18 Pages (Including Cover Page)

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2

Calculation RNP-M/MECH-1815, Revision 1

SYSTEM# 5095
CALC. SUB-TYPE MC
PRIORITY CODE NA
QUALITY CLASS A

NUCLEAR GENERATION GROUP

RNP-M/MECH-1815
(Calculation #)

EVALUATION OF EMERGENCY DIESEL GENERATOR STARTING CAPABILITY AT 150 PSIG
(Title including structures, systems, components)

☐ BNP UNIT ____

☐ CR3 ☐ HNP ☒ RNP ☐ NCP ☐ ALL

APPROVAL ☒ Electronically Approved

REV	PREPARED BY	REVIEWED BY	SUPERVISOR
0	Signature Signed Electronically Name Date	Signature Signed Electronically Name Date	Signature Signed Electronically Name Date
1	Signature Signed Electronically Name Date	Signature Signed Electronically Name Date	Signature Signed Electronically Name Date

(For Vendor Calculations)

Vendor N/A Vendor Document No. N/A

Owner's Review By N/A Date N/A

LIST OF EFFECTIVE PAGES

PAGE	REV	PAGE	REV	ATTACHMENTS		
				Number	Rev	Number of Pages
i	1					
ii	1					
iii	1					
1	0					
2	0					
3	0			1	1	4
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6	0					
7	0					
				AMENDMENTS		
				Letter	Rev	Number of Pages
				None		

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Rev. #	Revision Summary (list ECs incorporated)
0	Initial Revision
1	Corrected Reference 14 to Reference 11 on Attachment 1 Page 1 of 4. Added Attachment 3 – Design Verification Form for Rev. 1.

PURPOSE

Reference 1 provides the following request:

> "Provide an analysis or calculation to justify the Fairbanks Morse recommendation that a minimum air pressure of 150 psig in the air start receiver will ensure a reliable start for each Robinson EDG."

This request was in response to information provided in Reference 2.

REFERENCES

1. NRC Letter RRA-12-0005, H.B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO.2 -REQUEST FOR ADDITIONAL INFORMATION RELATED TO REQUEST FOR TECHNICAL SPECIFICATIONS CHANGES TO SECTION 3.8.3, DIESEL FUEL OIL AND STARTING AIR, AND SECTION 3.8.5, DC SOURCES· SHUTDOWN (TAC NO. ME5408), January 24, 2012.
2. Progress Energy Letter, REQUEST FOR TECHNICAL SPECIFICATIONS CHANGES TO SECTION 3.8.3, DIESEL FUEL OIL AND STARTING AIR, AND SECTION 3.8.5, DC SOURCES - SHUTDOWN (ADAMS Accession No. ML110310012) January 20, 2011.
3. Vendor Technical Manual VTMA 729-063-16, FAIRBANKS MORSE POWER SYSTEMS PRODUCTS, Rev. 76.
4. Diesel Engine Engineering, Thermodynamics, Design, and Control, Andrei Makartchouk, 2002 Marcel Dekker.
5. RNP UFSAR Section 8.3.1, AC Power Systems.
6. Design Basis Document Emergency Diesel Generator System Document No. DBD/R87038/SD05, Rev. 10.
7. RNP Calculation 87-17, Rev. 0, DG AIR START SYSTEM.
8. Introduction to Chemical Engineering Thermodynamics, Smith and Van Ness, McGraw Hill, Third Edition, 1975.
9. Fairbanks Morse Publication E3440-1, August 1979.
10. Fairbanks Morse Publication E1102-1, August 1979.
11. Pre-Operational Tests of Emergency Diesel Generator Robinson File No. PO-35.
12. Matheson Gas Data Book, seventh edition, 2001.
13. Mark's Standard Handbook for Mechanical Engineer's, Eighth Edition.
14. RNP Technical Specifications 3.8.1, AC Sources - Operating.

