PART-LOAD ECONOMY OF DIESEL-ELECTRIC GENERATORS

FINAL REPORT

by

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ABSTRACT

Diesel-electric generators used to produce power in rural Alaska are often found to be inefficient and suffer from premature mechanical failures. Such failures are commonly caused by hydrocarbon build-up in the engine resulting from long-term operation under light-load conditions.

There are several feasible approaches to this problem which use proven technology. The most technologically direct approach is to properly size systems. Another involves the optimum control of engine oil, coolant and intake air temperature with thermostatically-controlled electric heaters. Economic analysis shows that this approach could save as much as $13,000 per year in the cost of electricity for a 100 kw diesel generator operating at 25% load. However, further research is needed to establish that the mechanical problems associated with part-load operation are actually abated with proper control of operating temperatures. Practical experience implies that this should be the case.

Acoustically tuned low restriction intake and exhaust systems are also an attractive approach because they provide a definite increase in efficiency under all operating conditions. However, these units must be developed for a specific engine and operating speed range. They are not presently commercially available, but could be developed in a continuing research effort.

Parallel operation of small diesel-electric generators was suggested by many vendors and operators as a method of improving part-load performance. Though it has the benefit of redundant reliability, the economic analysis does not show a clear advantage because of higher electrical costs near full-load conditions. At very low loads, single small units may also suffer from the same mechanical problems as the large units.

The other methods of improving part-load performance which include the use of improved injectors and microprocessor-controlled injection pumps are not presently feasible. However, the state of diesel engine technology is changing so rapidly that these items could become feasible in less than two years. These developments should be monitored closely.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Diesel-electric generating sets are used in many rural Alaska state buildings to produce electricity. As with other engineering systems in remote locations, maintaining proper operating conditions is difficult. Properly specifying systems and following sound operation and maintenance procedures is of paramount importance. Moreover, waste heat recovery is often a desirable strategy. However, this study will focus on part-load problems. For various reasons, these sets have poor part-load energy conversion efficiency which translates into high electric power costs. The objective of this study was to assess the feasibility of several methods of improving the part-load efficiency of diesel-electric generating sets. These methods are:

1. improvement of combustion, intake and exhaust system efficiency by pumping loss reduction and acoustical pulsation tuning;

2. aspiration or fumigation of natural gas, methanol or other fuels into the intake system to improve part-load combustion;

3. improve part-load combustion through better fuel atomization and by maintaining optimum fuel, intake air and combustion chamber wall temperatures; and

4. improve governor and injection pump controls for optimum part-load injection timing.

This work was accomplished with an extensive literature search, a survey of vendors and users of diesel-electric plants located in Alaska and a survey of vendors and manufacturers of diesel-electric generator sets in the lower 48 states. An engineering economic analysis of the best methods emerging from this study is presented along with a plan and cost estimate for a continuing research program.

SUMMARY

None of the proposed methods have been conclusively shown to improve part-load performance of diesel generators and also reduce the concurrent mechanical problems such as wet-stacking (also called "slobbering" in the exhaust) and carbon build-up. However, the study identifies several methods, based on current information, that appear to be feasible. If further research were to verify their efficacy, one could save as much as $18,000 per year in the cost of electricity for a 100 kw unit operating at 25 percent load. These methods are listed below (assuming the system available is oversized at least part of each year).

1. Maintain optimum fuel, intake air, engine coolant and oil temperature with auxiliary electric heaters. This is called the part-load package. The radiator-mounted load bank is an attempt at providing the same results. This kind of system does not increase the maintenance or personnel skill requirements much above what is presently needed. In calculating the cost savings for this methods, no attempt was made to account for the increase in efficiency other than that which occurs when the added electrical load of the part-load package raises the engine operation to a higher point on the load versus efficiency curve. There may actually be an increase in efficiency due to the higher operating temperature associated with the part-load package but we do not have sufficient data to quantify this.

2. Provide for parallel operation of smaller sized units. The economics of this method must be examined very carefully because higher investment costs can cause this arrangement to be more costly to operate at part-load. But, it certainly would be a way of reducing part-load problems.

3. Install acoustically tuned and aerodynamically optimized intake and exhaust systems. A definite increase in part-load efficiency could be obtained with these items and they require no maintenance. However, each engine would require a different manifold.

Aspiration of alcohol is not a feasible method of improving part-load performance because research has shown it to degrade part-load performance. Aspiration of other fuels may improve part-load performance, but more research is needed to verify this.

Advancing injection pump timing has been shown to improve part-load economy in some cases. There are several new vehicle and industrial engines that have this built into the injection pumps to improve part-load economy and emissions. The hardware is also available to incorporate this into existing designs, but it is an engine-specific modification that requires considerable engine test and system development work.

The microprocessor-controlled injector pumps that are currently being advertised are about two years from commercial use. They may also present maintenance and reliability problems in the bush areas of Alaska.

Improving fuel atomization by better injector design is another proven way of increasing part-load efficiency. Again, these devices are being developed for new engine designs and are not available for existing units. An alternative to this is derating the engine by using small injectors. This improves atomization and part-load performance, but is a semi-permanent modification suited for long-term part-load operation.

BACKGROUND

The diesel-electric generator set is currently the only economically feasible method of providing electric power in rural Alaska (Malosh, 1983). The overall energy conversion efficiency of the generator set is one of the factors that determine the cost of producing electric power. The full-load efficiency of a diesel-electric generator is about 30 percent under ideal conditions. If water jacket and waste heat recovery is included, the efficiency rises to about 60 percent, again under ideal conditions.

However, the part-load energy conversion efficiency of a diesel-electric plant is much less than the full-load value because diesel-electric plants are usually sized for peak demand. Furthermore, they cannot be operated for long periods of time at much less than 40 to 60 percent load without eventually suffering from mechanical failures. This is partly the result of design deficiencies in the diesel engine because in theory, the part-load performance of the diesel is much superior to any other reciprocating engine (Doolittle, 1964). Mechanical failures, of course, are also related to other factors such as improper maintenance and improper system specifications. In this report, however, we are focusing on part-load problems.

Since power consumption in rural facilities may average only 30 to 40 percent of full load, a dummy load is often required to keep the plant adequately loaded for nondetrimental operation. This significantly reduces the part-load energy conversion efficiency of the diesel-electric plant in some applications to values as low as 10 percent.

If the part-load efficiency could be maintained at the full-load level, fuel use can be reduced by as much as 35 percent. This would result in an estimated annual savings of $200 to $400 for a rural household. A substantial savings could also be expected for a rural school. The 1982 State of Alaska Long-term Energy Plan Report echoes these figures and specifies that an "increased generating efficiency of small diesel power plants" should be a specific energy conservation activity over the next five years.

The task of improving the part-load efficiency of a diesel-electric generator is a two-fold problem, but some solutions to one aspect also improve the other aspect. The first aspect concerns the reduced efficiency of the diesel engine when it is operated at low loads. In most diesel engines, the thermal efficiency either remains constant or decreases as load decreases. However, at part-load, the overall efficiency is still greater than the plant in which part of the excess output is dissipated in a dummy load. The second aspect concerns modifications of the engine so that it can operate at less than 60 percent capacity without suffering mechanical failures. It is convenient that the modifications that will allow the diesel to operate at low-loads will also increase the thermal efficiency.

The mechanical failures of diesel-electric generators that have been operated at low loads for long periods are associated with the poor combustion processes under these conditions. Good combustion requires that the ignition delay, the time between the start of injection and ignition, be as short as possible and that injected spray have good distribution and mixing in the combustion chamber (E.S. Taylor and C.F. Taylor, 1961).

At part-load, both inlet air and combustion chamber temperatures fall, which increases the ignition delay. Since most stationary diesels presently operate with fixed injection timing, increased ignition delay can cause combustion to occur well into the expansion stroke, which results in low output and poor efficiency (A.S. Campbell, 1979; C.F. Taylor, 1982). The quantity of fuel injected at part-load can be very small, which will result in poor atomization, penetration and distribution in the combustion chamber. These factors, combined with the low air and wall temperatures, promote carbon and varnish formation, that may plug injectors, stick piston rings and build up on the valves (C.F. Taylor, 1982).

