PSI HEAVY-DUTY

21.9L

	Std	Metric	1500		1800	
	Rev:	C				
	Units		21.9L			
General Engine Data						
Type	N/A		V-type 4 cycle			
Number of cylinders	N/A		12			
Aspiration	N/A		Turbo Charge Air Cooled			
Bore	in	mm	5.04	128	5.04	128
Stroke	in	mm	5.59	142	5.59	142
Displacement	in^3	L	1338	21.9	1338	21.9
Compression Ratio	N/A		10.5			
Mean Piston Speed	ft/min	m/s	1398	7.1	1677	8.52
Gross Standby Power Rating[1,2,3] Per ISO 3046 at the Flywheel						
NG	Hp	kW	507	378	684	510
LP	Hp	kW	370	276	472	352
MEP (@ rated Load on NG)	psi	bar	200	13.8	225	15.5
MEP (@ rated Load on LP)	psi	bar	146	10.1	155	10.7
Gross Prime Power Rating[1,2,3] Per ISO 3046 at the Flywheel						
NG	Hp	kW	456	340	581	434
LP	Hp	kW	333	248	401	299
MEP (@ rated Load on NG)	psi	bar	180	12.4	191	13.2
MEP (@ rated Load on LP)	psi	bar	131	9.1	132	9.1
RPM Range (Min-Max)	RPM		1500-1800			
Rotation Viewed from Flywheel	N/A		Counter Clockwise			
Firing Order	N/A		1-12-5-8-3-10-6-7-2-11-4-9			
Dry Weight						
Fan to Flywheel	lb	kg	3638	1650	3638	1650
Rad to Flywheel	lb	kg	5238	2376	5238	2376
Wet Weight						
Fan to Flywheel	lb	kg	3813	1706	3813	1706
Rad to Flywheel	lb	kg	5760	2620	5760	2620
CG						
Distance from FW housing	in	mm	24	602	24	602
Distance above center of crankshaft	in	mm	7	182	7	182
Engine Mounting						
Maximum Allowable Bending Moment at Rear of Block	lb ft	N m	4425	6000	4425	6000
Moment of Inertia About Roll Axis	lb ft^2	kg m^2				
Flywheel housing	N/A		SAE No.1			
Flywheel	N/A		No. 14			
Number of Flywheel Teeth	N/A		160			
Exhaust System						
Type			Water Cooled Manifold			
Maximum allowable Back pressure	in HG	kPa	3	10.2	3	10.2
Standard Catalyst Back pressure	in HG	kPa	1.5	5.1	1.5	5.1
Exhaust Outlet Pipe Size						
Maximum Turbine Inlet Temperature	F	C	1382	750	1382	750
Exhaust Flow at Rated Power	lb/hr	kg/hr	3184	1444	4038	1832
Exhaust Flow at Rated Power @1350F	cfm	m^3/min	2427	68.7	2995	84.8
Air Induction System						
Maximum allowable Intake Air Restriction with Air Cleaner						
Clean	inH2O	kPa	5	1.24	5	1.24
Dirty	inH2O	kPa	15	3.74	15	3.74
Combustion Air required (entire engine)	lb/hr	kg/hr	3004	1362	3810	1728
Combustion Air required (entire engine)	cfm	m^3/min	763	22	968	27

