaSAE.net

B.9.2.2.3 - Hydraulic Systems

Hydraulic systems shall protect against hazardous release of energy. Hydraulic hoses shall have jacketing that meets HYDRAULIC SPEC. Hydraulic relief valves shall safely vent to the tank and away from people. Any hydraulic hoses running through the cockpit to the front axle shall be protected from damage by a driver entering or exiting the vehicle. Protection shall be made by a sturdy, robust cover. Note that hydraulic systems shall meet the requirements of B.2.6.1 - Hydraulic.

B.9.2.2.4 - Axle Shafts

Axle shafts and associated CV or universal joints forward of the firewall directly connecting the front wheels/uprights to the front differential do not require specific guarding for track workers and bystanders, but shall be separated from the driver and cockpit by way of methods meeting requirements of B.8.5 - Panels and B.8.6 - Skid Plate.

OPERATION

This system utilizes a shaft coming off of the gearbox to power a hydraulic pump as shown in **Figure 1**. The pump then pushes fluid through two ball valves that control the 2WD and 4WD system. From the valves, the fluid splits to both motors to power the front wheels. Before returning to the reservoir, the fluid passes through a 10 hp heat exchanger to prevent overheating in the system. This system is illustrated in **Figure 2** where the green lines represent flow out and the red indicates returning flow and yellow is the change while in the 2WD configuration.

Figure 1

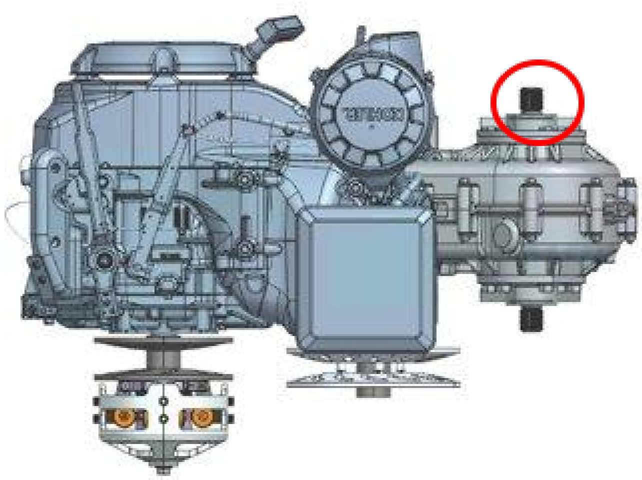
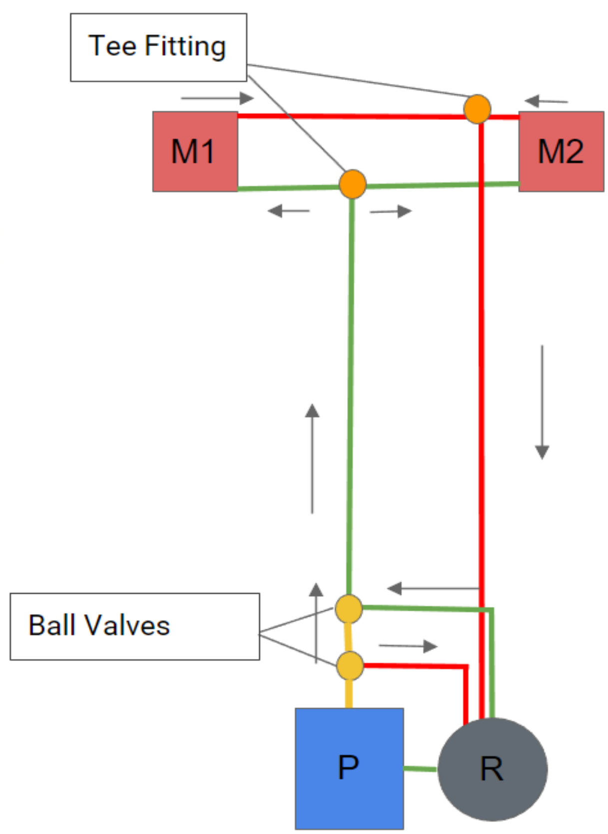


Figure 2



DESIGN GOALS

The goal of this system is to rotate a 24 inch diameter wheel while maintaining ground clearance, ensure there are not any frame alterations to accommodate the system, and pass inspection at competition.