The overall energy conversion efficiency of the diesel-engine can be increased by raising the combustion and volumetric efficiency. The major method of increasing combustion efficiency is to decrease ignition delay. Increasing turbulence in the combustion chamber by imparting a strong swirl to the inlet air decreases ignition delay by improved mixing (C.F. Taylor, 1982). However, this involves the design of the combustion chamber, intake and exhaust ports. In this study, the modifications are limited to those that can be performed without removing the cylinder heads from the engine. Therefore, increasing turbulence is not considered.

Mixing can also be enhanced by optimized injector design for better part-load fuel atomization. Since injectors can be changed without removing the cylinder head, this modification is examined.

Increased ignition delay at part-load can be compensated for by advancing the injection timing. It is frequently used as a cold-starting aid on diesel engines. However, this is an engine-specific modification because in some cases, advancing the injection timing may increase ignition delay (C.F. Taylor, 1982).

The temperature of the fuel, inlet air and combustion chamber wall all have a significant effect on ignition delay. The temperature of the fuel determines its viscosity and this strongly influences the drop size of the injected fuel (Lichty, 1967). A higher viscosity fuel produces larger drops for a given injector size that results in less efficient mixing and resultant combustion.

Increased inlet air temperature and combustion chamber wall temperature decrease ignition delay by improving the mixing processes (Taylor, 1982). The combustion chamber wall temperature is important in engines that rely on spray impingement to help in the mixing process (Taylor, 1982). Impingement occurs in most diesel engines at some point in their operating range.

Ignition delay can also be reduced by aspirating a volatile fuel, such as methanol or natural gas, into the inlet air. This is called fumigation. The amount of injected fuel can be reduced accordingly (Taylor, 1982).

Pilot injection is required when fumigation is used, but pilot injection will also reduce delay in a normal diesel engine (Taylor, 1982). Pilot injection involves injection of a small amount of fuel several crank angle degrees ahead of the main injection.

Increasing the inlet air pressure is a major method of reducing ignition delay. This can be accomplished by two methods. Pressure charging without after-cooling increases the inlet pressure and temperature and is very effective in reducing ignition delay (Taylor, 1979). Acoustical pulsation tuning can also be incorporated in a pressure charging system to increase inlet pressure at part-load conditions.

The volumetric efficiency of a diesel engine can be increased by reducing the intake and exhaust system pumping losses (Lichty, 1967). Practical experience with diesel engines has shown that a 1-inch Hg increase in exhaust system back pressure will increase fuel consumption by 0.5 percent (Kleinburg and Schmiechel, 1981). Improvements in volumetric efficiency at particular speeds can also be affected by proper acoustical pulsation tuning of these system. Pumping losses can be reduced by low restriction exhaust systems (including mufflers) and aerodynamic design of intake systems.

SCOPE OF WORK

The scope of this project addresses methods or modifications to the diesel-electric generator that do not involve major work on the engine, such as removing the cylinder heads or pistons. The approach taken is to consider methods in which improvement would result from an added system or control modification. The following methods of improving part-load efficiency were evaluated.

Improve combustion efficiency:

1. maintain optimum fuel, inlet air and combustion chamber wall temperatures at part-load conditions;

2. modify injection design for better part-load fuel atomization;

3. aspirate or fumigate natural gas, methanol or other fuels into the intake system; and

4. improve governor and injection pump scheduling for optimum part-load injector timing.

Improve combustion, intake and exhaust system efficiency:

1. optimize pulsation tuning of intake and exhaust systems; and

2. reduce pumping losses in intake and exhaust systems.

The feasibility of these methods was judged by the following factors:

1. improvement in part-load efficiency;

2. purchase and installation costs;

3. maintenance and operating costs;

4. maintenance requirements in terms of personnel skill level and parts availability; and

5. cost of electricity at part-load.

This task was accomplished by the following methods:

1. a literature search of the following resources:

    a. Lockheed Dialog System
    b. The Electric Power Data Book
    c. Compendex (Engineering Index)
    d. The publications of the Diesel-gas Engine Power Division of the Society of Automotive Engineers and American Society of Mechanical Engineers

2. a field survey of Alaskan operators of typical diesel-electric plants to determine the specific kinds of problems they have with part-load performance;

3. a survey of Alaskan vendors and users to determine the most common diesel engines and generators being sold and the most common ones currently in use; and

4. a survey of manufacturers and vendors in the lower 48 states concerning the modifications that are presently available to improve part-load performance and the cost of these modifications.

In addition, the following items are also presented:

1. a program and cost estimate for a small-scale test of the best method; and

2. an engineering cost analysis of the most promising alternatives.

LITERATURE SEARCH

This literature search was conducted in two phases. The first was performed on the Lockheed DIALOG system, and includes the Electric Power Database, COMPENDEX, ISMEC, NTIS and SCISEARCH databases. The following descriptions of these databases is taken from material provided by the University of Alaska library.

The COMPENDEX database is the version of Engineering Index that provides abstracted information from the world's significant engineering and technological literature. It provides worldwide coverage of approximately 3,500 journals, publications of engineering societies and organizations, papers from the proceedings of conferences and selected government reports and books.

ISMEC (Information Service in Mechanical Engineering) indexes significant articles in all aspects of mechanical engineering from approximately 250 journals published throughout the world. In addition, books, reports and conference proceedings are indexed. The primary emphasis is on comprehensive coverage of leading international journals and conferences on mechanical engineering subjects.

The NTIS (National Technical Information Service) database consists of government-sponsored research, development and engineering plus analyses prepared by federal agencies, their contractors or grantees. It is the means by which reports are made available for sale from such agencies as NASA, DOE, HUD, DOT, Department of Commerce and other government agencies.

SCISEARCH is a multidisciplinary index to the literature of science and technology prepared by the Institute for Scientific Information (ISI). It contains all the records published in Science Citation Index (SCI) and additional records from the

Current Contents series of publications that are not included in the printed version of SCI.

The keywords "diesel engine," "combustion," "cold," "diffusion," "diesel generator," "diesel-electric generator" and "part-load" were used to search these indexes and approximately 180 citations were listed. Of these, several were pertinent to the study and are included in the discussion below.

The second phase of the literature search covered the diesel-gas engine power publications of the American Society of Mechanical Engineers (ASME), the Society of Automotive Engineers (SAE) and trade publications such as Automotive Engineering and Diesel and Gas Turbine Progress. During this phase, many pertinent references were found, some of which will be discussed below.

The literature search produced no instances where the improvement of part-load fuel economy was directly addressed. However, all of the factors influencing part-load fuel economy were each covered in at least one publication.

Part-load fuel economy of a diesel engine can be improved by increasing the combustion efficiency and the intake and exhaust system volumetric efficiency. Improvements in volumetric efficiency also tend to raise the combustion efficiency. Combustion efficiency at part-load is increased when ignition delay is reduced. In their recent article on heavy-duty diesel fuel economy, Foster and Meyers (1982) listed ignition delay as one of the major influences on fuel economy.

The following factors influence ignition delay:

1. combustion chamber temperature;

2. fuel temperature and atomization;

3. injection timing; and

4. fumigation of supplemental fuels.

Intake and exhaust system volumetric efficiency can be improved by the following factors:

5. reduced pumping losses; and

6. pulsation tuning.

The results of the literature as they pertain to these six factors are discussed below.

Intake air temperature has a significant effect on part-load performance. According to Garret (1978), heating the intake air of a cold idling diesel engine reduces unburned hydrocarbons and soot. He also found that inlet throttling accomplished similar results. Watanabe (1973) also found that inlet throttling was effective in improving fuel economy of two-stroke diesels at light loads. This is contrary to the idea of decreasing pumping losses, but may have some merit at very low loads. Foster and Myers (1982) also suggested that cooling the inlet air with energy supplied by the exhaust gas may improve performance by reducing real gas losses. This would be very effective at full load conditions, but at part-load, the cooled inlet air would increase ignition delay.

In addition to ignition delay, there are other problems that may occur in a diesel engine that operates with cold intake air. These problems are discussed in the Cummins Service Bulletin entitled, "Operation of Diesel Engines in Cold Climates" (see References). Some of these problems are:

1. cracked blocks;

2. blown head gaskets;

3. excessive bearing loading;

4. loose or broken head bolts;

5. cracked pistons;

6. burned pistons; and

7. sticking valves and rings.