PSI HEAVY-DUTY

21.9L

	Std	Metric	1500		1800	
Rev:	C					
	Units		21.9L			
	Std	Metric	1500		1800	
Electrical System						
Minimum Recommended Battery Capacity	AH		200			
Cold Cranking Current						
Engine only	CCA		1000			
Engine with Drive train	CCA		1000			
Maximum Allowable Resistance of Starting Circuit	Ohms		0.002			
Starting Motor Power	HP	kW	9.4	7	9.4	7
Battery Charging Alternator						
Voltage	Volts		24			
Current	Amps		45			
Coil primary Resistance	Ohms		0.59Ω ± 10%			
Spark Plug p/n			IFR7F-4D			
Spark plug gap	inches	mm	.015" (-0/+.008") .38mm (-0/+.2mm)			
Cooling System						
Coolant Capacity						
Engine only	gal	L	11.5	52.3	11.5	52.3
Engine with Radiator	gal	L	50.1	228	50.1	228
Engine Coolant Flow	gal/min	L/min	145	550	174	660
Water Pump Speed	RPM		2547		3056	
Heat rejected to Cooling water at rated Load	btu/min	kcal/sec	21451	90.1	25760	108.2
Maximum Intake Air Temperature (IAT)	F	C	155	68	155	68
ECU IAT Warning	F	C	140	60	140	60
ECU IAT Shutdown	F	C	155	69	155	69
Maximum Coolant Friction Head External to the engine	psi	bar	5.8	0.4	5.8	0.4
Maximum Air Restriction Across a Radiator	inH2O	mmH2O	0.5	12.8	0.5	12.8
Standard Thermostat Range						
Cracking Temperature	F	C	160	71	160	71
Full Open Temperature	F	C	185	85	185	85
Maximum Allowable Pressure Cap	psi	bar	14.7	1	14.7	1
Ambient Clearance Open Genset (water) (Air-to-Boil)						
Specified	F	C	142	61	142	61
Acutal	F	C			142	61
Ambient Clearance (Oil)						
Specified	F	C	142	61	142	61
Acutal	F	C			144	62
CAC Rise over Ambient (Charge)						
Specified	F	C	15	9	15	9
Acutal	F	C			11	6
Maximum Allowable Top Tank Temperature	F	C	230	110	230	110
ECU Warning	F	C	220	104	220	104
ECU Shutdown	F	C	230	110	230	110
Fan Power	HP	kW	24	17.9	42	31.3
Fan Diameter, including blades	in	mm	52	1321	52	1321
Fan Speed	RPM		1200		1440	
Cooling Fan Air Flow @ 1" Static H2O Pressure and 125F @ radiator	CFM	m^3/min	34,286	971	40,000	1,133
Charge Air Cooler						
Compressor Outlet Temperature	F	C	246	120	300	150
Compressor Flow Rate per CAC	lb/hr	kg/hr	1592	722	2019	916
Heat Rejection per CAC	btu/min	kW	TBD		3040	53.5

PSI HEAVY-DUTY

21.9L

	Std	Metric	21.9L 1500		21.9L 1800	
Rev:	C					
Lubrication System						
Oil Specification			SAE 15W-40 Low Ash Gas engine oil (.25-.5% by wt), API CD/CF or higher			
Oil Pressure						
Idle						
Min	Psi	Bar	13	0.9	13	0.9
Max	Psi	Bar	43.5	3	43.5	3
Rated Speed						
Min	Psi	Bar	43.5	3	43.5	3
Max	Psi	Bar	94.5	6.5	94.5	6.5
Maximum Allowable Oil Temperature	F	C	250	121	250	121
Engine Oil Capacity						
Min	Qts	L	34.75	33	34.75	33
Max	Qts	L	42.25	40	42.25	40
Oil Filter Capacity	Qts	L	7.5	7.1	7.5	7.1
ECU Oil Pressure Warning[5]	psi		30			
ECU Oil Pressure Shut Down[5]	psi		25			
Fuel System						
Fuel Consumption[6]						
NG	Ft^3/hr	kg/hr	3779	86	4230	96
LP	Ft^3/hr	kg/hr	1186	63	1408	75
Maximum EPR Rated Pressure	psi	kPa	1.0	6.9	1.0	6.9
Maximum Running pressure to Electronic Pressure Regulator (EPR)	inH2O	kPa	11.0	2.7	11.0	2.7
Minimum Running pressure to EPR	inH2O	kPa	7.0	1.7	7.0	1.7
Minimum Gas Supply Pipe Size			2 x 2" NPT			
Maximum EPR Rated Pressure	psi	kPa	1.0	6.9	1.0	6.9
Maximum Running Pressure to EPR	inH2O	kPa	11.0	2.7	11.0	2.7
Minimum Running Pressure to EPR	inH2O	kPa	7.0	1.7	7.0	1.7
Minimum LPG Supply Pipe Size[4]			2 x 2" NPT			

[1] Standby and overload ratings based on ISO3046.

[2] All ratings are gross flywheel horsepower corrected to 77°F at an altitude of 328feet with no cooling fan or alternator losses using heating value for NG of 1015 BTU/SCF.

[3] Production tolerances in engines and installed components can account for power variations of +/- 5%. Altitude, temperature and excessive exhaust and intake restrictions should be applied to power calculations.

[4] The preceeding pipe sizes are only suggestions and piping sizes may vary with temperature, pressure, distance from supply and application of local codes. Gas must be available at adequate volume and pressure for engine at the EPR.

[5] >1400RPM

[6] See PSI HD Technical Spec. 56300002 - Fuel Specification

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Emergency Standby Power Rating: Applicable for supplying emergency power for the duration of utility power outage. There is no overload capability for the emergency standby rating. Any use of the generator above the emergency standby rating is prohibited. Any unit operating in parallel with a public utility is not considered emergency standby. Emergency standby engine is applicable to a variable load with a maximum average load factor of 82% and 200 hours of operation per year. Emergency standby rating should only be applied in emergency power outages.

