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Form 6918
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STARTING AND OPERATION OF DIESEL ENGINES AT –25° F (APPLICATION OF PNEUMATIC CRANKING METHODS)

ABSTRACT

The successful starting of diesel engines becomes more difficult as ambient temperatures drop. Various adversities are introduced that impede the starting characteristics enjoyed at warmer temperatures.

Pneumatic starting systems have existed as an accepted method of engine cranking since the 1940's. However, it is necessary to understand the effects of the above mentioned adversities in order to know what steps must be taken to maximize the efficiency of the pneumatic cranking motor during cold weather operation.

INTRODUCTION

Under intensely cold climatic conditions, the use of pneumatic cranking motors (air starters) provides basic properties that can lay the ground work for the favorable starting of diesel engines. It is the purpose of this paper to address these properties and their effects on the starting process.

It is important for one to understand the negative characteristics that apply to engine cranking and starting at –25° F. These characteristics are not present in a warmer environment. The performance comparisons of an air starter in warm and cold climates should only be the first in a series of critical data an operator analyzes when deciding on the proper integration of other aids to apply to his starting procedure. It is also important to understand the idiosyncrasies of this particular method of engine cranking, its operational characteristics, its pitfalls and how to combine these factors to insure a system of optimum integrity.

All of the above concerns will be addressed, discussed and hopefully clarified by this paper.

COLD WEATHER CRANKING CONDITIONS AND ADVERSITIES

In a low temperature environment, parasitics are introduced that negatively affect a diesel engine's startability. These same parasitic factors will also negatively affect a starter's ability to crank. When these factors are properly addressed, their negative effects will be reduced. By so doing, it can be shown that the air cranking system can become most effective for cold climate applications.

The concept of starting and running a diesel engine is based on the principle of spontaneous combustion. Different diesel fuels in an atomized state have variable flash points. On each piston stroke, the compression capability of the engine must supply the necessary heat required to raise the temperature of the fuel–air mixture to its flash point. (Inherent in this statement is the introduction of the negative effects of cold weather on engine starting). As the ambient temperature of the engine lowers, the following can be expected:

1. Assuming the combustion point of diesel fuel is 725° F at 80° F ambient, the temperature increase provided by the compression process is 645° F. With an ambient temperature –25° F, the temperature increase to attain combustion has been widened to 750° F.

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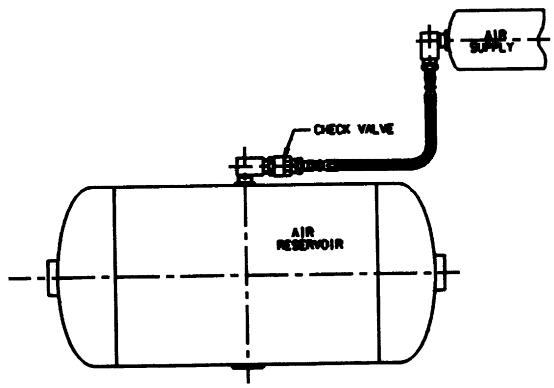
2. In addition to this heat requirement, at –25° F, much of the heat generated by the compression stroke is absorbed into the walls of the combustion chamber. This further negates the objectives of the compression stroke and adds to the requirement of additional heat.
3. Engine lubricants used to remove the friction of moving parts become more viscous as temperatures drop. When the ambient temperature reaches –25° F, increased viscosity creates an impediment to the cranking process. This results in a significant increase in the torque required to crank the engine.

AIR START SYSTEM REVIEW

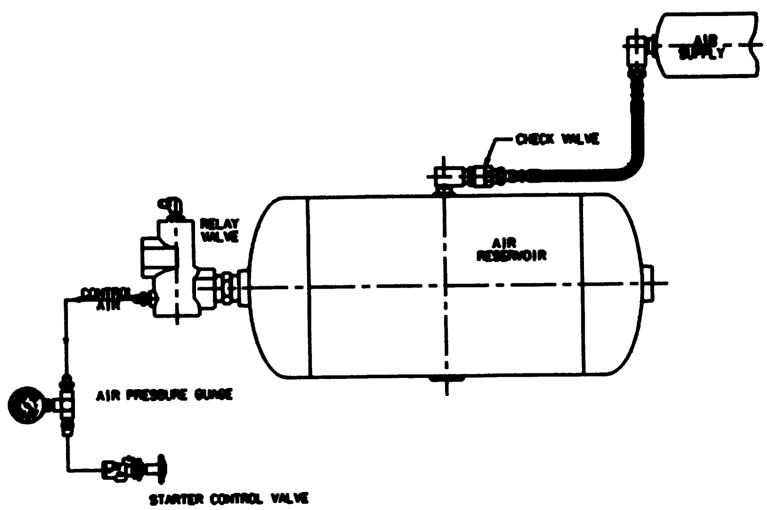
The principle of an air starting system is the transferral of stored energy in the form of compressed air to a rotary motion through an air motor. This transferral of energy from its source to and through the starter is controlled by simple fluid power logic. A basic air start system is generically termed as pre–engaged in nature. A schematic of this type of system is described as follows:

1. An independent energy source (air reservoir) dedicated solely to the air starter is required. To insure its integrity, it is divorced from its supply source with a check valve.



Dwg. TPD1127

2. A push–type starter control valve, remotely located yet convenient to the operator is the mode used to initiate the cranking cycle.