These problems arise with cold intake air because:

1. cold intake air has a higher density and raises peak cylinder pressures; and

2. cold intake air reduces combustion temperatures that increase reaction lag and promote the formation of carbon and varnish.

Sekar (1982) studied the effect of charge air cooling on heavy-duty diesels and found that the optimum intake air temperature (in the inlet manifold downstream of the turbocharger) for best full- and part-load performance was 140°F. This was based on minimum fuel consumption and emission considerations.

It is apparent from the Cummins bulletin and work of Sekar (1982) that maintaining an optimum intake air temperature is necessary for improved part-load economy. The reduction of soot and unburned hydrocarbons with heated intake air implies that mechanical problems such as ring sticking, carbon build-up and "slobbering" will also be reduced.

Combustion chamber temperature has a significant influence on ignition delay. Munro (1983) found that piston modifications that increased combustion chamber temperatures also reduced ignition delay. He found that this can be carried to extreme where ignition occurs before mixing is complete and fuel consumption increases.

However, proper design and control of combustion chamber temperature can increase fuel economy. Kirloskar (1979) described a semi-adiabatic diesel with a cast iron piston that yielded a brake thermal efficiency of 39 percent. Thaler (1983), in tests on several large diesels, found that by raising the coolant temperature from 80°C to 140°C, a 4 percent improvement in the full-load fuel economy and a 20 percent improvement in the no-load fuel economy resulted. He also found that increasing the oil temperature from 80 to 100°C reduced friction and lowered the fuel consumption by 1 percent at full load and 4 percent at 25 percent load. Because both oil and coolant temperature influence combustion chamber temperature, it is apparent from this work that good control and maintenance of proper oil and coolant temperature is necessary for good fuel economy, both at part- and full-load.

According to Hulsing (1979), the performance of the fuel atomizing system is one of the most significant influences on diesel engine thermal efficiency. The open literature shows that many diesel engine manufacturers are currently improving injection systems. For example, Yamaguchi (1983) describes a new injector particularly designed to improve light load performance.

To insure proper performance of the fuel system, the fuel temperature must be maintained above 40°F. Dainty (1980) also found that CO concentration in the exhaust was reduced by heating the diesel fuel. Since fuel viscosity has a direct influence on the atomization efficiency of a nozzle, it follows that for proper atomization, fuel temperature should be maintained at design conditions.

As the load is decreased on a diesel engine, the ignition lag generally increases. The ignition timing must be advanced to compensate for this tendency. Hinayasu (1980) showed that advanced injection timing also reduces carbon formation.

With the newly developed electronic governors and injection systems presently available, precise control of injection timing is easily accomplished. Scott (1983) describes an electronic injection system that provides pilot or early injection of fuel to increase overall fuel economy by 17 percent. Day (1982) and Gaschlin (1983) describe electronic fuel control systems that are presently available for diesel engines. Some of the capabilities of these systems are listed below:

1. isochronus governors;

2. torque curve shaping;

3. precise air-fuel control;

4. variable timing control; and

5. engine monitoring and diagnostics.

When tied to the generator controls, a fuel control system such as this could provide the necessary adjustments in injection timing to optimize part-load performance.

This kind of system is presently available on some vehicle diesel engines. Scott (1984) and Ring (1984) describe engines with electronically controlled injection systems that advance the timing for improved emissions and light load economy. In the "Engine Round-up" of the June 1984 issue of Diesel Progress - North American, several examples of these systems are also described. In one case, a new 120 hp diesel engine produced by Onan for generator sets has light load advance built into the injection pump. In another case, both Stanadyne and United Technologies have developed injection pumps that have built-in injection advance for control of emissions and improved fuel economy.

Fumigation or the addition to the fuel system of alternative fuels such as methane or ethanol has been the subject of much research in pursuit of better fuel economy in diesel engines. Fujisawa (1981) reported that ethanol improved specific fuel consumption at high loads but did not change fuel consumption at low loads. Both Gao (1983) and Chen (1981) demonstrated that ethanol fumigation increases thermal efficiency at high loads but decreases it at low loads. This decrease is attributed to increased ignition delay that is in the wrong direction for improved part-load fuel economy. It can be concluded that alcohol fumigation will not improve diesel engine part-load fuel economy.

However, aspiration of other fuels may improve part-load fuel economy. Vande and Frame (1983) found that the diesel engine thermal efficiency was dependent on the fraction of hydrogen aspirated into the engine. In particular, the normal decrease in efficiency as the load fell from 100 percent to 82 percent could be compensated for by the aspiration of hydrogen. Whether this benefit could be maintained at lower loads remains to be determined.

The volumetric efficiency of a diesel engine influences the fuel economy under all loading conditions. The volumetric efficiency can be improved by reducing pumping losses and by applying pulsation or resonant tuning to the intake and exhaust system. Foster and Myers

(1982) list the reduction of pumping losses as one of the avenues to improved heavy-duty diesel engine fuel economy. Kleinberg and Schmeichel (1981) determined through extensive testing that for each 1-inch Hg increase of backpressure on a diesel exhaust system, the fuel consumption increases 0.5 percent on a turbocharged engine and 1 percent on a naturally aspirated engine. Backpressure can be as high as 3- to 4-inches Hg on a typical diesel engine. These results apply at all loading conditions. Scott (1979) describes a recent example of this approach where the output of a medium-duty diesel was upgraded by 10 percent, part of which was attributed to a low restriction exhaust manifold. Scott (1984) also describes how the volumetric efficiency of a small normally aspirated industrial diesel was improved by an aerodynamically optimized intake manifold.

Pulsation or resonant tuning of intake and exhaust systems has been the subject of considerable research in the last 20 years. It is maturing to the point that it can be found in many newly developed engines. Benson (1964) studied the design of these systems for large marine engines. His work was one of the first rational approaches to this problem. Since then, there are many examples of work on this problem. Meier (1977) describes a tuned system that improves part-load economy of large four-stroke diesels. Tabaczynski (1982) presents a detailed exposition of the importance of tuning to improved exhaust and intake system performance. According to his results, volumetric efficiency can be increased to 115 percent by proper tuning of the system. Scott (9183) describes six European and one American diesel engine manufacturers that are incorporating tuned systems into their engine designs, all of which have improved fuel economy and performance.

There are two basic methods of resonant tuning the intake and exhaust systems of a diesel engine. These methods are called the organ pipe theory and the Helmholtz resonator theory. Ohata (1982) describes an application of the organ pipe theory to the intake manifold of a four cylinder engine. Cser (1978) discusses the Helmholtz method applied particularly to diesel engines with turbochargers; although Vorum (1976) shows how both theories apply to some systems.

Both methods essentially use combinations of acoustical elements that utilize the energy present in the pulsations in the diesel engine intake and exhaust to improve the cylinder charging and exhaust scavenging. Both methods produce gains in volumetric efficiency of 10 percent and this gain can be tuned to a particular operating speed. The Helmholtz method has an advantage in that it doesn't require the amount of space that is necessary for the longer pipes used in the organ pipe method.

Based on the above work, both pumping loss reduction and pulsation tuning are attractive methods of improving the volumetric efficiency of the diesel engine. These methods are based on mature technology, and components embodying these techniques could be retrofitted to existing power plants.

A summarizing of the results of the literature search follows.

1. Part-load combustion efficiency can be improved by:

    a. maintaining the fuel, intake air, combustion chamber, coolant and oil temperature at design conditions;
    b. insuring complete fuel atomization by proper injector design; and
    c. controlling injection timing to compensate for ignition lag.

2. Alcohol fumigation does not improve part-load performance of diesel engines. Aspiration of other fuels may improve part-load fuel economy.

3. Both pulsation tuning and pumping loss reduction are attractive methods of improving the volumetric efficiency of a diesel engine.

ALASKA FIELD SURVEY

A survey (see Appendix A for a copy of the survey form) was sent out to 13 different Department of Transportation and Public Facilities (DOT&PF) maintenance shops in the DOT&PF Northern Region. Of these 13 units, 8 responded and the results were compiled. In addition, two more DOT&PF maintenance shops were contacted by phone and interviewed. Numerous individuals and vendors throughout the state were also consulted.

The most common problems cited when running a diesel engine at part-load include:

1. hydrocarbon build-up;

2. rings sticking;

3. plugged injectors;

4. glazed pistons and cylinder walls;

5. slobbering (the appearance of oil droplets in the exhaust);

6. burning oil; and

7. shortened engine life.