Prime Power rating: Applicable for supplying electrical power in lieu of commercially purchased power or providing guaranteed standby power. The prime power rating is applicable for variable loads with limited number of operating hours per year. The average power output shall not exceed 75% of the prime power rating. The total time at 100% Prime power shall not exceed 500 hours per year. A 110% overload rating is available one hour in every twelve hours with the total hours at 110% not to exceed 25 hours per year. Maximum number of hours per year is 2500.

Continuous Power Rating: The continuous power rating is applicable for variable loads with unlimited number of operating hours per year. The power output shall not exceed 75% of the prime power rating. There is no overload capability.

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PSI Heavy-Duty Technical Standard 56300001-A - Engine Oil Specification

PSI Heavy-Duty engines must use oils which meet the following standards:

SAE 15W-40 Low Ash Gas engine oil
API CD/CF or higher

Max oil temperature of 250F.

This specification applies to all PSI Heavy-Duty models including: D081L, D111L, D146L, D183L and D219L.

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PSI Heavy-Duty Technical Standard 56300002B – PSI Heavy-Duty Fuel Standard

PSI Heavy-Duty engines are designed and certified on commercially available pipeline quality gas. This standard is intended to further define pipeline quality gas.

		Natural Gas			Propane		
Fuel Constituent		**Low**	**High**	**Average**	**Low**	**High**	**Average**
Methane	CH_4	92	94.5	93.25	0	1.23	0.615
Ethane	C_2H_6	1	4.5	2.75	2.22	10.12	6.17
Propylene	C_3H_6			0			0
Propane	C_3H_8	0.09	0.44	0.265	87.68	96.7	92.19
i-Butane	C_4H_{10}	0	0.06	0.03	0.56	1.87	1.215
n-Butane	C_4H_{10}	0	0.12	0.06	0.04	1.28	0.66
i-Pentane	C_5H_{12}	0	0.02	0.01	0	0	0
n-Pentane	C_5H_{12}	0	0.01	0.005	0	0	0
Hexane+	C_6H_{14}	0	0.02	0.01	0	0	0
n-Heptane	C_7H_{16}						
n-Octane	C_8H_{18}						
n-Nonane	C_9H_{20}						
n-Decane	$C_{10}H_{22}$						
Hydrogen Sulfide	H_2S						
Carbon Dioxide	CO_2	0.05	0.25	0.15	0.11	0.01	0.06
Nitrogen	N_2	1.5	1.5	1.5	0.76	0.17	0.465
Oxygen	O_2						
Water (gas)	H_2O						
Specific Gravity ($S_g=M_{gas}/M_{air}$ where M_{air}=28.964g/mol)		0.537	0.600	0.568	1.379	1.649	1.514
Wobbe index (Iw=HHV/sqrt(Sg) where HHV =BTU/SCF)		**1295**	**1359**	**1328**	**1930**	**2125**	**2030**
Wobbe index (MJ/Sm3 1000Btu/scf=37.3MJ/Sm3)		**47.92**	**50.28**	**49.12**	**71.40**	**78.61**	**75.09**
LHV (Btu/cubic ft.)		857	952	904	2116	2563	2338
HHV (Btu/cubic ft.)		949	1053	1001	2266	2728	2497

If the gas is not commercially available pipe line quality gas that meets the above specification, it is the end user's responsibility to understand and comply with the certification regulations.

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PSI Heavy-Duty Technical Standard 56300000B - Engine Rating Guidelines

All PSI Heavy-Duty engines are rated following the standards found in ISO 3046-1:2002 for gross power. When ambient conditions do not meet standard temperature, pressure and humidity the standard provides a set of equations to adjust power to ambient conditions. For turbo CAC engines the equations used for power adjustment take into account ambient temperature, pressure, charge temperature and relative humidity. For NA engine charge temperature is eliminated.

All PSI Heavy-Duty engines carry a rating tolerance of +/-5%.

When gross engine power is used to match an engine to equipment it is important to correct the power for typical engine losses. Because of the complexity of the equations used to calculate ISO power adjustments the approximations are provide for customer's convenience. If power is critical and on the bubble OEM should test complete system to guarantee performance.