BODY OF CALCULATION

Diesel Generator Set

Onsite emergency power is available from two emergency diesel generator sets. Each diesel generator set consists of a Fairbanks-Morse Model 38TD8-1/8 engine coupled to a Fairbanks-Morse generator. The emergency diesels are automatically started by injecting compressed air into the cylinders. Each engine has compressed air storage sufficient for 8 cold diesel engine starts. However, the diesel engine will only consume enough air for one of these eight cold starts upon receiving an automatic start signal. This is due to the engine control system which is designed to stop cranking within 10 sec. To ensure rapid start, each unit is equipped with heaters and pumps for circulation of lube oil and jacket water when the unit is not running (Ref. 5).

Lube Oil Subsystem

A motor-driven standby circulating pump circulates the oil through the lubricating oil heater and back to the engine sump to maintain the lube oil warm (130F minimum) to support rapid starting and loading. Lube oil used in the EDG lube oil Subsystem is controlled as a "Q-List consumable" or equivalent item. This guarantees that lube oil quality will not interfere with the safety-related function of the EDGS (Ref. 3 and 6).

Jacket Water Cooling Subsystem

This system, like the Lube Oil system, is used to maintain the diesel generators in a warm standby status. Jacket water is heated as needed (110F minimum) to facilitate fast engine starting. A motor driven standby pump circulates flow through an 18 KW heater (Ref. 3 and 6).

Diesel Starting (Ref. 4)

To start a diesel engine it is necessary to rotate its crankshaft at a speed such that the fuel oil that is injected into the cylinders during start mode can self-ignite. The forces of resistance that appear inside a diesel engine when the starting air rotates the crankshaft during startup are:

1. The forces of friction of reciprocating and rotating parts.
2. The forces of resistance to air and gas flow in the intake and exhaust systems.
3. The force of resistance of the auxiliary mechanisms mounted on the engine.

Prior to the engine starting the force of cylinder charge compression is approximately equal to the force of cylinder charge expansion. Therefore, the work of cylinder charge compression does not contribute to the work of the resistant forces. Additionally, the starting system must impart sufficient kinetic energy to the engine rotating mass to achieve engine start.

Vendor Recommendation

Fairbanks Morse (Ref. 9) states that reliable engine starting may be expected at starting air receiver pressures between 250 psig and 150 psig. The RNP EDG Fairbanks Morse Vendor manual states that air for the starting system is required at between 150 and 250 psig (Ref. 3, Pg. 446 of 1036). Fairbanks Morse (Ref. 10) states that the starting air receiver sizing basis is based on 45.0 ft3 of free air per start.

Historical Data

Reference 11 documents a special test run on the "B" EDG to evaluate a proposed engine lockout after a 20 second overcrank with a failure to start. In this test the ability to start is determined after a simulated failure to auto start of the EDG. The data below is the recorded data from Ref. 11; the data is further analyzed in Attachment 1.

Start #	Crank Time (sec)	Start Air Pressure (psig)	End Air Pressure (psig)
Did Not Start (1)	20	245	120
1 (2)	2	120	110
Notes: 1. Simulated failure to start. Fuel shut off for the 20 second over-crank. 2. Successful start.			

Evaluation of Historical Data versus Vendor Recommendation

The historical data tabulated above cannot be used directly to justify reliable starting of the Robinson EDG's at a minimum air pressure of 150 psig in the air start receiver. This is because the actual starting of the "B" EDG in the above test run occurred after a 20 second overcrank in which the EDG was not allowed to start. The differences between starting the EDG with a minimum air pressure of 150 psig in the air start receiver and after a 20 second overcrank in which the EDG was not allowed to start, will be examined.

The differences between starting the EDG with no prior start and the successful start after a 20 second overcrank are mainly due to differences in the static and dynamic coefficients of friction and differences in initial temperature of the EDG. Reference 13 discusses static and dynamic coefficients of friction and states that the coefficients of sliding (dynamic) friction are smaller than the coefficients of static friction. Comparing starting the EDG with a minimum air pressure of 150 psig in the air start receiver and starting the EDG after a 20 second overcrank, it should be noted that both starting regimes have a static component and a dynamic component because both starts occur from rest.