Shortened engine life is, of course, caused by some of these other problems. These problems cost the generator set owner quite a bit of money when down time, labor and parts are considered.

Some of the plausible solutions or problem alleviations given were to:

1. use electric heaters or variable load banks to keep the engine running at a level closer to capacity;

2. derate the fuel system;

3. run the engine at full-load periodically to help purge it of hydrocarbon deposits;

4. keep the block temperature high;

5. use an efficient fuel injection system;

6. size the generator set correctly (avoid oversizing);

7. use a turbocharger to help keep block temperature and air pressure high enough; and

8. instruct operators how to correctly maintain and care for the generator set(s) they use.

Many of these solutions have been attempted in Alaska at some time with 1 and 3 being commonly used. Even though 4 is used on stand-by emergency units, it is not used in Alaska as a solution to part-load problems. Turbochargers (7) are a standard part of many engines. But, this feature is not deliberately utilized in Alaska as a solution to part-load problems.

DIESEL ENGINE PROBLEMS AT PART-LOAD OPERATION

Hydrocarbon Build-up

Hydrocarbon deposits are probably the most prevalent problem encountered when operating a diesel engine below 60 to 70 percent load. These deposits may prevent the valves from opening and closing properly. When hydrocarbons collect on the rings, the rings do not seal properly and this can lead to blow by and high oil consumption, according to Mr. Mickey Allen, a diesel engine mechanic at N C Machinery, Inc., in Fairbanks.

Mr. Scott Butterfoss, a remote maintenance worker at DOT&PF's Chandalar Unit, stated that although the problem occurs infrequently, he has come across carbon build-up in the crankcase ventilation tube where it is emitted into the exhaust system on their 75 kw Detroit diesel that is operated between 50 and 70 percent of capacity.

According to Mr. Don Kling, a sales representative at the Kem Equipment Company in Anchorage, carbon build-up becomes a problem when the engines are run at less than 40 percent of full load, and can occur even at loads up to 60 percent of capacity.

Mr. Jim Renk of Alaska Generator and Sales, Inc., in Anchorage, recommends maintaining a load of at least 50 percent with a load of 85 percent preferred.

Rings Sticking

Mr. Richard Burton, foreman at DOT&PF's South Fork Unit, wrote that they have a Perkins-Kohler diesel engine-generator set that is run continuously at 50 percent capacity. Although electric heaters are used to help increase the load, there was still a problem with rings sticking. As a consequence, the engine began using excessive oil and also began blowing oil out of the rear main. The rings had to be replaced and the engine overhauled.

Plugged Injectors

Although plugged injectors were expected to be a problem encountered with diesel engines running at part-load, none of the nine DOT&PF employees surveyed listed it as a problem. Also, none of the seven vendors or miscellaneous users questioned mentioned that they had any trouble with injectors plugging.

Mr. Mickey Allen of N. C. Machinery in Fairbanks, did state that he thought that plugged injectors would not be a problem because any dirt getting into the fuel would first create problems in the fuel supply system prior to the injectors. Of course, dirt getting into the fuel would not be a part-load problem per se.

Glazed Pistons and Cylinder Walls

Mr. Jon Holmgren, mine foreman for Northwest Exploration, said that a major problem they have with running their diesels at part-load, besides the shortened engine life, is the glazing of pistons and cylinder walls.

After the pistons and cylinder walls become glazed, the engine begins burning oil and the problem increases until the engine is rebuilt. Mr. Holmgren believes the problem could be alleviated if they could either purge the engine periodically by running it at full capacity or by using dummy loads. But, because Northwest Exploration doesn't have enough electric heaters and those they do have are in cabins where little or no heat is desired during the summer, they are never able to do this. So, they must rebuild the cylinders, heads, valves and replace the pistons every third summer, which is the equivalent of one year of continuous use.

Mr. Cacy Patton of the Bedrock Mining Company in Fairbanks, and Mr. Joe Sullivan, a mechanical engineer for the Bethel School District, both reported problems with carbon build-up on valves and rings on units run at part-load.

Slobbering and Burning Oil

Mr. Dennis Moen, Building's Superintendent, DOT&PF Northern Region, defines slobbering as the appearance of unburned fuel and/or oil in the exhaust. According to Mr. Moen, slobbering is one symptom of part-load induced problems.

Mr. Tom Bowdre, foreman at DOT&PF's Gardiner Creek Unit, stated that the camp used to operate a 50 kw generator set and did not have a big enough load on it to prevent it from blowing oil out the exhaust. They solved this problem by replacing the 50 kw unit with a 30 kw generator set.

In addition to Mr. Tom Bowdre; Mr. Cacy Patton of Bedrock Mining Company, Mr. Don Kling of Kem Equipment Company, Mr. Wayne Gibson of Gibson Placer Mines and Mr. Joe Sullivan of the Bethel School District stated they had observed slobbering of the exhaust in diesel engines operated for prolonged periods of time at part-load.

Another symptom of part-load operation is the excessive oil used and burned. Mr. Don Bascom, foreman at DOT&PF's Eighty-Mile Camp, wrote that their 22 kw Kohler, which is run at 25 percent of capacity, uses excessive oil.

Shortened Engine Life

Although not seeming to be a direct problem like those previously discussed, shortened engine life is a serious and expensive result of operating a diesel at part-load for prolonged periods of time. Both repair and replacement are costly endeavors and only temporary solutions to the problem.

Mr. Jon Holmgren of Northwest Exploration, feels that shortened engine life is probably the worst effect of part-load operation. Engine overhauls are expensive -- especially if there is not a skilled mechanic on site and the engine must be flown to Fairbanks or Anchorage, or a mechanic flown out to the job site. He mentioned a figure of around 10,000 hours for the mean time between overhauls (mtbo) for an air cooled Deutz-diesel Kato 50 kw generator set operated typically at about 10 percent of capacity. No one else surveyed had detailed information on mtbo. Both Jim Lake, a consulting electrical engineer in Fairbanks, and Fred Henkel, branch manager of Emerson Diesel in Fairbanks, said there were too many variables to generalize. But, they each indicated that a mtbo of at least 20,000 hours should be possible for a properly maintained and operated system. They did not have enough information to be quantitative concerning the effect of part-load on mtbo.

RECOMMENDATIONS

Elevated Block Temperature

Mr. R.M. "Rusty" Foyle of Generator Systems and Technology in Fairbanks, thinks the best solution to problems induced by part-load operation is to keep the block temperature high enough so that the fuel burns better at partial load. This could be done by thermostatically regulating the water jacket temperature and the intake air temperature.

A recommendation by Mr. Brendan Sandiford and Mr. Christopher Wade in their report "Improving Part Load Performance of Diesel-electric Generators" is to fit an auxiliary electric coolant heater to the engine powered by the generator unit (see References). This heater would help keep the engine at operating temperature and also supply a slight load on the generator, thereby improving the engine's efficiency.

Load Banks

Dummy loads are resistive load banks (i.e., electric heaters) added to the generator to bring the total load closer to capacity and out of the part-load range. Most of the users and vendors contacted mentioned the use of load banks and thought it a practical method of alleviating the part-load induced problems.

It was interesting to observe that out of the six DOT&PF maintenance units surveyed that had part-load problems, only three used load banks. Using resistance heating or installing electric heaters might be a worthwhile investment at these sites.

Mr. Harry Dullinger, Building Maintenance Manager for DOT&PF Central Region, recommends using the excess power in rural schools for electrical heat and, in this way, keep the generator operating more efficiently while supply the school with an economical source of heat.

Mr. Mickey Allen of N.C. Machinery, Inc., in Fairbanks, recommends normal operation at at least 30 percent load and the use of load banks for conditions when the load falls below 30 percent. He estimated that the load factor varied from 10 to 80 percent for diesel-generators he has observed with the average being around 30 percent. Most generators are warm by virtue of being in warm buildings and Mr. Allen recommends the intake air be kept at at least 60°F. The exhaust temperature is typically around 950°F and one must be leary of exhaust temperatures above 1,000°F because of the danger of overheating. Similarly, one must be cautious if fumigation is practiced because of the danger of excessive cylinder temperatures and pressures.