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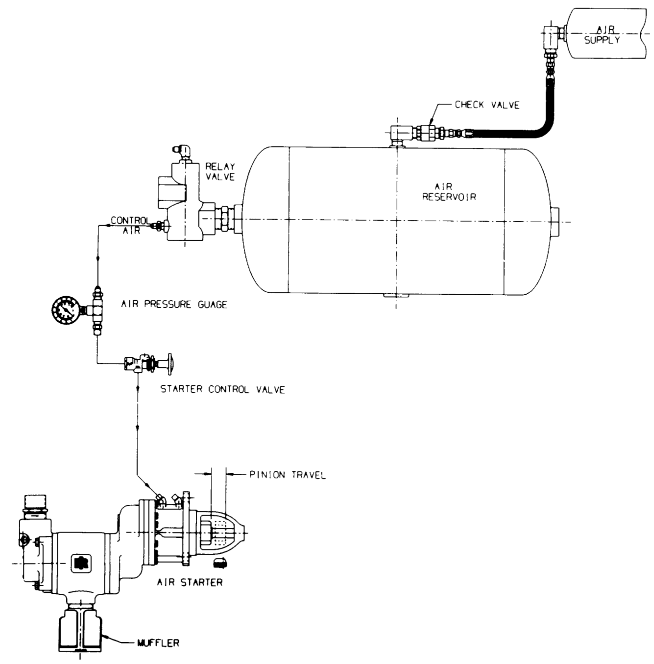
3. Upon operator command, the air signal is directed from the push button to the drive housing of the starter. The object here is to, through administration of air to the drive housing piston, engage the drive pinion with the ring gear prior to activating the air start motor.



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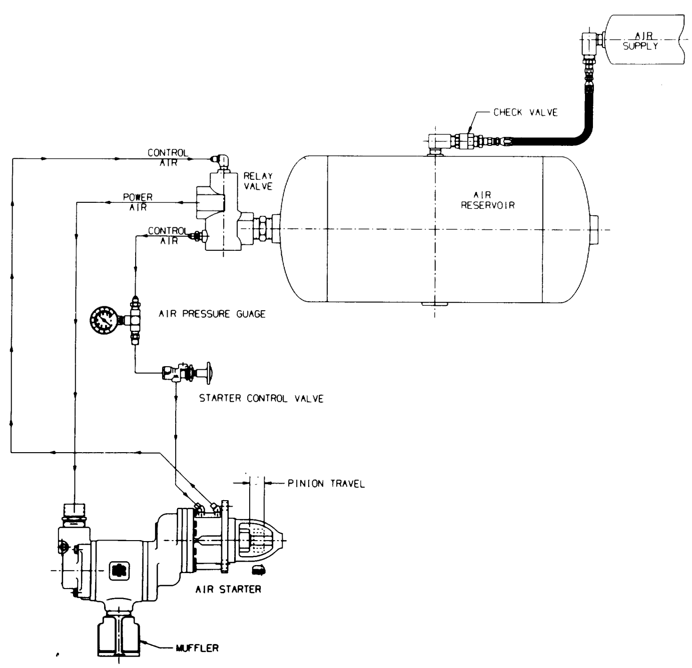
4. Upon engagement of the drive pinion with the ring gear, the air signal then passes from the starter drive housing to the relay valve located on the reservoir. The relay valve then opens, directing main power air from the reservoir to the starter motor initiating the cranking of the engine.



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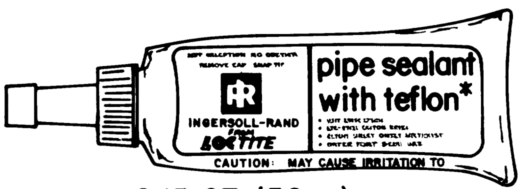
TEMPERATURE VARIANCES AND THEIR NEGATIVE EFFECTS ON THE AIR STARTING SYSTEM

Ambient temperature variances affect an air starting system in much the same way a diesel engine is affected. The colder temperatures become, the more negative their impact is. The operator must be aware of these effects and must take steps to counteract or minimize them. By proceeding step by step through the air start system, the affected points can be isolated and the counteractive measures used to minimize the negative effects can be defined. It is intended now to proceed on that course.

The air reservoir, as previously stated, is the energy source of the air start system. As such, regardless of temperature concerns, system integrity is paramount. It is essential that leak potential be kept to a minimum. Threaded joints and other possible leak points such as mounted valves must be properly sealed. It is recommended that liquid Teflon sealant be used in all of these areas.



NET. WT. 2.15 OZ. (50cc)

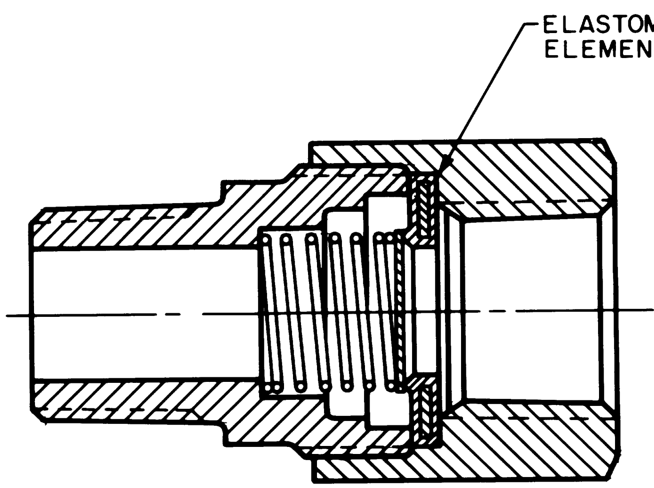
PIPE SEALANT WITH TEFLON IS A BETTER WAY TO SEAL THREADS BECAUSE IT PROTECTS AGAINST CORROSION; ASSURES 100 % SOLID SEAL; DOES NOT RUN OR DRIP; ASSURES EASY REMOVAL AFTER YEARS OF SERVICE.

Dwg. DR–510

Condensation is the nemesis of all air starting systems. In sub–zero climates, condensation turns to ice. This can cause air start system valves to stick in an open or closed position, either of which can be detrimental to efficient air start operation. It is **imperative** that all steps be taken to supply clean, dry air to the air start system.

As previously stated, the air start system is controlled by the use of three valves. All of these valves can be negatively impacted through exposure to cold weather.

The first of these valves is a reservoir mounted check valve. Its purpose is to divorce the air start system from its compressor supply source.