There is expected to be little difference in the dynamic coefficients of friction between the two starts because the engine was not fired during the 20 second overcrank period and very little engine heatup would have occurred. Therefore the main difference between the 150 psig start under consideration and the start after the 20 second overcrank, lies in the reduction of the static coefficient of friction caused by the 20 second overcrank. The effect of this difference is minimized because each EDG is operated monthly for at least 60 minutes per RNP technical Specification Surveillance Requirements (Ref. 14).

Ability to Do Work

To start the EDG, the starting air system must have the ability to do work. This work is divided between the work required to overcome the forces resisting the rotation of the engine and the kinetic energy imparted to the rotational mass.

Examining the historical data, the amount of work required to start the EDG can be determined, this is provided in Attachment 1.

Calculate Starting Air Receiver Stored Energy @150 psig

Fairbanks Morse recommends that 45.0 ft^3 of free air (Ref. 10) be available to start the engine. The amount of available energy 45.0 ft^3 of free air discharged from an initial air receiver pressure of 150 psig will be determined.

Given an initial receiver air pressure of 150 psig, determine the final receiver air pressure after a discharge of 45.0 ft^3:

$P_1V_1 = P_2 V_2$

P1 = air start receiver initial pressure (psia)

P1 = 150 psig

P1 = (14.7 + 150) (psia)

P1 = 164.7 (psia)

V1 = 34.0 ft3

P2 = air start receiver final pressure (psia)

P2 = 0.0 psig

P2 = (14.7 + 0.0) (psia)

P2 =14.7 (psia)

Determine V2:

$V2 = (P_1V_1)/ P_2$

V2 = [(164.7 psia)(34.0ft3)]/(14.7 psia)

V2 = 380.94 ft3

A discharge of 45.0 ft3 of free air would yield the following volume of free air left in the air receiver:

V2 = 380.94 ft3 - 45.0 ft3

V2 = 335.94 ft3

This is equivalent to the following pressure in the air receiver:

P3 = (P2V2)/V3

P3 = [(14.7 psia)(335.94 ft3)]/(34.0 ft3)

P3 = 145.25 psia

or

P3 = 130.55 psig

Thus after a 45.0 ft3 discharge the expected air receiver pressure would be greater than 130.0 psig.

Calculate the amount of stored energy represented by the above discharge of 45.0 ft3 of free air stored in the air receiver:

Because the engine starts quickly and there is little time for heat transfer, it is reasonable to use an adiabatic expansion from the air start receiver initial pressure to the final pressure, to calculate the amount of energy this represents.

From Ref. 8, Page 71:

$$W = \frac{P1V1}{\gamma - 1}\left[1 - \left(\frac{P2}{P1}\right)^{\frac{(\gamma-1)}{\gamma}}\right]$$

P1 = air start receiver initial pressure (psia)

P1 = 150 psig

P1 = (14.7 + 150) (psia)

P1 = 164.7 (psia)

P2 = air start receiver final pressure (psia)

P2 =145.25 (psia)

V1 = 34.0 ft3 (Ref. 7, Page 5)

γ = Ratio of Heat capacities Cp/Cv

γ = 1.33 (Ref. 12, Page 8)

$$W = \frac{(164.7\ \text{psia})(34.0\ \text{ft3})}{(0.33)}\left[1 - \left(\frac{(145.25\ \text{psia})}{(164.7\ \text{psia})}\right)^{\frac{(0.33)}{1.33}}\right](144\ \text{in2/ft2})$$

W	$= 7.50 \times 10^4$ ft lbf

From Attachment 1, Start #1 consumed the following amount of air receiver energy:

W	$= 3.80 \times 10^4$ ft lbf

Calculate ratio between work available at 150 psig and work expended for actual start at 120 psig:

Ratio $= 7.50 \times 10^4$ ft lbf / 3.80×10^4 ft lbf

Ratio = 1.97

CONCLUSION

By examining the historical startup data, the amount of stored energy in the air receiver expended to start the diesel engine at a 120 psig initial receiver air pressure can be determined. As demonstrated above, the amount of stored energy in the air receiver that is available at 150 psig to start the diesel engine is approximately twice the value expended at 120 psig to actually start the diesel during the historical test.