ASSUMPTIONS

A list of assumptions were created to have a baseline to begin calculations to ensure the hydraulic system will meet the requirements of the vehicle.

- Top speed of 30 mph
- Engine has 10 hp and power to be distributed evenly between front and rear wheels
- 4.75 hp is estimated with efficiency losses to go to the front wheels
- Gearbox shaft rotates at a 3.75:1 ratio with the rear wheels
- Reservoir size cannot be over 2 gallons due to size
- Reservoir to be placed near the gearbox

RESEARCH AND CALCULATIONS

After conducting research, the first step was to calculate how fast the wheels are turning then to use the ratio established above, found by lifting the vehicle off the ground and rotating the rear wheels, to find the final shaft rpm at full speed.

$$Vehicle\ Speed\ =\ (Wheel\ RPM\ x\ Tire\ Diameter\ x\ \pi\ x\ 60)\ /\ 63,360$$
$$30\ =\ (Wheel\ RPM\ x\ 24\ x\ \pi\ x\ 60)\ /\ 63,360$$
$$Wheel\ RPM\ =\ 420.38\ RPM\ @\ 30\ mph$$

$$Shaft\ RPM\ =\ Wheel\ RPM\ x\ Shaft\ to\ Wheel\ Ratio$$
$$Shaft\ RPM\ =\ 420.38\ x\ 3.75$$
$$Shaft\ RPM\ =\ 1,576.425\ RPM\ @\ 30\ mph$$

PUMP- One way to reduce fluid movement due to the small reservoir size is to use a pump with lower displacement. The pump selected has a displacement of 0.61 Cu.in / rev. To find the GPM of a pump the equation below was utilized.

$$GPM\ Pump\ =\ (Displacement\ x\ Max\ Rpm)\ /\ 231$$
$$GPM\ Pump\ =\ (0.61\ cu.in/rev\ x\ 1,576.425\ RPM)\ /\ 231$$
$$GPM\ Pump\ =\ 4.16\ GPM\ @\ 30\ mph$$

MOTOR- To ensure the reservoir does not run dry, the motor must have an equal or higher GPM to send fluid back to the reservoir. Using the same equation, the motor GPM is calculated. A motor with a displacement of 1.159 cu.in / rev with the wheel RPM is used.

$$GPM\ Motor = (Displacement\ x\ Max\ Rpm)\ /\ 231$$
$$GPM\ Motor = (1.159\ cu.in/rev\ x\ 420.38\ RPM)\ /\ 231$$
$$GPM\ Motor = 2.109\ GPM\ @\ 30\ mph\ per\ motor$$

The pump and motors used were purchased from Northern Tool and took only a few days to receive. They were selected based on displacement, GPM, and they are both bi-rotational. The motor has larger input and output ports and will require an additional fitting to be reduced in size to match the pump and valves.

POWER- Using the estimated horsepower from the gearbox, GPM and Pump efficiency, output pressure can be found. This pressure is then used as the input pressure for each motor.