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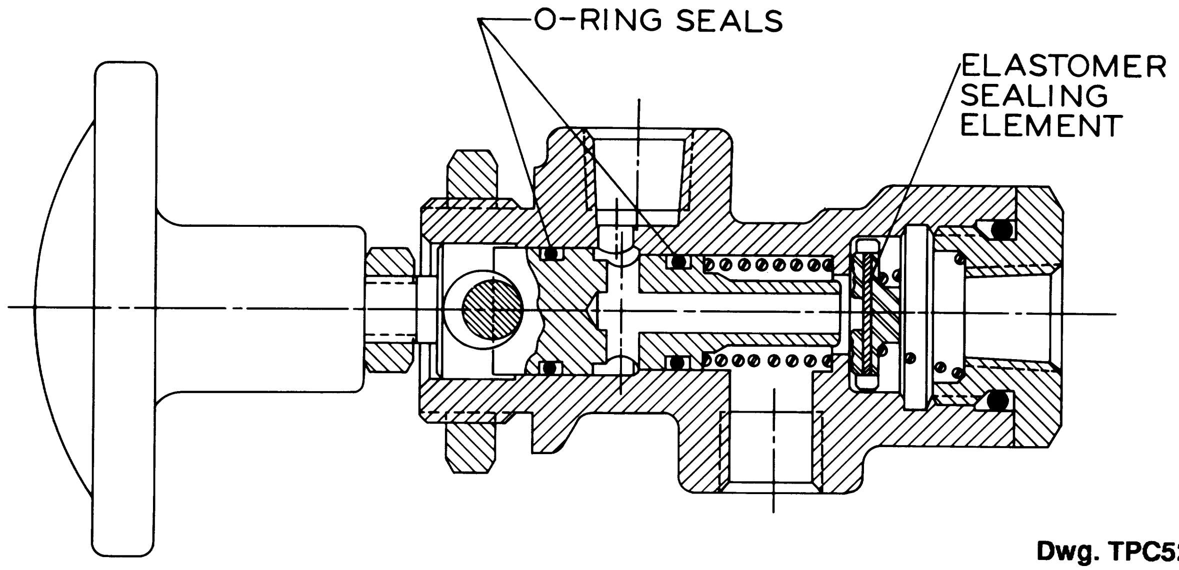
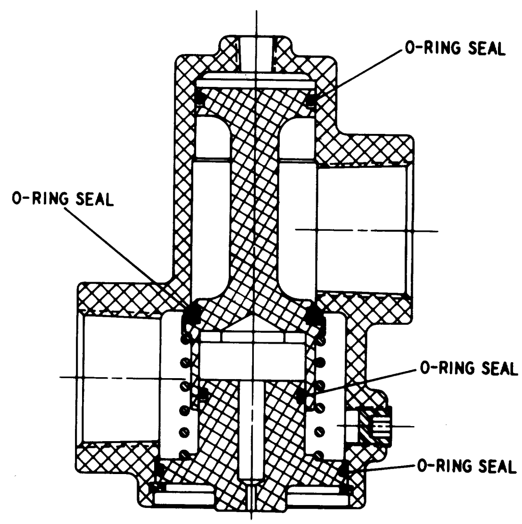
Second is the remote mounted control valve. This valve is used by the operator to initiate the crank cycle. Each of these valves is composed of a brass body and an internally located spring–loaded elastomeric seat.The control valve incorporates a palm controlled plunger for overcoming air pressure.



Dwg. TPC528

The third valve in the system is the air start relay valve. This valve directs the main supply air to the starting motor. As such, it must be designed so that it supplies enough pressure and volume to meet the cranking motor requirements. The valve is composed of a die cast aluminum body with an internally located spring–loaded plunger. The plunger is made from machined aluminum bar while the spring is made from stainless steel. To insure airtight properties, the valve incorporates four viton 0–rings.



Dwg. TPD1124

The relay valve is considered normally closed with live air found at its base. Admission of air to the head of the valve depresses the plunger clearing the way for the main supply air to be directed to the starter.

At this point, lubrication in the valves and starting motor should be addressed. As in any mechanical device, moving parts require lubrication. The inherent characteristics of lubricants are affected by temperature variance. To insure maximum efficiency of the air start system, lubricants must supply lubrication at low temperatures without adversely affecting a valve's operation or a starter's performance.

In the check valve and control valve, at –25° F the lubrication must provide freedom of movement of the elastomeric seat in order to accommodate nominal air flow and proper seating.

Under the same conditions, the relay valve must be provided with smooth movement of the plunger in response to the starting pressure signal. This condition must be respective to both opening and closing actions. Also, proper sealing characteristics must be encouraged for O–rings when the valve is in the normally closed position.

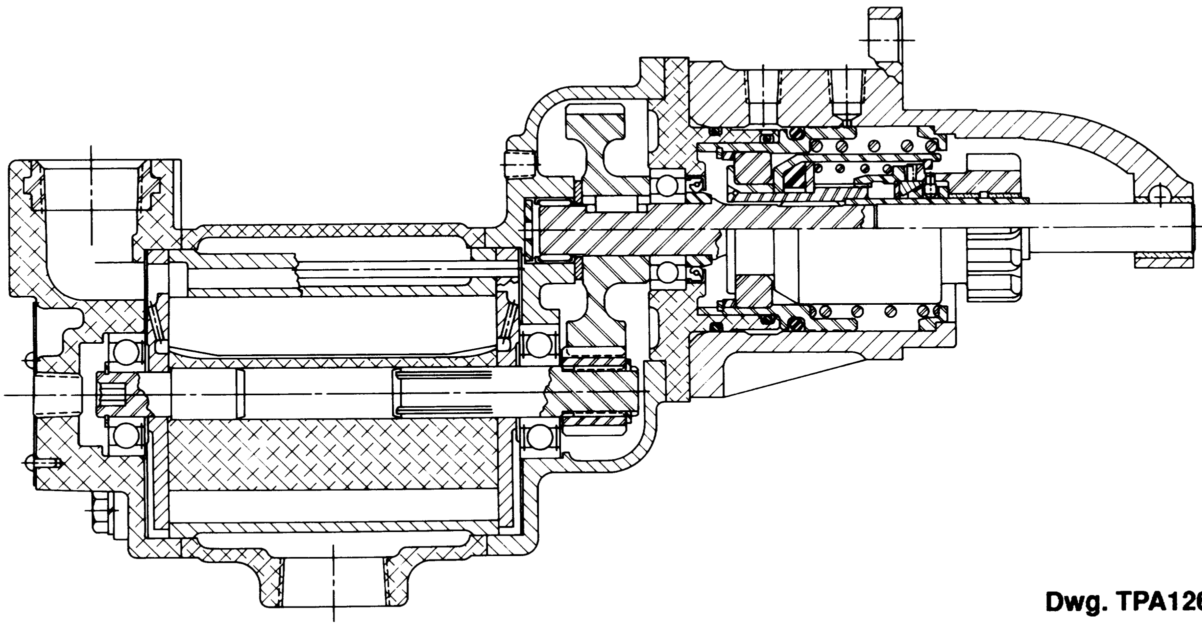
–Respective to the starter, lubrication must provide the following:

–Smooth movement of the pinion engagement mechanism.