With all initial parameters the same, there would be expected to be differences in the amount of energy required to start a diesel engine at 150 psig with no prior starts and that required to start a diesel engine following a 20 second overcrank. These differences lie mainly in the breakaway frictional forces required to start the cylinders and crankshaft moving and the frictional forces from heat up of the engine represented by the 20 second overcrank.

The difference in breakaway frictional forces present after the overcrank and the breakaway frictional forces present with no prior cranking is considered to have a relatively small impact to engine starting forces. This is primarily due to the benefit of the engine keep warm system and monthly operation of the diesel in minimizing the difference in breakaway friction and to the fact that the engine was not started during the overcrank reducing the effect of engine heatup.

Given that the amount of stored energy in the air receiver that is available at 150 psig to start the diesel engine is approximately twice the value expended starting the engine from a lower air pressure of 120 psig during the historical startup, and that the differences in work required to start the engine are not expected to be 100 % more between the two examined starting conditions, there is sufficient air at a minimum air pressure of 150 psig in the air start receiver to ensure a reliable start for each Robinson EDG.

Document Type (e.g. CALC, DWG, TAG, PROCEDURE, SOFTWARE)	**ID Number** (e.g., Calc No., Dwg. No., Equip. Tag No., Procedure No., Software name and version)	**Function** (i.e. IN for design inputs or references; OUT for affected documents)	**Relationship to Calc.** (e.g. design input, assumption basis, reference, document affected by results)	**Action** (specify if Doc. Services or Config. Mgt. to Add, Deleted or Retain) (e.g., CM Add, DS Delete)
VTMA	729-063-16	IN	REFERENCE	CM ADD
DRAW	5379-01161	IN	REFERENCE	CM ADD
CALC	87-17	IN	REFERENCE	CM ADD

(For the purpose of creating cross references to documents in the Document Management System and equipment in the Equipment Data Base)

Analysis of Historical Data

Reference 11 discusses a test run on the "B" EDG to determine the ability to start after a simulated failure to auto start the EDG. During the simulated failure to auto start the engine was cranked for 20 seconds. The data in the first four columns is the recorded data from Ref. 11; the fifth and sixth columns are calculated in this Attachment:

20 Second Overcrank + 1 Engine Start					
Start #	Crank Time (sec)	Start Air Pressure (psig)	End Air Pressure (psig)	Volume of Free Air Consumed (ft3)	Air Receiver Expended Energy
Did Not Start (1)	20	245	120	n/a	n/a
1 (2)	2	120	110	23.13	38024.84
Notes: 1. Simulated failure to start. Fuel shut off for the 20 second over-crank. 2. Successful start.					

Calculate Volume of Free Air Consumed

Calculate Volume of Free Air Consumed used in the fifth column of the Table above:

Start #1

Since the beginning and ending air temperatures will be approximately equal, we can use:

$P_1V_1 = P_2 V_2$

Volume of Free Air Consumed	= Volume of Free Air @ Higher Pressure - Volume of Free Air @ Lower Pressure
Volume of Free Air @ Higher Pressure	= (PHigher VHigher)/14.7 psia
Volume of Free Air @ Higher Pressure	= [(120 + 14.7)psia 34 ft3]/14.7 psia
Volume of Free Air @ Higher Pressure	= 311.55 ft3
Volume of Free Air @ Lower Pressure	= (P Lower V Lower)/14.7 psia
Volume of Free Air @ Lower Pressure	= [(110 + 14.7)psia 34 ft3]/14.7 psia
Volume of Free Air @ Lower Pressure	= 288.42 ft3
Volume of Free Air Consumed	= 378.63 ft3 - 364.75.3 ft3
Volume of Free Air Consumed	= 23.13 ft3

Calculate Starting Air Receiver Stored Energy Expended

Because the engine starts quickly and there is little time for heat transfer, it is reasonable to use an adiabatic expansion from the air start receiver initial pressure to the final pressure for Start #1, to calculate amount of energy this represents.