Net Power = Gross Power* – Parasitic Losses – Ambient corrections – Induction losses

Net Power is the usable power generated at the flywheel of the engine after all engine parasitic losses and ambient derates are removed. This does not account for OE equipment losses such as electrical losses for generators or hydraulic losses on pump applications.

Parasitic Losses are losses taken off for the accessories required to run and cool the engine under normal conditions and can include battery charging alternator, engine driven water pump and cooling fan.

Ambient corrections are losses taken because PSI Heavy-Duty power ratings are corrected to a standard temperature of 77°F inlet air temperature and an altitude of 1200 feet above sea level. Temperatures and altitudes greater than this standard must be accounted for as follows:

- A derate of -1.5% for every 10°F over 77°F air inlet temperature must be applied.
- A derate of -2.5% for every 1000 feet above 1200 ft above sea level must be applied.

Induction Losses in the engine are caused by excessive restriction on either the intake or exhaust system. Intake losses of up to 6" on the intake side and 3 inches Hg on the exhaust side do not need to be removed from the gross power. Losses greater than this will have to be accounted for in Net power calculations as follows:

- A derate of -4% must be applied for every 3.4kPa (13 in of H_2O) air inlet restriction over 6 inches H_2O.
- A derate of 1% must be applied for every 1 in of Hg increase in exhaust restriction over 3 inches of Hg.

* Gross power assumes that fuel quality meet specifications outlined in 56300002.

Purpose: To calculate Safety Factors and Allowable Torsional Stress in a generator shaft based upon the material properties and the nature of the the loading (e.g. cyclic loading, completely reversed).

Shaft P/N:	42222806
EMI:	G472138
Frame:	LSA47.2L9
Inputs	Outputs

Material Data:

UTS = 82 ksi Yield = 45 ksi

USS =.8*UTS = 65.6 ksi SYS = .577*Yield = 25.97 ksi

Fatigue Strength: $S_{n'}$ = 0.5 UTS (steel)

Load Factor C_L = 0.577 (torsion)

$$k_c = \begin{cases} 0.923 & \text{axial loading} \quad S_{ut} \le 220 \text{ kpsi (1520 MPa)} \\ 1 & \text{axial loading} \quad S_{ut} > 220 \text{ kpsi (1520 MPa)} \\ 1 & \text{bending} \\ 0.577 & \text{torsion and shear} \end{cases}$$

Size Factor C_G = 0.75 (greater than 2" diameter in torsion)

$$k_b = \begin{cases} \left(\frac{d}{0.3}\right)^{-0.1133} \text{ in} & 0.11 \le d \le 2 \text{ in} \\ \left(\frac{d}{7.62}\right)^{-0.1133} \text{ mm} & 2.79 \le d \le 51 \text{ mm} \end{cases}$$

For larger sizes, k_b varies from 0.60 to 0.75 for bending and torsion. For axial loading there is no size effect. Therefore, use

$k_b = 1$

Surface Factor C_S = 0.839852643 (mach. surface) a = 2.7 b = -0.265

SURFACE FINISH	FACTOR *a* kpsi	FACTOR *a* MPa	EXPONENT *b*
Ground	1.34	1.58	−0.085
Machined or cold-drawn	2.70	4.51	−0.265
Hot-rolled	14.4	57.7	−0.718
As forged	39.9	272.	−0.995

$S_n = S_{n'} C_L C_G C_S$ = 14.901 ksi

Gen. Torque Calculation:

RPM= 1800

Efficiency= 0.946

KW= 510

$$T = \frac{7043.3 \cdot KW}{RPM \cdot Efficiency}$$ = 2109.5155 ft-lbs, 25314.186 in-lbs

Torque Conversion	
9400.0	N-m
6927.8	ft-lbs
83133.6	in-lbs

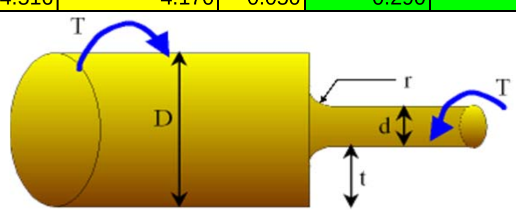
Stress Concentration Factors:

D	d	Under-cut Radius	t	K_q	K_p	K_t
4.516	4.170	0.050	0.290	2.198	4.679	2.025

$$K_t = \frac{1}{\sqrt{\left(\frac{1}{0.263 \cdot K_p}\right)^2 + \left(\frac{1}{0.843 \cdot K_q}\right)^2}} + 1$$

$$K_p = \sqrt{\frac{t}{r} \cdot \frac{\frac{d}{D}}{\left(1 - \frac{d}{D}\right)} + 1} - 1$$

$$K_q = \frac{1}{\sqrt{\frac{r}{t}}}$$



q = 0.9 (notch sensitivity)