–Free function of all bearings.

–Proper functioning of the gear train without increasing resistance which could adversely affect power transmission.

–Any other rotating or moving member must be evaluated and provisions made for changes in operating characteristics caused by negative temperature variances.



Dwg. TPA1264

Ingersoll–Rand has substantiated the above stated premises through a testing process conducted at –25° F. The following is an overview of that test program.

Test Objective: **Identify the cranking characteristics of a standard pneumatic starting system at –25° F.**

I. Test Equipment

A. Engine: Cummins Model Fleet 300 No. 11231743
Date Mfg. 12/84 S.O. No. 18245
Ref. No. A5601
C.I.D. 855 Family 093E CPC 0718
Idle speed 575–650 rpm
Model BC II
6 cyl turbocharged
Oil in crankcase: Delvec 5–40
103 teeth on ring gear

B. Starting System:

1. Starter: Ingersoll– Rand Model 150BMPE78RH–6
Serial No. RMJ15163
Pinion data: 11T cut on 12T Blank
6/8 D.P
20° P.A.
Gear ratio of starter: 3.47:1
2. Relay Valve: Ingersoll–Rand Part No. SRV125 with 1–1/4" NPT connections
3. Control Valve: Ingersoll–Rand Part No. SMB–618
4. Air Tank: Ingersoll-‐Rand Part No. 55RS, 55 gal capacity. Two tanks were connected in series with a hand operated globe valve between them.
5. Check Valve: Ingersoll–Rand Part No. 150BMP–1054
6. Air Supply: Energy source contributed by compressing –25° F refrigerated air to 120 psi.

C. Data Acquisition Equipment

1. Data Acquisition Computer, Compudas Corp., Model "Sentinel"; engine test program scans 7 channels 5 times per second.
2. Pressure Transducer: Paine Instruments, Inc. Part No. 210–15–050–02
3. Thermocouple: Omega Industries K–Type, grounded junction
4. Chart Recorder: Technirite No. TR–444

II. Test Arrangement

A. The starting system was installed in standard format as shown in schematic on page 3.

B. Pressure transducers were installed in the following locations:

1. In the air tank
2. In the starter inlet
3. In the starter exhaust

C. Thermocouples were installed in the following locations:

1. The exhaust ports of three cylinders
2. The starter inlet
3. The starter exhaust
4. The air tank

D. Test Facility– The test cell was designed to accommodate the cold soak of the engine, starting system and accessories at –25° F and to maintain this temperature on a continuing basis.

III. Test Procedure

A. Charge the air reservoir to 120 psi.

B Set valve for 1 or 2 reservoir operation.

C. Activate recording equipment.

D. Activate and hold control valve.

E. When cranking stops or engine starts, deactivate the control valve and recording equipment.

IV. Specific Test Objectives

Test No. 1 – Measure cranking time and engine rpm with engine in no–start mode with one 55 gal tank of air at approximately 75° F.

Test No. 2 – Measure cranking time and engine rpm with engine in no–start mode with one 55 gal tank of air, all soaked for 24 hours at –25° F.

Test No. 3 – Same as Test No. 2. Engine set up in start mode. Measure cranking time and engine rpm at time of ignition.

Test No. 4 – Same as tests 2 and 3. Measure cranking time and engine rpm at time of ignition subsequent to a measured admission and 8 second fumigation of ether at the intake manifold.

V. Test Results

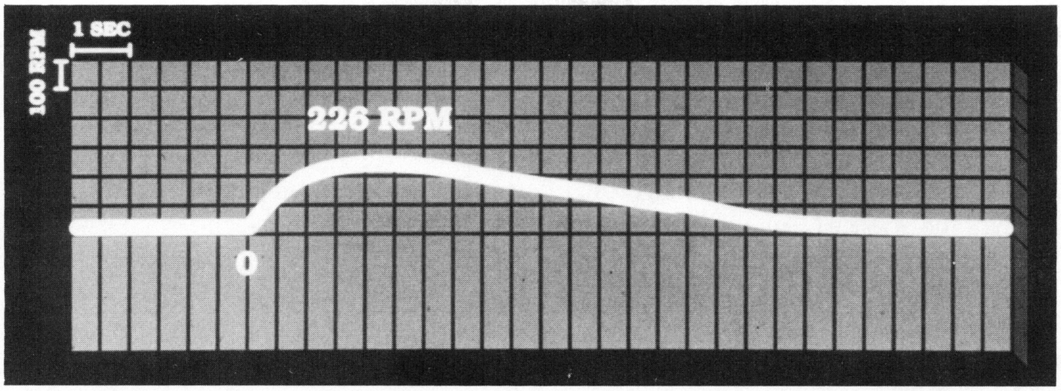
Test No. 1–226 maximum rpm achieved. Crank time of 6.8 seconds above 100 rpm. Total crank time of 9 seconds.

Test No. 2–95 rpm maximum achieved. 3.2 seconds above 50 rpm. Total crank time of 5 seconds.