From Ref. 8, Page 71:

W $\approx \frac{P1V1}{\gamma-1}\left[1-\left(\frac{P2}{P1}\right)^{\frac{(\gamma-1)}{\gamma}}\right]$

P1 ≈ air start receiver initial pressure (psia)

P1 ≈ 120 psig

P1 ≈ (14.7 + 120) (psia)

P1 ≈ 134.7 (psia)

P2 ≈ air start receiver final pressure (psia)

P2 ≈ 110 psig

P2 ≈ (14.7 + 110) (psia)

P2 ≈124.7 (psia)

V1 ≈ 34.0 ft3 (Ref. 7, Page 5)

γ ≈ Ratio of Heat capacities Cp/Cv

γ ≈ 1.33 (Ref. 12, Page 8)

$$W = \frac{(134.7\ \text{psia})(34.0\ \text{ft3})}{(0.33)}\left[1 - \left(\frac{(124.7\ \text{psia})}{(134.7\ \text{psia})}\right)^{\frac{(0.33)}{1.33}}\right](144\ \text{in2/ft2})$$

$$W = 3.80 \times 10^{4}\ \text{ft lbf}$$

ATTACHMENT 2
Sheet 1 of 1
Record of Lead Review

Document RNP-M/MECH-1815 **Revision 0**

The signature below of the Lead Reviewer records that:
- the review indicated below has been performed by the Lead Reviewer;
- appropriate reviews were performed and errors/deficiencies (for all reviews performed) have been resolved and these records are included in the design package;
- the review was performed in accordance with EGR-NGGC-0003.

☒ **Design Verification Review** ☐ **Engineering Review** ☐ **Owner's Review**
☒ Design Review
☐ Alternate Calculation
☐ Qualification Testing

☐ **Special Engineering Review**__________

☐ YES ☐ N/A **Other Records are attached.**

Don Phillips (signed electronically) mechanical 2/14/12
Lead Reviewer (print/sign) Discipline Date

Item No.	Deficiency	Resolution
1	The best argument that the engine will start is a test. Think a much better argument can be made using the 20 second no start cranking test results. There are 2 tests that show the engine will start cold with the starting air pressure less than that being evaluated. The only difference between the test and the condition of interest is the prior cranking without start. That should only make a difference in the static friction that needs to be overcome. Static friction does increase over time. Based on references, the difference between oiled steel static and dynamic friction is only the difference between 0.10 and 0.08. Considering the friction load is a small part of the overall load in cranking the engine, the change is small, and the engine was in fact stopped for a period of time before cranking, the affect on the engine would be very small.	Revised to include 20 second overcrank test.
2	The historical data section should include the 20 second no start tests.	Revised to include 20 second overcrank test.

FORM EGR-NGGC-0003-2-10
This form is a QA Record when completed and included with a completed design package. Owner's Reviews may be processed as stand alone QA records when Owner's Review is completed.

ATTACHMENT 2
Sheet 1 of 1
Record of Lead Review

Document RNP-M/MECH-1815 **Revision 1**

The signature below of the Lead Reviewer records that:
- the review indicated below has been performed by the Lead Reviewer;
- appropriate reviews were performed and errors/deficiencies (for all reviews performed) have been resolved and these records are included in the design package;
- the review was performed in accordance with EGR-NGGC-0003.