Derating the Fuel System

The Bethel School District was having part-load problems with their generators at Kipnuk and Akiak. After contemplating the idea of installing load banks to increase the load on the generators, the district decided to try another approach. Cummins, who manufactured the two 855T diesels the district was having trouble with, suggested derating the fuel pumps so that capacity would be 75 kw instead of the original capacity which was about twice that amount. The total cost including shipping was around $200. According to Mr. Joe Sullivan, this derating will eventually be done for all the generators in the Bethel School District.

Mr. Fred Henkel, branch manager of Emerson Diesel in Fairbanks, stated that derating the fuel pump should help for all engines, but also said that there could still be problems if the engine is oversized. He added that derating may extend the life of a system.

Mr. Tom Cowden of Evans Equipment Company in Anchorage, also recommended derating the Fuel system if the diesel engine is going to be run at part-load frequently. Mr. Cowden also said that another possible solution to the part-load problem might be to use a small fuel injector. Of course, if full-load conditions are anticipated occasionally, derating is not a solution unless another source of electricity is available.

Purging Engine Periodically

Several users recommended purging the engine periodically to break the glaze on the cylinder liners and to get rid of hydrocarbon build-up on the valves and pistons that accumulated during part-load operation.

If the valves are gummed up, Mr. Mickey Allen of N.C. Machinery in Fairbanks, recommends running the engine at full load for 13 hours to clean out the deposits.

Mr. Fred Henke of Emerson Diesel, mentioned that purging is helpful if done early enough. If the engine is allowed to run at part-load for too long, the inner cylinder walls will have to be rehoned to eliminate the glazing.

Mr. Dennis Moen of DOT&PF Northern Region, recommends running the diesel engine at full load every 10 days or so during the summer months to remove the hydrocarbon deposits.

Mr. Jim Lake, a consulting electrical engineer in Fairbanks, provides specifications for installation of diesel-alternators. He recommends running at at least 75 percent load and finds that loads of greater than 50 percent are acceptable. Mr. Lake has found that engines putting out as little as 15 percent of their normal capacity can be brought back to reasonable operating condition by running at full load for, say, three days. To help maintain proper temperatures in the engine block, Jim sometimes provides modulating valves in the cooling system.

Turbocharging or Supercharging

Turbocharging helps minimize the drop in combustion chamber temperature and pressure under part-load operation by heating the intake air. Providing the inlet air density is maintained at reasonable levels, the higher inlet temperature can help compensate for the lower combustion temperatures encountered in part-load operations. Some of the vendors contacted recommended installing a turbocharged engine over a naturally aspirated one for better part-load operation. Fred Henkel mentioned that he didn't think turbocharging was a high maintenance item. None of the operators surveyed mentioned anything about turbocharging or recommended it.

> AUTHOR'S NOTE: A recent article by Mr. G.I. Coupe in Diagnostic Engineering, the newsletter of the Institution of Diagnostic Engineers (November/December 1984; see references) discussed some part-load carbon build-up problems that occurred in diesel generator sets used on ocean going ships. These engines were turbocharged and burned heavy fuel oil. Severe carbon fouling was found in the inlet ports of one engine at 1,100 hours in service at less than 60 percent rated load. The problem, particularly at lower loads, was that the scavenge air pressure was not high enough to overcome the

exhaust pressure due to the turbocharger during valve overlap, and blow-back of incomplete combustion products was occurring in the intake ports. This caused the carbon build-up in the intake system.

Two suggestions were made to alleviate this problem: (1) valve overlap should be reduced by installing a camshaft that opens the exhaust valve earlier and closes the intake valve later, and (2) the engines should be fitted with a turbocharger that maintains higher intake manifold pressures at lower load ratings. From this article, it is apparent that the turbocharger design can have a significant influence on the part-load life of a diesel engine.

Sizing Generators Properly

Much of the part-load operation problem can be eliminated from the start by correctly sizing the generator to the immediate and near future (not long term) needs of the owner. If the engine is sized too large, it will have to run at a reduced load for an extended period and may ultimately fail before it can be used to its full economic potential. As mentioned earlier, running the generator for a long time at part-load shortens its usable life. It will also cost more to run and maintain if it were used more efficiently or a smaller generator could do the same job.

Mr. Lloyd Hodson, General Manager of the Alaska Village Electric Co-operative, Inc., emphasized the importance of a properly sized generator so that one could operate away from the low load portion of the efficiency curve. If one is forced to operate in this region, a large portion of the energy input is used to simply overcome basic friction and pumping losses.

Mr. Jerry Larsen and Mr. Peter Hansen of the Alaska Power Authority, felt very strongly that many problems in rural Alaska relate to a lack of engineering in providing system specifications and improper operation and maintenance. They believe the vast majority of systems in Alaskan villages to be oversized.

Mr. Richard Burton, foreman at DOT&PF's South Fork Unit, recommended that the DOT&PF Engineering Department do some research on the generator size requirements at the different DOT&PF units. For winter use, Mr. Burton recommends a large generator and for summer use a small generator that could also act as the standby unit during the winter.

Instructing Operators in the Care and Maintenance of Diesel-electric Generator Sets

Mr. David Rowland of Alaska Diesel Electric, Inc., in Anchorage, thinks that the number one problem connected with running the engines at part-load is the ignorance of the operators. Alaska Diesel Electric, Inc., has been giving Lister engine maintenance and trouble shooting classes in an effort to solve this problem.

Mr. Mickey Allen of N.C. Machinery, Inc., in Fairbanks, has noticed oil not being changed often enough in the field and often a failure to use rust inhibitors in cooling systems. This can lead to pitch forming on the cooling system side of the cylinder liners. Moreover, minute amounts of combustion gases can get into the cooling systems and create acidic conditions. This, in turn, can eventually lead to leaks in the cylinder liners. The proper pressure must be maintained on the cooling system side to avoid boiling which leads to pitted liners and poor heat transfer. These concepts don't directly relate to part-load operation, but the basic idea is that proper operation and maintenance will help immensely in preventing problems from occurring. Mr. Allen believes operating and maintenance procedures could be improved for all segments of diesel engine users including DOT&PF. Similarly, the users would benefit greatly from additional training.

Miscellaneous

Other comments of Mickey Allen that could have an impact on the understanding of part-load operation relate to some of the construction and operational details of diesel engines. Since engine performance and efficiency under any kind of load is related to the delay angle between the end of fuel injection and the beginning of the pronounced pressure rise, a rational approach to minimize part-load problems must account for differences between engines. For example, the timing is fixed on the large diesel engines used to drive generators because they are set to run at 1,800 or 1,200 rpm. So, one can't compensate for changes in delay angle under part-load by altering the timing.

> AUTHOR'S NOTE: In diesel engines, as in Otto engines, speed is mainly controlled by the amount of fuel injected or ingested into the engine, not the timing of the injection. In automobile engines, fixed ignition timing was abandoned in the late 1920s. With diesel and Otto engines, the ignition or injection timing must vary with load if the engine is going to respond efficiently to changes in both speed and load. The use of fixed injection in a diesel engine is an archaic concept that has remained with us, first, because of its simplicity, and second, because it has been satisfactory for heavily loaded constant speed engines. The engine manufacturer's lack of motivation to change has maintained its existence. When the users have demanded better economy and emissions, the injection system designs have changed to accommodate the demands. This is indicated by the new systems described in the literature (Ring, 1984; Scott 1984).

A couple of different vendors also mentioned that automatic systems should be used so that one generator can be operated at full load and another on standby that can be started on line when the power demand exceeds the maximum output of the primary generator. An example of a device that can do this is the Woodward 2301 electric generator system with a parallel (load sharing) control box.

Another recommendation was given by Mr. Jim Renk of Alaska Generator and Engine Sales, Inc. He recommends using a water separating unit on the diesel to remove any water from the fuel system. This would be a good thing to have on any diesel engine -- not just those run at part-load. Water separators are inexpensive and simple to install.

Mr. Robert Brouillette, Manager of Operations and Maintenance for Alaska Village Electric Co-operative (AVEC), emphasized the importance of keeping the generator set as simple as possible and to avoid highly technological adaptions or accessories that might improve performance at part-load, but would definitely give maintenance and repair problems to most rural communities that do not have highly skilled mechanics operating their generator sets.