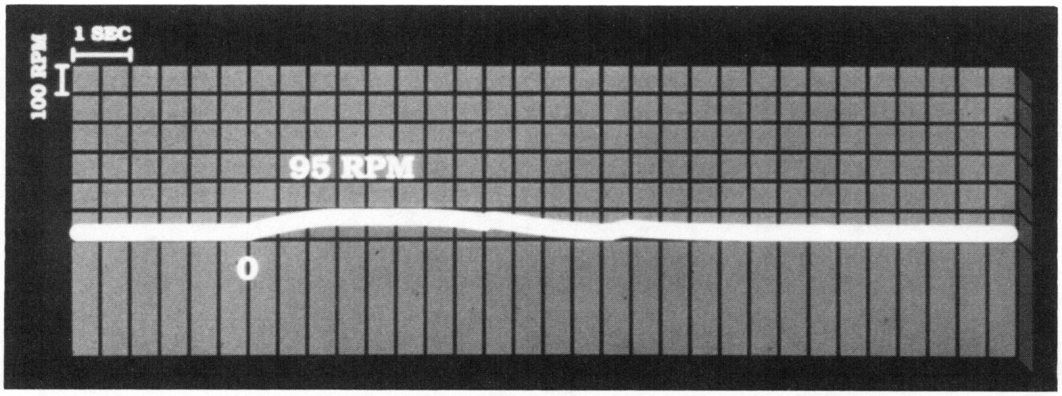
Test No. 3–95 rpm maximum achieved. 3.2 seconds above 50 rpm. Total crank time of 5 seconds.

Test No. 4– 3 second crank duration with positive ignition achieved at 80 rpm.To sustain operation, ether administration was used following initial ignition.

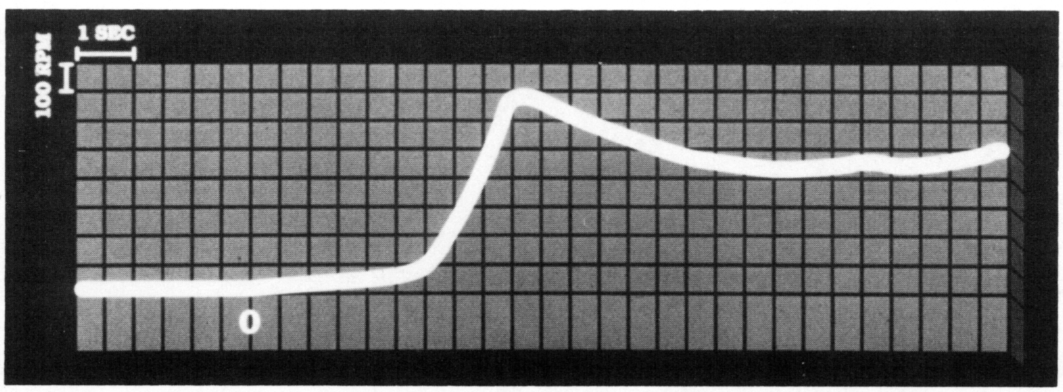
GRAPHS SHOWING RPM VS TIME IN SECONDS



TEST NO. 1



TEST NO. 2 AND 3



TEST NO. 4

	Test at 75° F		Test at –25° F	
Test No.	1		2	
Pressure	96	80	96	82
Sequence No.	30	34	6	52
Engine rpm	198	226	83	38

These rpm values are incidental in a chain of events. They are another set of numbers used in the identification of the effect of low temperatures.

SUMMARY

The starter system as tested used the same standard components (starter, valves and hoses) as used in today's truck, bus and off–highway equipment market.

In preparing for this series of tests, caution was exercised to assure that the lubricants used in the starter and valves were functional at –25° F. Bearing and sliding elements were lubricated and lowered in temperature to –25° F. The increase in operating resistance was not discernible.

To minimize the effect of icing, cold room air was taken into the compressor. No other attempt was made to remove moisture from the air. Evidence of icing on the muffler of the starter was minimal.

We feel that the tests, as conducted, show accurately the effect of a temperature of –25° F on the total engine and pneumatic cranking system. Further testing is required to identify specific areas requiring improvement.

Not until an 8 second fumigation of ether into the intake manifold and continued admission of ether subsequent to initial firing was a true start achieved.

CONCLUSION

The environment discussed in this paper predicates that the responsibility for attaining positive starting results must be shared equally by both the manufacturer and the operator. However, the operator must assume the responsibility for the proper mix of aids to be used in the cranking procedure.

The test results demonstrate that a heavy–duty diesel engine can be started at –25° after cold soaking when equipped with an air start system and the use of an ether cold start kit.

APPENDIX A

Data printout of Test No. 3. This is typical of the printout for all test runs. Five cycle counts were recorded per second.

Cycle Count = 0	**C temp**	**F temp**			
Ex. Port Cyl. 1–	–32.5	–26.5	Air Tank Pressure–	2.5	117.6
Ex. Port Cyl. 2–	–32.2	–26	Inlet Air Pressure–	.9	23.1
Ex. Port Cyl. 3–	–32.4	–26.3	Ex. Air Pressure–	.5	– 26.2
Ex. Port Cyl. 4–	–32.7	–26.9	% Opacity	–101.4	
Air Tank Temp–	–32.8	–27	RPM–	.5	
Inlet Air Temp–	–32.5	–27.2	Battery Voltage–	0	
Ex. Air Temp–	–33	–27.4	Fuel Sol. Signal–	–.1	
			Ether V. Signal–	0	

Cycle Count = 1	**C temp**	**F temp**			
Ex. Port Cyl. 1–	–32.5	–26.5	Air Tank Pressure–	2.5	117.6
Ex. Port Cyl. 2–	–32.3	–26	Inlet Air Pressure–	2.5	146.2
Ex. Port Cyl. 3–	–32.4	–26.3	Ex. Air Pressure–	.6	–19.1
Ex. Port Cyl. 4–	–32.6	–26.7	% Opacity–	–101.2	
Air Tank Temp–	–32.7	–26.9	RPM–	22.5	
Inlet Air Temp–	–29.8	–21.6	Battery Voltage	0	
Ex. Air Temp–	–33.8	–28.8	Fuel Sol. Signal–	–.1	
			Ether V. Signal–	0	