☒ **Design Verification Review** ☐ **Engineering Review** ☐ **Owner's Review**
- ☒ Design Review
- ☐ Alternate Calculation
- ☐ Qualification Testing

☐ **Special Engineering Review**______________________

☐ YES ☐ N/A **Other Records are attached.**

Dave Markle (signed electronically)	Mechanical	2/21/12
Lead Reviewer (print/sign)	**Discipline**	**Date**

Item No.	Deficiency	Resolution
1	None	NA

FORM EGR-NGGC-0003-2-10
This form is a QA Record when completed and included with a completed design package. Owner's Reviews may be processed as stand alone QA records when Owner's Review is completed.

5 Pages (Including Cover Page)

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2

References for Calculation RNP-M/MECH-1815, Revision 1

R. AIR START SYSTEM

General

The air starting system consists of the starting air piping and the engine starting mechanism.

Air for the starting system is required at between 150 and 250 psi (250 psi preferred) at the engine and is stored in suitable air tanks.

Engine starting is accomplished by the action of compressed air on the pistons in their proper firing order.

The engine starting mechanism includes the air start control valve, air start distributor, the air header, the pilot air tubing and the air start check valves at the individual cylinders, Illus. R1. The air start control valve and the distributor are amply lubricated by the splash of engine oil. The air start check valves receive lubricating oil with the air from the distributor.

NOTE: The distributor on the 6-9 cylinder engines is driven from the control end of the upper crankshaft. On 12 cylinder engines, the distributor is mounted opposite the governor drive on the pump mounting plate and is driven from the lower crankshaft.

Starting Mechanism

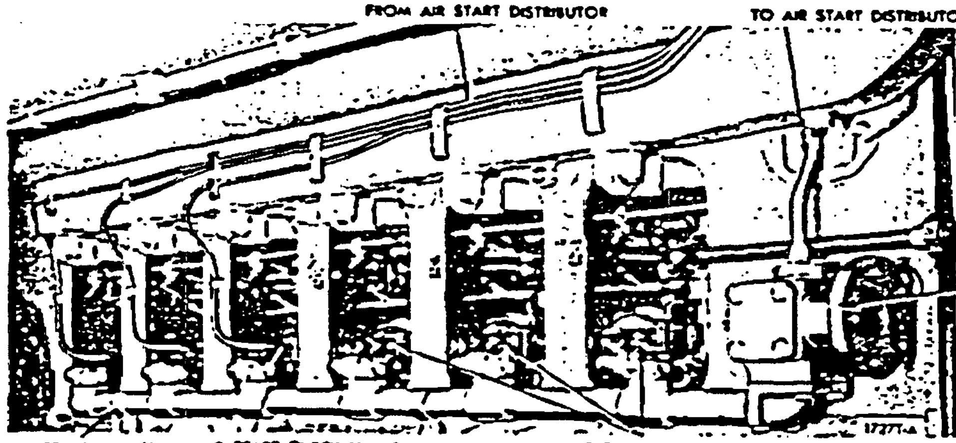
The air start control valve is mounted near the control or governor end of the engine on the side opposite the controls. When the control shaft lever is moved to "START" position, a lever linkage opens the air start control valve. This is explained and illustrated in Sec. J.

With the air start control valve open, compressed air passes into the header, Illus. R1, which leads to the individual cylinder air start check valves. Air also passes into the pilot air supply pipe connected to the air start distributor.

The air start distributor includes one pilot air valve for each air start check valve. The valves are arranged radially and in cylinder firing order around the air start distributor camshaft, Illus. R2. A spring holds each valve normally out of contact with the cam, as shown in Illus. R3. Air enters the distributor from the air start control valve, air pressure overcomes the spring tension and forces each valve plunger down into contact with the cam.