$$HP = (PSI\ x\ GPM)\ /\ (1714\ x\ \%\ Pump\ Efficiency)$$

Solve for PSI

$$Torque = (PSI\ x\ Pump\ Displacement)\ /\ (6.28\ x\ 2\pi)$$

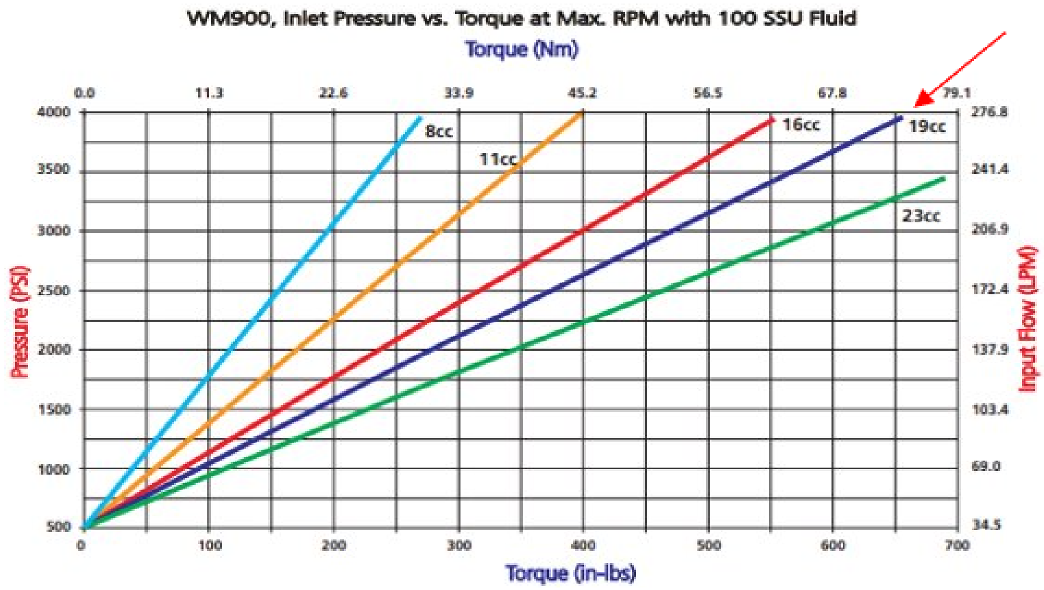
Pump Input Horsepower:

4.75 HP (Power) = [1663.5 PSI (Pressure) X 4.16 GPM (Flow)] / [1714 X 85 % (Pump Efficiency)]

Torque[1]:

161.53 lb-in (Torque) = [1663. PSI (Pressure) X .61 cu.in. / rev. (Displacement)] / 6.28 (2π)

Using the chart below, that was provided by the motor manufacturer, the input pressure found above can be used to find the output Torque of each motor.



The output torque of the motors can be estimated to be about 15.83 ft-lbs of torque.

HEAT- Heat needs to be considered when working with hydraulics, as too much heat will cause premature wearing of all components as the oil itself will break down. Below is the equation to calculate the heat. Most heat exchangers use HP as the unit of measurement so conversions will need to be made.

Pump Heat Generation:

$$BTU/hr = 1.5\ x\ psi\ x\ gpm$$
$$BTU/hr = 1.5\ x\ 1663.5\ psi\ x\ 4.16\ gpm$$
$$BTU/hr = 10,337.12$$
$$Watts = 3,041.198$$
$$HP = 4.078$$

Given that the motors return to the reservoir and no pressure is built, very little heat is generated from them. A 10HP heat exchanger was selected from Grainger to meet the hydraulic systems needs and it allows for a large factory of safety.

FLUID IN SYSTEM- Determine how much fluid is needed in the system, to fill all of the lines and not including the reservoir use the volume of a cylinder then convert to gallons.

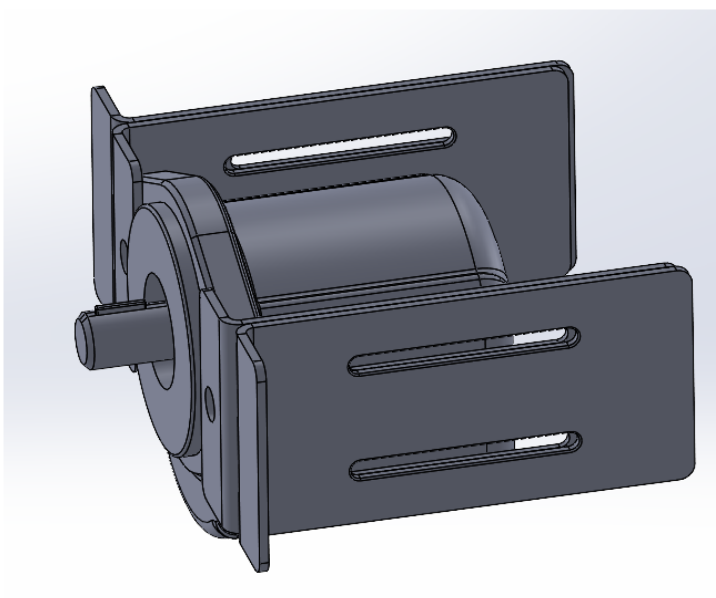
$Volume\ of\ Cylinder\ =\ \pi\ x\ r^2\ x\ height$, *Height is the length of the hose.*