Cycle Count = 2	**C temp**	**F temp**			
Ex. Port Cyl. 1–	–32.2	–26	Air Tank Pressure–	2.4	110.6
Ex. Port Cyl. 2–	–32.2	–26	Inlet Air Pressure–	2.4	138.5
Ex. Port Cyl. 3–	–32.4	–26.3	Ex. Air Pressure–	.7	–12
Ex. Port Cyl. 4–	–32.5	–26.5	% Opacity–	–100.9	
Air Tank Temp–	–32.8	–27	RPM–	38.5	
Inlet Air Temp–	–29.2	–20.6	Battery Voltage–	0	
Ex. Air Temp–	–36.6	–33.9	Fuel Sol. Signal–	0	
			Ether V. Signal–	0	

Cycle Count = 3	**C temp**	**F temp**			
Ex. Port Cyl. 1–	–32	–25.6	Air Tank Pressure–	2.5	117.6
Ex. Port Cyl. 2–	–32.1	–25.8	Inlet Air Pressure–	2.4	138.5
Ex. Port Cyl. 3–	–32.4	–26.3	Ex. Air Pressure–	.7	–12
Ex. Port Cyl. 4–	–32.4	–26.3	% Opacity–	–100.8	
Air Tank Temp–	–32.8	–27	RPM–	57.5	
Inlet Air Temp–	–29.6	–21.3	Battery Voltage–	0	
Ex. Air Temp–	–40.2	–40.4	Fuel Sol. Signal–	–.1	
			Ether V. Signal–	0	

Cycle Count = 4	C temp	F temp			
Ex. Port Cyl. 1–	–31.8	–25.2	Air Tank Pressure–	2.4	117.6
Ex. Port Cyl. 2–	–32.3	–26	Inlet Air Pressure–	2.3	130.8
Ex. Port Cyl. 3–	–32.6	–26.7	Ex. Air Pressure–	.7	–12
Ex. Port Cyl. 4–	–32.4	–26.3	% Opacity–	–100.8	
Air Tank Temp–	–32.7	–26.9	RPM–	57.5	
Inlet Air Temp–	–30.4	–22.7	Battery Voltage–	0	
Ex. Air Temp–	–43.8	–46.8	Fuel Sol. Signal–	–.1	
			Ether V. Signal–	0	

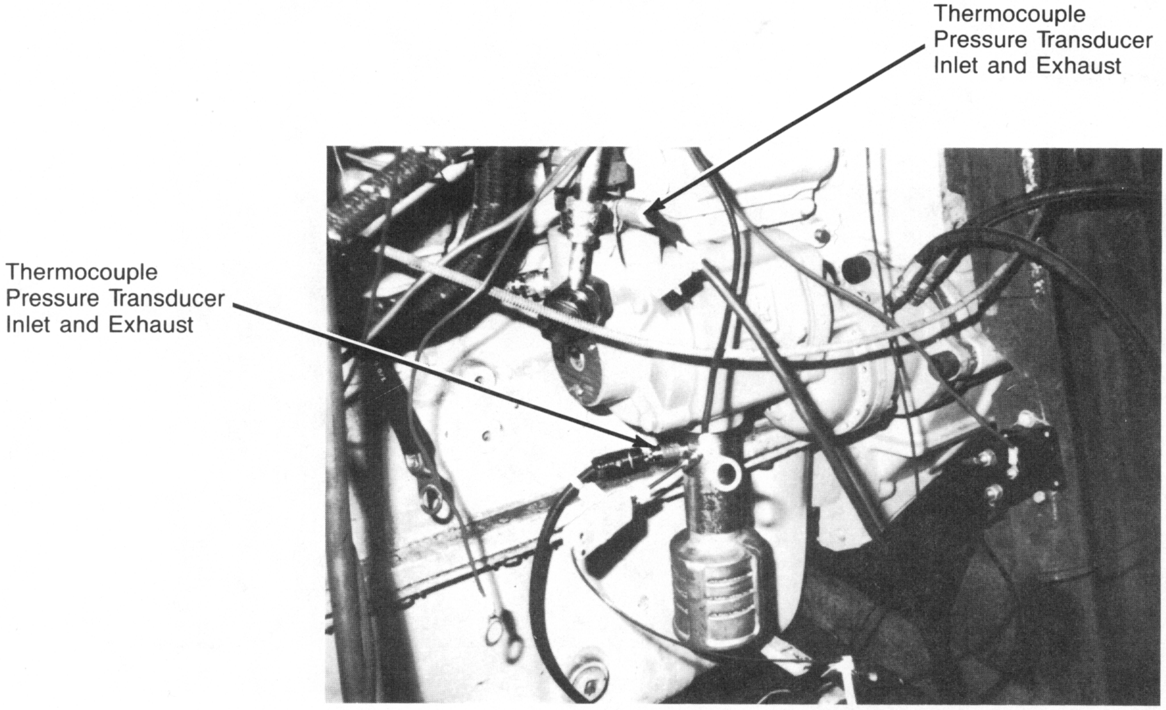
Cycle Count = 5	C temp	F temp			
Ex. Port Cyl. 1–	–31.6	–24.9	Air Tank Pressure–	2.4	110.6
Ex. Port Cyl. 2–	–32.1	–25.8	Inlet Air Pressure–	2.3	130.8
Ex. Port Cyl. 3–	–32.8	–27	Ex. Air Pressure–	.7	–12
Ex. Port Cyl. 4–	–32.4	–26.3	% Opacity–	–100.7	
Air Tank Temp–	–32.7	–26.9	RPM–	70	
Inlet Air Temp–	–31.3	–24.3	Battery Voltage–	0	
Ex. Air Temp–	–47.1	–52.8	Fuel Sol. Signal–	–.1	
			Ether V. Signal–	0	

Cycle Count = 6	C temp	F temp			
Ex. Port Cyl. 1–	–31.6	–24.9	Air Tank Pressure–	2.4	110.6
Ex. Port Cyl. 2–	–32.5	–26.5	Inlet Air Pressure–	2.3	130.8
Ex. Port Cyl. 3–	–32.9	–27.2	Ex. Air Pressure–	.6	–19.1
Ex. Port Cyl. 4–	–32.6	–26.7	% Opacity–	–100.5	
Air Tank Temp–	–32.8	–27	RPM–	94.5	
Inlet Air Temp–	–32.1	–25.8	Battery Voltage–	.2	
Ex. Air Temp–	–50	–58	Fuel Sol. Signal–	–.1	
			Ether V. Signal–	0	