Regardless of where the camshaft stopped, one valve will be on the low point of the cam and will therefore be open, as shown in Illus. R4. Two other valves, one on each side of the open valve, will be partially open. Each of the pilot air valves, when open, admits air through a connecting tube, Illus. R1, to an air start check valve. The air, under pressure, opens the air start check valve. The actual starting air then rushes into the cylinder from the air header. The starting air forces the pistons apart and thus causes the crankshafts to rotate.

The air start distributor camshaft rotates with the upper crankshaft on 6-9 cylinder engines and with the lower crankshaft on 12 cylinder engines. The cam opens and closes the valves in sequence to the engine firing order. Soon the engine begins to fire. The control shaft lever should then be moved to "RUN" position. This actuates linkage on the control shaft which



Illus. R1. Air Start System - 6 Cyl. Engines

STARTING AIR SYSTEM
-- Stationary Engines

The basic starting air system is shown in Fig. 1. The air compressor charges the air tanks to nearly 250 psi, storing sufficient energy for several starts. On starting, air flows from the tanks to the engine where it is admitted into the cylinders with required timing to rapidly turn the engine (and attached generator or other driven equipment). Rate of air flow during starting is very high but it is of short duration (usually 3 or 4 seconds). Reliable starting may be expected at pressures between 250 and 150 psi.

A filter and 250/70 psi regulator is required as a 70 psi air source for the pneumatic remote shutdown system, which is controlled by a solenoid valve in the line. This source also supplies control air for dual fuel engine fuel/air ratio control and, on the turbocharged dual fuel engine, for control of switch-back to diesel on overspeed trip.

A 250/20 psi filter-regulator is required for the turbocharged dual fuel engine as a 20 psi source for the pneumatic air receiver temperature control in the air cooler water system.

If the engine has been ordered with a worm gear barring device (hand ratchet device is standard), a larger filter and 250/70 psi regulator will be required as a 70 psi air source for the portable air barring motor which is used with it.

If the engine is installed in an existing plant with adequate starting air pressure and tankage available and with piping essentially as shown in Fig. 1 so water does not get into the air line to the engine, the plant system may be used.

STARTING AIR STORAGE TANKS:
Required storage tank volume may be calculated by the formula:

$$V_T = \frac{P_A}{(P_H - P_L)} \times V_f \times N$$

V_T = Required total tank volume, cu. ft.

P_A = Atmospheric pressure, PSIA (14.7 nominally)

P_H = Highest pressure for starting, PSIG (245 PSIG)

P_L = Lowest pressure for starting, PSIG (150 PSIG)

V_f = Volume of free air required per start, cu. ft. (from Data Page E1102-2 for blower scavenged engines or E1102-11 for turbocharged engines)

N = Number of starts desired without recharging air tanks.

The number of starts to be expected from a given available tank volume may be calculated by transposed formula:

$$N = \frac{V_T \times (P_H - P_L)}{V_f \times P_A}$$

Standard FM air tanks are vertically mounted with a base ring to support the bottom head 6" off the foundation to allow for drain piping. Sizes are as follows:

FM No.	O.D. - In.	Length Over Heads - In.	Vol. - Cu. Ft.
16109954	30	84	31.7
16111127	30	96	36.2

Special tanks of different size or for horizontal mounting can be provided if required.

The volume of free air required per start given on Data Pages E1102-2 and E1102-11 is based on the engine being at keep-warm temperature and being directly connected to an average alternator. An initial start at lower temperature and/or with greater connected rotating mass may require as much as twice that volume of free air.

Examples (assuming keep-warm systems are ordered):

1. A 12-cylinder turbocharged engine is to be installed with a new starting air system. Ten starts are desired without recharging air tanks. How much air tankage is required?

   V_f = 45 cu. ft. (Pg. E1102-11) N = 10

   $$V_T = \frac{14.7}{(245-150)} \times 45 \times 10 = 69.7 \text{ cu. ft.}$$

   Two air tanks 30" OD x 96" OTH with a volume of 72.4 cu. ft. would meet the requirement.