K_f = 1.922639859 (fatigue stress concentration factor)

Gen. Nominal Torsional Stress:

r = 2.08505 in (radius under each step)

$J = \pi (2r)^4/32$ = 29.688 in^4

$$t_m = \frac{T \cdot r}{J}$$ = 1.778 ksi

$K_f \cdot t_m$ = 3.42 ksi

Engine Manufacturer:

Engine Manufacturer Stress:

T_e = 55884 in-lbs (Vibratory torque from torsional analysis of engine manufacturer)

$$t_a = \frac{T_e \cdot r}{J}$$ = 3.925 ksi

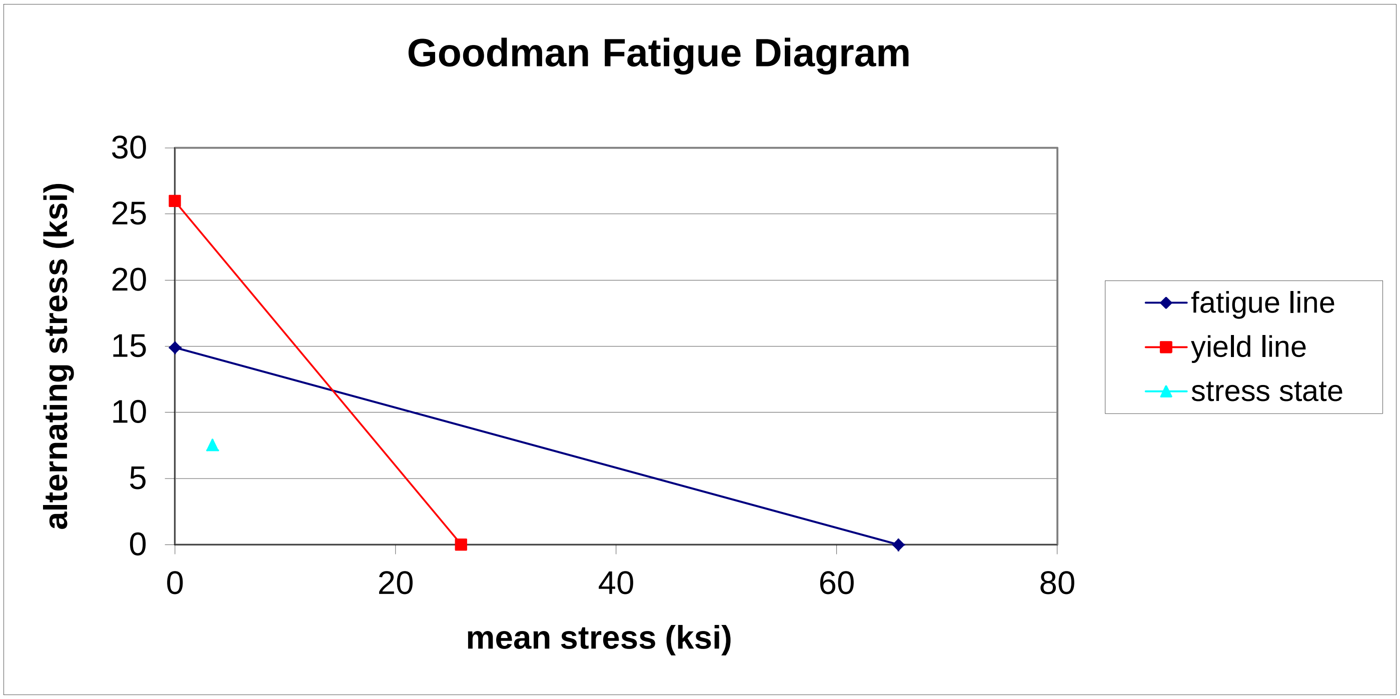
$K_f \cdot t_a$ = 7.55 ksi

Safety Factor:

$R = K_f t_m / K_f t_a$ = 0.453

$$SF = \frac{S_n \, USS}{K_f t_a (S_n R + USS)}$$ = 1.790

(A minimum Safety Factor of 2 is recommended.)



Conclusion: The Safety Factor falls just short of the recommended min. of 2. However, the Goodman Diagram shows the stress level well below both the yield and fatigue line for infinite life. The shaft is approved for use in this application.

Analysis Completed by: Billy Todd

Date: 1/12/17