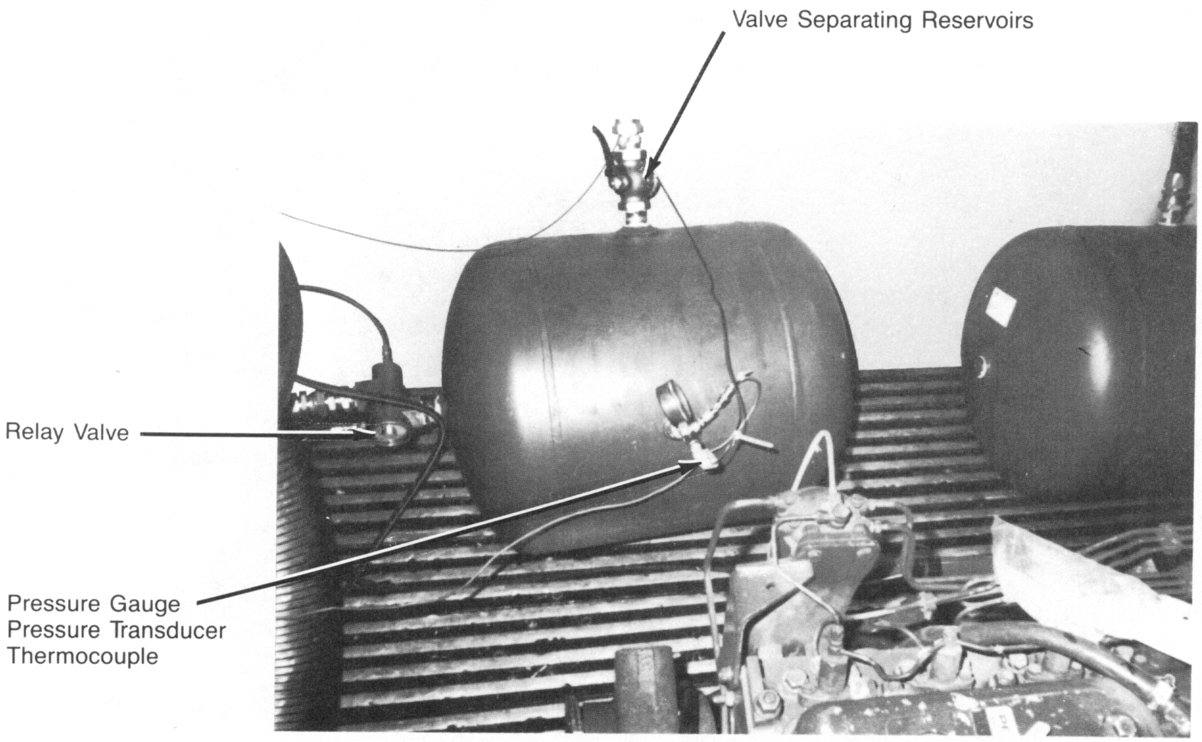
Cycle Count = 7	C temp	F temp			
Ex. Port Cyl. 1–	–32.1	–25.8	Air Tank Pressure–	2.3	103.5
Ex. Port Cyl. 2–	–32.7	–26.9	Inlet Air Pressure–	2.3	130.8
Ex. Port Cyl. 3–	–33	–27.4	Ex. Air Pressure–	.6	–19.1
Ex. Port Cyl. 4–	–32.8	–27	% Opacity–	–100.3	
Air Tank Temp–	–33	–27.4	RPM–	95	
Inlet Air Temp–	–32.8	–27	Battery Voltage–	0	
Ex. Air Temp–	–52.5	–62.5	Fuel Sol. Signal–	0	
			Ether V. Signal–	0	

APPENDIX B

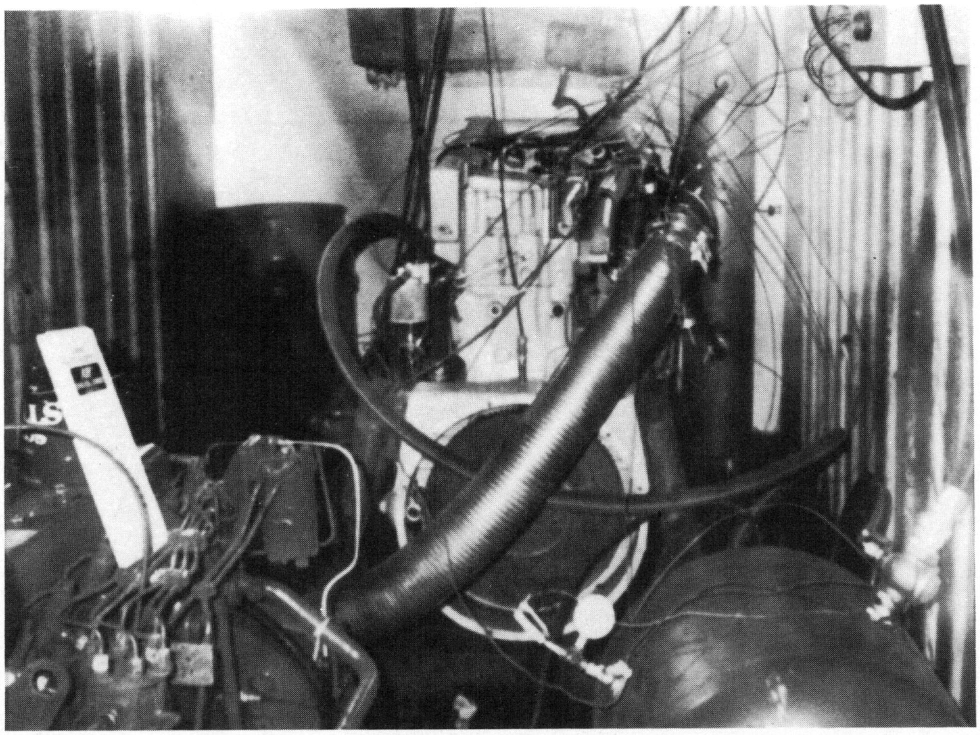
Following are photographs showing the test equipment as set up while tests were being run.