Sandiford and Wade (1983) found that heating the intake air and using a fuel additive each increased thermal efficiency at loads below 60 percent. However, the opposite effect was observed at higher loads. These data were obtained using a small (17 hp) and minimally instrumented diesel. More work is needed to clarify these conclusions.

The Chena Hot Springs Resort has a 30 kw diesel running during the day and typically adds a 20 kw unit to that at night. According to Mr. Phil Panaritus, the generators run at close to full load continuously and have presented no problems. They perform all the routine maintenance except pull the heads. The units are about four years old.

Three people mentioned that they had little or no problems with operating their diesels at part-load. Mr. Richard Symons, Highway Maintenance Foreman II at DOT&PF's Central Maintenance Station, said that they have no problem with their 30 kw Cummins that is run at only 25 percent load. He did recommend that the oil be changed every 240 hours.

Mr. Robert Brouillette said that AVEC has been very pleased with the overall success that they have had with their Allis Chalmers generator sets due to their simple design.

Mr. Frank Papasavas, Alaska Sales Representative for Cummins Northwest-diesel, Inc., in Anchorage, does not think that there are serious problems with running the diesels at part-load. He did say that there is some carbon build-up, but that it isn't a real problem.

Aside from these individuals, most everyone felt that considerable problems could be encountered by running a diesel engine at partial load.

Mr. Jim Lake insists the generator and engine be tested together by either the generator or engine manufacturer before being used in the field. He also insists on enclosures and specifies block heaters. For unusual motor starting conditions, he may specify a booster package to excite the generator so the output voltage will not decrease excessively under heavy motor starting loads. Nelson absorber systems are recommended for generators that run more or less continuously because of concern with vapor emissions from the crankcase. Only very small engines are air-cooled and this can present problems if the system is only exposed to warm building air. If the engine is in contact with ambient air, one must allow for it to be gradually warmed up before starting.

Even though 1,800 rpm machines are standard, Mr. Lake finds 1,200 rpm units present less maintenance problems. These units are constructed by altering an existing 1,800 rpm engine. Generally, his specifications are based on standards manufacturer data such as that available from Caterpillar, Kohler, John Deere, GM and Cummins. Although Mr. Lake mentioned that most governors today are electronic, Mr. Allen stated that the state of Alaska used diesels such as those made by Caterpillar and Detroit that have mechanical governors.

Essentially all the engines mentioned in the 30 kw to, say, 500 kw size range are water cooled. Deutz makes air cooled engines in this size range. Likewise, these engines are all four-stroke per cycle units with Detroit Diesel being the exception. Jim Lake mentioned Caterpillar, Cummins, Onan and Detroit Diesel as being widely used and dependable engines. Fred Henkel said these "heavy duty engines would cost more initially, but last longer." No one contacted had information in life cycle costs.

In summary, the problem encountered by the various operators, users and vendors included: (a) hydrocarbon build-up, (b) rings sticking, (c) plugged injectors, (d) glazed pistons and cylinder walls, (e) slobbering, (f) burning oil and (g) shortened engine life. Of these problems, the one most often complained about was hydrocarbon build-up.

The recommendations given included: (a) using load banks, (b) derating the fuel system, (c) periodically purging the engine, (d) keeping the block temperature high, (e) using an efficient fuel injection system, (f) sizing the generator set correctly, (g) installing or purchasing a generator set with a turbocharger and (h) instructing operators and users in the proper care and maintenance of diesel-electric generator sets.

Of the recommendations, installing load banks was the one listed most frequently.

ALASKAN EQUIPMENT SURVEY

In an effort to find out who the diesel electric generator manufacturers are that are supplying Alaska with generator sets in the 30 kw to 150 kw range, vendors and users were contacted throughout the state.

Vendors in Fairbanks and Anchorage were asked to rank the diesel engines and generators they sold in order of most volume sales. Various users were consulted and asked which generator sets they were currently using. The results of this survey are given below.

DISCUSSION

Vendors Contacted

Fourteen vendors were contacted in Anchorage and four in Fairbanks. The Anchorage vendors consulted were:

1. Alaska Diesel Electric, Inc.
2. Alaska Generator and Engine Sales, Inc.
3. Craig Taylor Equipment Company
4. Cummins Northwest-Diesel, Inc.
5. Evans Equipment Company
6. Fessler Equipment Services, Inc.
7. Hayden Electric Motors, Inc.
8. Industrial Engine Specialists
9. Industry Services, Inc.
10. Kem Equipment
11. Kenworth Alaska
12. North Country Diesel
13. Northern Hydraulics, Ltd.
14. Waukesha Alaska Corporation

The Fairbanks vendors contacted were:

1. Emerson GM Diesel, Inc.
2. Evans Equipment Company
3. Generator Systems and Technology
4. N C Machinery Company

The addresses of the vendors are listed in Appendix B.

Users Contacted

1. Alaska Department of Transportation and Public Facilities
2. Bedrock Mining Company
3. Gibson Placer Mines
4. Northwest Exploration

TYPES OF EQUIPMENT IN USE

Diesel Engines

The vendors surveyed sell diesel engines manufactured by 25 different companies. Engine suppliers that are sold by two or more vendors include:

1. Caterpillar
2. Cummins
3. Detroit Diesel-Allison
4. Deutz Diesel
5. John Deere
6. Komatsu
7. Lister
8. Mitsubishi
9. MWM-Murphy
10. Waukesha Diesel

Of these manufacturers, the following are sold by at least three different vendors:

1. Cummins
2. Detroit Diesel-Allison
3. John Deere
4. Lister
5. MWM-Murphy

Detroit Diesel-Allison is carried by four different vendors.

Detroit Diesel-Allison and Caterpillar are the two main suppliers of diesel engines in Fairbanks. Emerson GM Diesel, Inc., and Evans Equipment Company sell Detroit Diesels and N C Machinery sells Caterpillars. Evans Equipment Company also sells Komatsu engines.

Generator Systems and Technology sells:

1. Lister
2. Deutz Diesels
3. John Deere
4. Onan Diesels

Generators

In the Anchorage area, there are three generator suppliers that are overwhelmingly popular in the 30 kw to 150 kw range:

1. Kato
2. Lima
3. Marathon

Kato is carried by six Anchorage vendors, and Lima and Marathon are both carried by four different Anchorage vendors.

The most common Fairbanks generator suppliers are:

1. Kato
2. Lima

3. International Electric
4. Marathon

Most diesel-electric generator sets come up to Alaska already assembled. Anchorage vendors that do assemble some of their own generator sets include Alaska Diesel Electric, Inc., Waukesha Alaska Corporation, North Country Diesel and Industry Services, Inc.

Emerson GM Diesel, Inc., does some diesel-electric generator set assembly in Fairbanks, but most sets come assembled from General Motor's plant in Seattle. Detroit Diesel-Allison no longer supplies Emerson GM Diesel with complete generator sets.

The Alaska Department of Transportation and Public Facilities (DOT&PF) owns approximately 34 diesel-electric generator sets in the Interior. Most of these in use today are manufactured by Caterpillar. DOT&PF also owns diesel-electric generator sets manufactured by:

1. Kohler
2. John Deere
3. Onan
4. Waukesha
5. Detroit Diesel-Allison
6. Witte

SUMMARY

Table I lists the various diesel engines and generators currently being sold in Anchorage and Fairbanks and those being operated by several diesel electric generator set users. The letters in each column represent different vendors or users. Each company can be identified by consulting Figure 1, which is the key to Table I. If a vendor stated that a specific engine or generator manufacturer was the number one seller in the store, the letter representing the vendor was placed in the column title "#1 Seller by Vendor" in the row beside the manufacturer's name. If the vendor said the engine or generator manufacturer was the second or third best seller, the vendor's identifying letter was placed beside the appropriate supplier's name under column two or three, respectively. The last column represents the total number of vendors that sell and the total number of users that use a specific brand of diesel engine or generator.