$V\ =\ 254.46in^3$

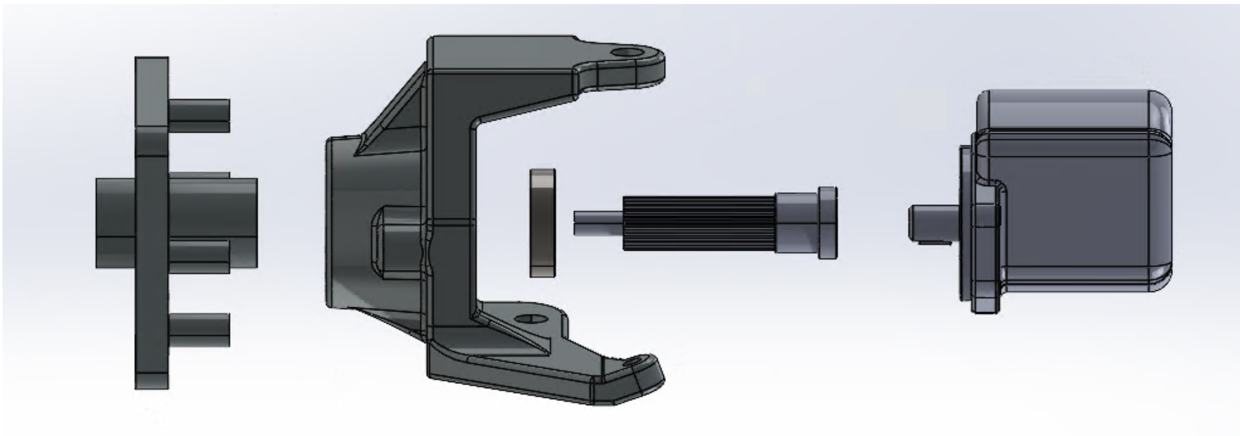
$V\ =\ 1.019\ gallons\ of\ fluid\ needed\ to\ fill\ hoses$

MOUNTING

MOUNTING OF PUMP- The pump has a keyed shaft that will need to join the keyed shaft on the gearbox. There are three ways to do this, a custom coupling, a keyway to keyway coupling, or a love joy coupling. The lovejoy coupling was selected because of its ease to connect and disconnect and did not require machine time to manufacture. The pump also needs to be supported onto the frame, for ease of maintenance a slotted guided bracket was made using the plasma cutter then bent to allow for a larger surface to be welded onto the frame as shown below. This slotted bracket will allow one to loosen four bolts and pull the pump away from the frame allowing for access to the gearbox



MOUNTING OF MOTORS- When mounting motors directly to the uprights, custom uprights need to be made and bearings are needed to allow for the rotation of the shafts. The motors attach to the uprights through two bolts while the shaft is held inside by a bearing as seen below. The shaft then holds all of the components together with a nut on the end just past the hub.



The main issue with mounting directly to the upright is the difficulty of manufacturing in the upright as it is machined down from a large aluminum billet to maintain strength. The uprights went through a total of 9 revisions to ensure fitment of the hydraulics, break lines and other surrounding steering components.

COST SUMMARY

UC Bearcat BAJA Cost Summary			
PART:	QUANTITY:	PRICE:	TOTAL:
55" Hose lines	2	$76.12	152.24
55" Hose lines	1	$42.24	42.24
12" Hose lines	4	$24.03	96.12
12" Hose lines	2	$24.83	49.66
3-way Valve	2	$55	110
Female Tee Fitting	2	$20	40
Female Tee Fitting	1	$20	20
Motor	2	$440	$880
Motor Coupling	2	$20	40
Pump	1	$277	277
Pump Coupling	1	$25.21	25.21
Bearing	2	$40	80
Shaft	2	$30	60
Pump Mount	1	$15	15
Bolts (Coupling to Shaft)	6	$2	12
Hydraulic Fluid (Gal Bottle)	1	$60	60
Steel Reservoir	1	$150	150
Reservoir Mounts	1	$15	15
Heat Exchanger	1	$277	$277
		TOTAL	2401.47