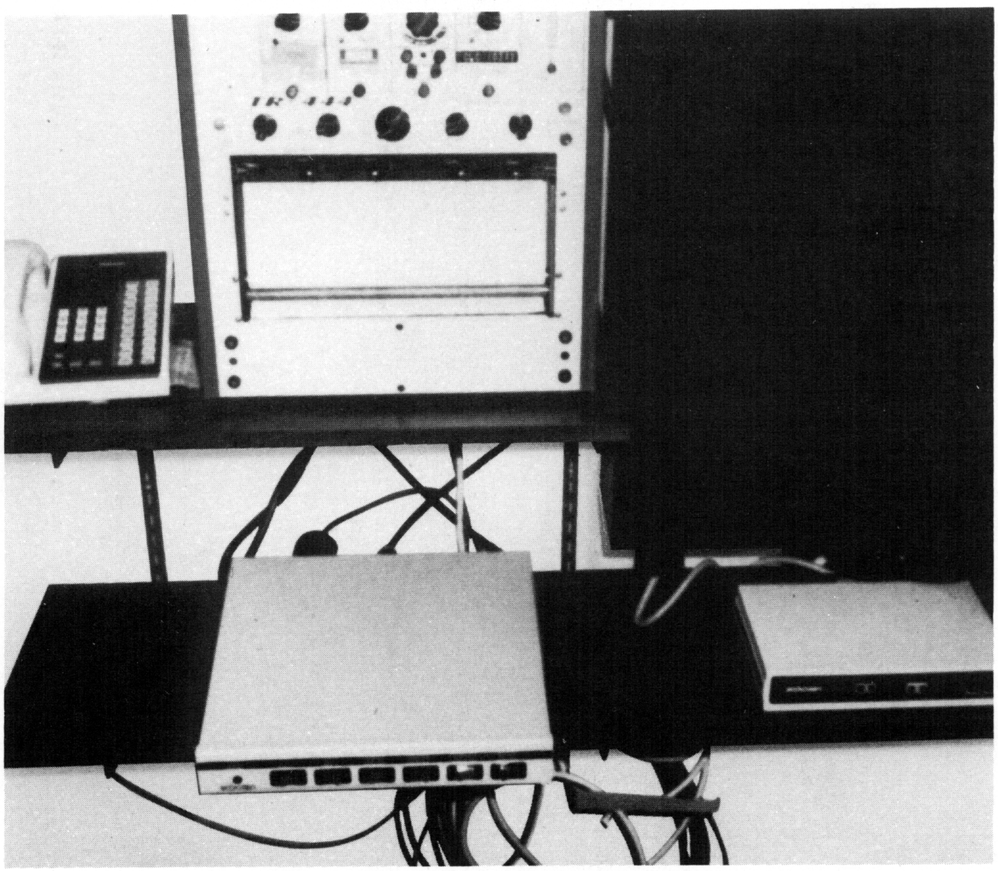
The starter as mounted on the engine showing the thermocouples and pressure transducers in the inlet and exhaust.



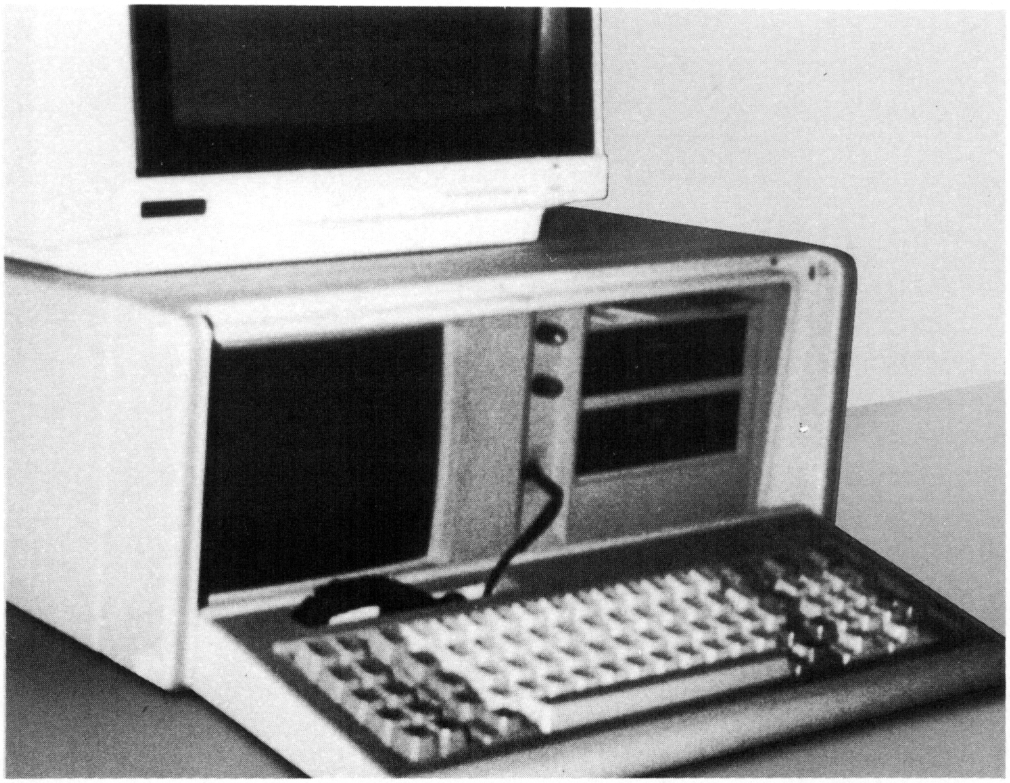
A view of the air reservoirs showing the thermocouple and pressure transducer with the pressure gauge. Also shown is the relay valve with the valve separating the reservoirs.



A general view showing the engine and interior of the cold room as set up for the test.



A view of the Technirite No. TR–444 chart recorder located adjacent to the test cell.



A view of the computer terminal located with the chart recorder adjacent to the test cell.