2. A 12-cylinder turbocharged engine is to be installed in a plant with existing 35.7 cu. ft. air tankage. How many starts may be expected without recharging air tanks?

   $$N = \frac{35.7 \times (245-150)}{45 \times 14.7} = 5 \text{ starts}$$

GENERAL DATA — (cont.)
-- Turbocharged Diesel and Dual Fuel Engines
Applicable to Continuous Ratings

GENERAL DATA			
Number of Cylinders	6	9	12
Bore and stroke — inches	8-1/8x10	8-1/8x10	8-1/8x10
Compression Ratio (Total swept volume)	13.8	13.8	13.8
Hot Engine Compression at Rated Speed — max. variation between cylinders — psi	50	50	50
Firing Pressure (approx.) — maximum psi	1340	1340	1340
Total Piston Displacement — cu. in.	6221	9332	12443
Piston Speed — fpm			
At 720 rpm	1200	1200	1200
At 750 rpm	1250	1250	1250
At 900 rpm	1500	1500	1500
Firing Order			
Note: For complete firing order data, with engine diagram, refer to page E1222-1.			
BLOWER			
Stationary Engines:			
Air Delivery (Turbocharger) — approx. cfm			
At 720 rpm	5960	8950	11930
At 900 rpm	6930	10400	13860
Marine Engines:			
Air Delivery (Turbocharger) — approx. cfm			
At 750 rpm	6210	9320	12430
At 900 rpm	6530	9800	13070
Scavenging Pressure — approx. psi			
At 720 rpm	17	17	17
At 750 rpm	18	18	18
At 900 rpm	23	23	23
BEARINGS			
Number of Main Bearings (upper and lower crankshaft) ea.	7	10	13
Main Bearing Size (upper and lower crankshaft) — in.	8x3	8x3	8x3
Number of Thrust Bearings (upper and lower crankshaft) ea.	1	1	1
Thrust Bearing Size (upper and lower) — in.	8x4	8x4	8x4
Crankpin Bearing Size — in.	6-3/4x3-3/4	6-3/4x3-3/4	6-3/4x3-3/4
Piston Pin Bearing Size — in.	3x3-3/16	3x3-3/16	3x3-3/16
EXHAUST			
Exhaust Temperature at Individual Cylinder Exhaust Ports at Full Load — Max. °F	1000	1000	1000
Stationary Engines: Exhaust Gas at Full Load — lbs. per hr.			
At 720 rpm	27360	41080	54760
At 900 rpm	31810	47740	63620
Marine Engines: Exhaust Gas at Full Load — lbs. per hr.			
At 750 rpm	28500	42780	57050
At 900 rpm	29970	44980	60000
STARTING AIR			
(Air Cylinder Start)			
Stationary — Diesel & Dual Fuel			
Cu. Ft. of free air per start	30	35	45
Starting Air to 1/2 the cylinders on 6 & 12 cyl. engines and to 5 cylinders on the 9 cyl. engine.			
Marine —			
Cu. Ft. of free air per start	40	45	55
Starting air to all cylinders.			

For Tank Sizing See: Marine — Page E3740
Stationary — Page E3440

Diesel B

9/16/69

Start No.	Cranking Time		Starting Air Press, PSIG	
	0 Seconds		243	9:50
	10 Seconds		1[illegible]	
1	3 Seconds		160	
2	1.8		156	
3	—	Datum Failure	149	
4	2 Seconds		143	
5	2		137	
6	1.7		133	
7	2.0		125	
8	2.0		120	
9	2.[illegible]		113	
10	3.0		106	
11	3.2		100	
12	3.0		95	
13	3.[illegible]		87	
14	1.5		78	
15	Would Not Start		[illegible]	10:08 [illegible]

Stopped [illegible] In 8 Seconds

① Stop watch used to time all [illegible]

② Total cranking time 44.2 sec. not counting the last trial which failed to fire diesel.

③ Air compressor [illegible]

[illegible] operator [illegible] Smith

[illegible]