DESIGN ALTERATIONS

Throughout the year the design has changed numerous times to improve a variety of requirements. The changes are listed below:

- 9 total revisions of the upright to ensure clearance with surrounding parts, improve manufacturability and to fit the correct bearing.
- The coupling went through 4 total revisions, these changed the shape, improved manufacturability and increased the strength.
- Hydraulic layout had numerous changes starting with the type of valves used and the number of them, addition of a heat exchanger, and the routing of the hoses.
- Changed the pump to improve performance and to utilize the same vendor as the motor.
- Selected an alternate bearing to increase safety factor.
- Switched from a keyed coupling for the pump to the gearbox to a lovejoy coupling for ease of maintenance.
- Increased heat dissipation rating of the heat exchanger from 8hp to 10hp to increase the factor of safety.
- 3 revisions for the pump brackets to improve functionality and increase the weld lengths on the frame
- Hose sizes changed to match new inlet ports of pump and motors

CONCLUSIONS

A hydraulically driven 4WD system does work for a Baja vehicle but comes with a much more complex solution than your traditional drive shaft and differential combination. In future years if hydraulics are chosen to power the front wheels, my recommendation is to utilize a singular motor to power a differential as the uprights can then be purchased rather than manufactured. The benefits to moving to a singular pump are:

- Less heat due to lower GPM
- Less hydraulic lines are needed
- Fewer fittings
- More cost effective
- Increased power to weight ratio
- Reduction in manufactured parts

LESSONS LEARNED

Project requirements that worked:

- Hydraulics can be a viable solution when trying to power the front wheels.
- Creating deadlines at the beginning of the year, this allowed the team to stay on track
- The lovejoy connection is the most ideal way of connecting two keyed shafts
- Including a heat exchanger, even if it is not needed for the time the car is driven, it will help keep parts at an optimal temperature.
- Keeping most parts easy to manufacture, the bracket and coupling took two day each to manufacture in house
- When using the lathe for the coupling, machining one side completely before removing the material and changing sides allowed for tighter tolerances and increased machine time

Project requirements that did not work:

- Custom uprights, three manufacturers were not able to complete the job due to time restraints
- Including two motors on the system, this lead to a series of challenges from heat to routing of hoses, cost, gathering the correct information to utilize when designing the system, and matching motors to the pump

In order to get a car to competition, decrease the amount of manufactured parts, use a system that is easy to research and has plenty of information to learn from. Use common parts wherever possible, this will decrease lead times and allow for easy replacement. Develop a simplistic solution to the problem.

REFERENCES

Womack Machine:
https://www.womackmachine.com/engineering-toolbox/formulas-and-calculations/heat-calculations/

https://www.womackmachine.com/engineering-toolbox/formulas-and-calculations/hydraulic-pump-calculations/

Metal tanks:
http://www.metaltanks.com/hydraulic-reservoir-guide

Omni Calculator:
https://www.omnicalculator.com/everyday-life/rpm

PART INFORMATION

PUMP

- Displacement Cubic In.: .61
- Maximum Flow at 1,800 RPM: 4.72 GPM
- Maximum Flow at 3,600 RPM: 9.44 GPM
- Maximum RPM at 4,000 PSI: 3,600
- Outlet: 7/8in.-14
- Rotation: CCW