Anchorage Vendors:

A - Alaska Diesel Electric, Inc.
B - Alaska Generator and Engine Sales, Inc.
C - Craig Taylor Equipment Company
D - Cummins Northwest-Diesel, Inc.
E - Evans Equipment Company
F - Fessler Equipment Services, Inc.
G - Hayden Electric Motors, Inc.
H - Industrial Engine Specialists
I - Industry Services, Inc.
J - Kem Equipment
K - Kenworth Alaska
L - Northern Hydraulics, Ltd.
M - Waukesha Alaska Corporation

Fairbanks Vendors:

N - Emerson GM Diesel
O - Generator Systems and Technology
P - N C Machinery

Users:

Q - Alaska Department of Transportation
R - Bedrock Mining Company
S - Gibson Placer Mines
T - Northwest Exploration

FIGURE 1 (TABLE I KEY)

TABLE I

ALASKAN VENDOR AND USER SURVEY

DIESEL ENGINES	#1 SELLER BY VENDOR	#2 SELLER	#3 SELLER	TOTAL VENDORS/ USERS
Allis-Chalmers				Q
Bolstad		B		B
Caterpillar	P	K		KPQ
Cummins	KD		E	DEKQS
Detroit Diesel-Allison	EHN		K	EHKNQ
Deutz Diesel	M			MOQRT
Fairbanks Morse				Q
Farymann Diesel	L			L
Ford Industrial				J
International Harvester				S
ISM				A
John Deere	C	A		ACOQR
Kohler				Q
Komatsu		E		AE
Kubota				A
Lister Diesels	AJ			AJO
Lombardini	I			I
MWM-Murphy		F		FCL
Mitsubishi				CJ
Onan				OQ
Pacific Diesel	B			B
Perkins	F			F
Volvo				A
Waukesha Diesel		M		JMQ
White Hercules	G			G
Witte				Q

GENERATORS	#1	#2	#3	TOTAL
Bolstad		B		B
Caterpillar	P			PQ
Cummins				D
Detroit Diesel-Allison				QS
Farymann	L			L
International Electric				N
John Deere				OQ
Kato	FGM		C	ACFGJMPQT
Kohler	I			IQ
Lima	AJ	CM		ACJMN
Marathon	D	F		CDFJN
Northern Lights		A		A
Onan				OQ
Pacific Diesel	B			B
Stamford	C			CJP
Waukesha				Q

SURVEY OF MANUFACTURERS AND VENDORS IN THE LOWER 48 STATES

This survey consisted of written and phone inquiries to diesel-generator and support equipment vendors and manufacturers in the lower 48 states. The results of the survey of the diesel-generator set manufacturers and dealers will be presented first, and the summary of information obtained from the equipment manufacturers and vendors will be presented second.

Diesel-generator Set Manufacturers and Dealers

The questionnaire used in this survey is shown in Appendix C. A complete list of all the manufacturers, vendors and personal contacts is also contained in this appendix. Response to the written inquiries was poor. Twelve forms were sent out and only two companies responded. However, much of the information was obtained from additional phone inquiries.

The results of the survey are presented below. The question is presented with the typical response given underneath it.

1. Does your firm sell diesel generators for service in arctic or subarctic climates such as the Alaskan bush?
   yes ______ no _____

   In all but one case, the response was yes. In that case, it was the local Caterpillar dealer whose territory did not cover Alaska.

2. If so, how many per year?

   The response to this question ranged from one to two per year to 500 total.

3. What are the optimum or recommended operating conditions for these units?

Fuel temperature? -- Above cloud point or use preheater.
Jacket Water Temperature? -- 180 to 200°F, 140°F min.
Combustion Intake Air Temperature? -- 85 to 122°F max.
(140°F max in intake manifold)
Lube Oil Temperature? -- 210 to 220°F max.
Minimum Continuous Operating Load? -- 25 to 50 percent.

4. What modifications do you perform on a standard diesel generator set to make it more suitable for service in arctic or subarctic climates? If you have a "standard arctic package," please describe its important features.

Only four vendors had an arctic package. The others build units to customers' specifications. Some of the important features of these packages were:

a. automatic radiator-mounted load banks;
b. jacket water heaters; and
c. fuel heaters.

5. What is the additional cost of your arctic package installed on a 100 kw unit?

Costs ranged from $1,500 to $10,000 depending on the customer's requirements.

6. Does your arctic package allow long term operation of the diesel generator at part-load?
yes _____ no _____

There were two "yes" responses to this question. One manufacturer stated that his units could operate at 25 percent load indefinitely. The common response was "no," however. One large manufacturer stated emphatically that diesel engines were not designed to operate at part-load, and should not be operated that way.

7. If not, what is the maximum recommended time for operation below the recommended minimum load? (Please answer this question even if you do not have an "arctic package.")

Typical response to this question were: continuously at 50 percent load, 2 hours at 25 percent, 6 hours at 40 percent, continuously at 25 percent and maximum of 2 hours at 50 percent.

8. Do you have a design document that provides guidance and recommendations in the application of your generator sets?
yes _____ no _____
(If you do, please send us a copy.)

Both Caterpillar and Cummins (see References) responded with very good design documents and handbooks relating to diesel-generator set applications.

9. What mechanical problems have you observed in diesel generators that operate at light loads for extended periods?

No new problems were uncovered. The major responses to this question were: "wet-stacking" (slobbering), "dilution of lube oil," "carbon build-up in cylinders," "coking of the stack" and "glazing of cylinder walls."

10. What is the climate where the problems are most severe?
cold _____ temperate _____ tropical _____

The majority of responses indicated the cold climate was most severe. However, one vendor thought the desert was the worst.

11. Are you aware of any modifications that will allow the diesel generator to operate at low loads without sustaining any long-term mechanical problems?
yes _____ no _____

If yes, please explain.

Two vendors responded to this question with the automatic radiator-mounted load bank. As the load on the generator falls below a preset level, a control circuit cuts in this load bank that is mounted on the radiator. The hot air for the load bank in turn heats the coolant and engine, thereby maintaining the coolant temperature. Automatic over-temperature controls are provided to keep the engine from overheating. This device is described in a reprint available from AVTRON Manufacturing, Inc., (see References).

12. Who are the vendors of these items and what are the prices?

The vendors for this item are AVTRON and Con-Select (Appendix C). The price is $2,100 for a 100 kw generator set.

13. Would you install retrofit devices on diesel-generators if they successfully improved part-load fuel economy?
yes _____ no _____

Most manufacturers and vendors would install devices if requested by the customer.

14. How would you solve the problem of supplying power with a diesel generator(s) when the load can vary between 20 and 100 percent and may stay at 20 percent for long periods (2 months)?

Other than using a load bank, the common reply was to properly size several units and parallel them.

15. Do you have any other comments pertaining to part-load fuel economy of diesel-electric generators?

The most common comments pertained to selecting the proper sized units using load banks and paralleling units. The chief engineer at the local Caterpillar dealer cautioned against using turbocharged engines in critical situations. The turbo adds complexity and is the most unreliable part of the engine.

16. Would you like an executive summary of the results of this study?

    yes _____ no _____

    Everyone polled wanted a copy.

Equipment Manufacturers and Vendors

The survey of equipment manufacturers and vendors was conducted by phone and personal letter. Generator manufacturers, fuel and control system companies, and load bank builders were included in this group. The purpose of the survey was to obtain information about specific products such as injector pumps and prices. Not all the price information is presented here. Some of it is contained in the Economic Analysis and Continuing Research sections of this report.

The major results of this survey are presented below:

1. Injection pumps with built-in automatic or manual advance have been produce by two companies; Stanadyne and United Technologies Corporation (UTC), for at least 25 years. They have been used mainly for cold-starting assistance by several engine manufacturers (Allis Chalmers, International Harvester, Mack).

2. Control systems that would advance injection timing automatically at low generator load can be assembled from presently available electro-mechanical components produced by Barber Coleman Company.

3. Microprocessor-controlled injector pumps will also advance timing under low load. However, they are a new product that is not on the market yet. Although the Stanadyne and UTC units are being heavily advertised, they are still in the development stage, and it may be two years before production units are available.

4. The major problem is that the injection advance point and magnitude must be determined by the engine manufacturer with performance tests. It is an engine-specific modification that the pump manufacturers do not perform. Therefore, the motivation to produce an injection pump and control system that advances the timing under part-load must come from the engine manufacturer. This kind of system most likely cannot be retrofitted to older engines.

5. The addition of a microprocessor-controlled part-load advance system would add about $1,000 to the cost of a generator set.