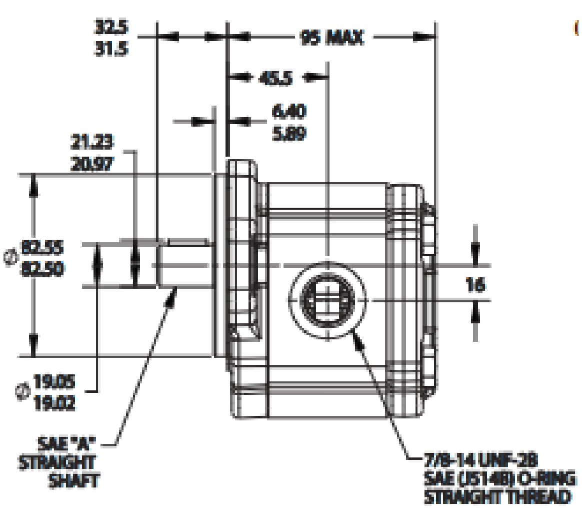
MOTOR NO. 1821215

W900 SERIES DISTRIBUTOR STOCK MOTORS								
Stock No.	Model Codes.	Displacement		Rotation	GPM @ 1800 RPM & 1000 PSI	GPM @ 3600 RPM & 1000 PSI	Max. Cont. PSI	Max. Speed, RPM
		C.I.R.	CC					
2-Bolt "A" Mount, 3/4" SAE "A" Straight Drive Shaft, and SAE Straight Thread Side Ports								
1821212	WM09A1C080B-03BA107N	0.488	8	Bi-Ro	3.73	7.45	4000	4000
1821213	WM09A1C111B-03BA107N	0.671	11	Bi-Ro	5.12	10.25	4000	3600
1821214	WM09A1C160B-03BA108N	0.976	16	Bi-Ro	7.45	14.91	4000	3000
1821215	WM09A1C190B-03BA108N	1.159	19	Bi-Ro	7.45	14.91	4000	3000
1821216	WM09A1C230B-03BA109N	1.403	23	Bi-Ro	10.71	21.43	3200	2800

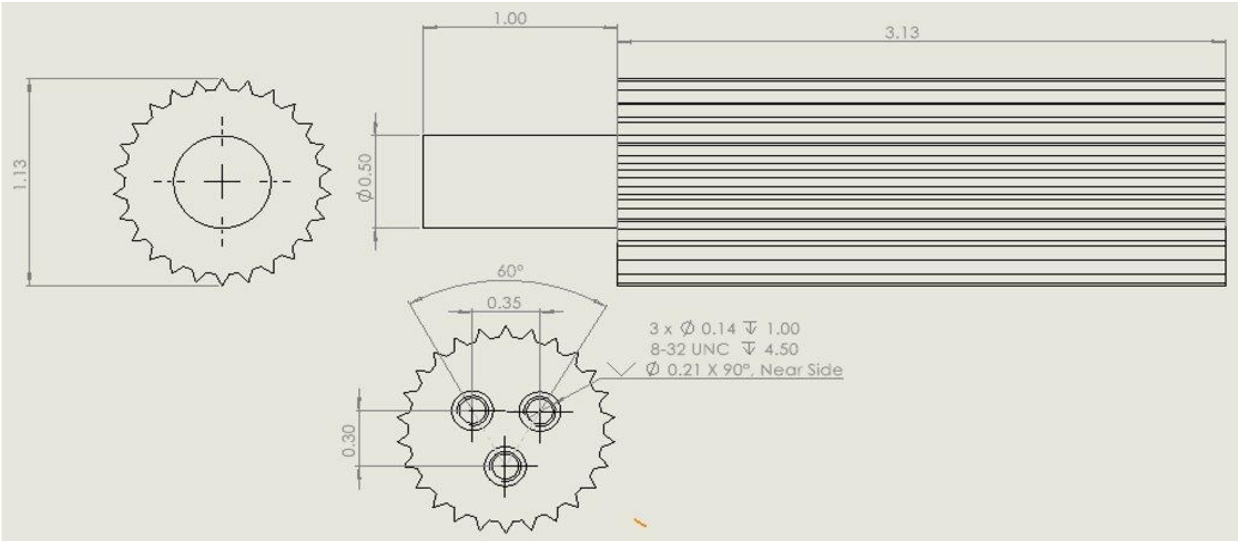
* Case drain must be used. See bottom of page 5.

MOTOR PORT SIZES

Inlet Port	Outlet Port	Case* Drain
7/8–14	7/8–14	7/16-20
7/8–14	7/8–14	7/16-20
1-1/16–12	1-1/16–12	7/16-20
1-1/16–12	1-1/16–12	7/16-20
1-5/16–12	1-5/16–12	7/16-20



SHAFT DIMENSIONS



COUPLING DIMENSIONS