ANALYSIS OF RESULTS

The objective of this study was to assess the feasibility of the following methods of improving the part-load efficiency of diesel-electric generators:

1. improvement of the combustion, intake and exhaust system efficiency by pumping loss reduction and acoustical pulsation tuning;

2. aspiration or fumigation of natural gas, methanol or other fuels into the intake system to improve part-load combustion;

3. improve part-load combustion through better fuel atomization and by maintaining optimum fuel, intake air and combustion chamber wall temperatures; and

4. improve governor and injection pump controls for optimum part-load injection timing.

The results of the literature search, Alaska field and equipment survey and the lower 48 manufacturer and vendor survey produced the following possible feasible methods of improving part-load efficiency.

1. Maintain optimum fuel, inlet air and combustion temperatures at part-load conditions. This can be accomplished with a fuel heater, engine coolant heater or radiator load bank. The intake air can be heated with a heat exchanger using waste exhaust heat.

2. Modify injector design for better part-load fuel atomization. Derating the engine by reducing the size of the injector or nozzle is one way to accomplish this goal. However, this is a semipermanent modification and can only be used where the load remains at a constant low level. Improved injector designs are continually being introduced, but these are being

developed for new engine designs. There are no injectors on the market specifically designed to improve part-load performance of present engine designs.

3. Optimized pulsation tuning and pumping loss reduction applied to intake and exhaust systems to improve efficiency. This technology is presently being incorporated in new design engines, and could be applied to existing engines if a development program were undertaken. This technology could be helpful in preventing blow-back in engines (described previously) where the turbocharger exhaust pressure is greater than the intake manifold pressure during valve overlap at low load.

4. Parallel operation of several smaller units so that they are always operating at high efficiency.

None of the methods of improving part-load efficiency are presently considered feasible. Fumigation of alcohol does not improve part-load efficiency, but fumigation of hydrogen does. More research is necessary on this subject.

Advance injection timing improves part-load efficiency in most cases, but the hardware is not presently available to use this method on existing engines. In the future, however, such devices will probably become commonplace.

ECONOMIC ANALYSIS

The final feasibility of the aforementioned methods of improving part-load performance will be determined by the following factors:

1. improvement of part-load efficiency;

2. purchase and installation costs;

3. maintenance and operating costs;

4. cost of electricity at part-load; and

5. maintenance requirements in terms of personnel skill level and parts availability.

All of these items except number 5 are part of the economic analysis and are ultimately reflected in the cost of electricity. Number 5 will be considered in the final recommendations. The method of analysis will be discussed first. Then the results will be summarized, and finally the details of the analysis, including cost data and assumptions will be discussed. We are not including costs for backup systems or distribution systems, only the basic diesel-electric generator.

The economic analysis is based on the method described below. In the analysis, the cost of electricity produced by the plant in dollars per kwhr is determined by summing the maintenance and operating cost, investment cost and fuel cost. This is described by the following formula (Berger, 1968):

$$C_E = \frac{(M+O)}{U} + \frac{C_m \left[\frac{1}{L} + i\right]}{U \times F} + \frac{K_r \times 3413}{T \times r_F} \qquad (1)$$

Where

C_E = cost of electricity in \$/kwhr
(M+O) = annual maintenance and operating cost in \$/kw
U = usage in hrs/yr including effect of availability
C_m = total investment cost in \$/kw, including installation cost
L = life in years
i = annual interest, percent
F = capacity in percent full load
K_r = fuel cost in \$/gal
T = fuel heating value, BTU/gal
r_F = efficiency as a function of capacity - percent

The methods of improving part-load performance were evaluated by comparing the cost of electricity and annual savings with these methods compared to a baseline. The baseline condition consists of the diesel-generator and external dummy load. It is hooked up such that the diesel generator never operates below 50 percent capacity and the extra power is dissipated.

Only three of the feasible methods of improving part-load performance were evaluated. The first method which consists of maintaining the optimum fuel, inlet air, oil and coolant temperature is called the part-load package. Derating the engine, though feasible in long-term part-load operation, is not considered. The second method, which consists of tuned and aerodynamically efficient manifolds is considered as an addition to the first. The third method, which is the parallel operation of smaller units, is compared separately.

Summary of Results

The cost analysis of these methods was performed on three engine combinations from two manufacturers, Caterpillar and Detroit Diesel. The matrix of these combinations is shown in Table II.

The results of the calculations of cost of electricity are shown with cost analysis data in Tables III and IV. The development of the cost data and underlying assumptions will be covered in the subsequent section. Figures 2 and 3 display the cost of electricity versus capacity for the Caterpillar and Detroit Diesel units, respectively.

In most of the cases on Figures 2 and 3, the difference in cost is only one or two cents per kwhr. But, a very low loads, the differences can be substantial. We can get a better picture of the advantage of one method over another by looking at the annual cost savings. The annual cost savings is calculated by subtracting the annual costs for the baseline condition from the annual cost for the plant with one of the part-load improvement methods. The annual cost savings are calculated for 10 and 25 percent capacity only. The results of these calculations are shown in Tables V, VI and VII. The output used in these calculations is based on the assumption that the unit operates at the part-load point for the whole year.

Table V (a) and (b) shows the results of these calculations for the Caterpillar 3304B diesel generator set. The annual savings resulting from the part-load package range from about \$13,000 to \$24,000. The addition of tuned low restriction manifolds did not increase the savings, and actually reduced them at 10 percent load. This is caused by the high investment costs assumed for the manifolds.

In Table VI (a) and (b), the calculations for the Caterpillar 3306B are presented. This is a 150 kw unit on which the annual cost savings is determined for the part-load package and compared with parallel operation of two 75 kw 3208 diesel generator sets. The results show the part-load package to provide savings from about \$23,000 to \$42,000 per year. The parallel units resulted in an annual savings of about \$42,000 at 10 percent load and \$28,000 at 25 percent load. This is a result, again, of the very low efficiencies at low loadings for the dummy load operation. There is also a question whether the parallel units would be able to operate at (20 percent individual load) 10 percent overall load without any modifications to improve part-load performance. Because of the higher capital costs, the parallel units do not provide a clear advantage near full-load.

The results for the Detroit-Diesel 4-71T unit including the part-load package and parallel operation of two 3-71N units are presented in Table VII. For the part-load package, the annual savings range from

TABLE II

COMPARISON MATRIX FOR COST ANALYSIS
CALCULATIONS ON DIESEL GENERATOR SETS

OPERATION	CATERPILLAR		DETROIT DIESEL
	100 kw	150 kw	100 kw
BASELINE, WITH DUMMY LOAD	3304 B	3306 B	4-71 T
WITH PART-LOAD PACKAGE	3304 B	3306 B	4-71 T
WITH PART-LOAD PACKAGE AND TUNED MANIFOLDS	3304 B	--	--
PARALLEL OPERATION OF 2 UNITS	--	2, 3208	2, 3-71 N

TABLE III. Cost of Electricity produced by Caterpillar diesel generator sets.

Diesel generator sets / Cost Data	100 kw 3304 B with dummy load	100 kw 3304 B with part-load package	100 kw 3304 B with part-load package and manifolds	150 kw 3306 B with dummy load	150 kw 3306 B with part-load package	150 kw 2-3208 in parallel operation
Investment Cost -- C_m, $/kw	$254/kw	$275/kw	$295/kw	$254/kw	$275/kw	$321/kw
Life -- L, years			5 years			
Interest -- i, %			15 %			
Annual Usage -- U, hours			8,322 hrs (95% availability)			
Annual Mnt. & Opr. Cost -- M+O, $/kw			$222/kw			
Fuel Cost -- K_r, $/gal			$1.26/gal			
Fuel Heating Value -- T, Btu/gal			138,618 Btu/gal			
Capacity -- F, %	10 25 50 75 100	10 25 50 75 100	10 25 50 75 100	10 25 50 75 100	10 25 50 75 100	10 25 50 75 100
Efficiency** -- r_F, %	6.0 15.0 30.0 31.3 30.8	14.0 22.0 30.0 31.3 30.8	14.5 22.7 31.1 32.4 31.8	5.9 14.7 29.3 31.3 31.0	17.2 23.0 29.3 31.3 31.0	19.5 27.4 33.1 30.0 33.1
Electricity Cost* -- C_E, $/kwh	.65 .28 .15 .14 .14	.36 .21 .15 .14 .14	.36 .21 .15 .14 .14	.66 .28 .15 .14 .14	.32 .21 .16 .14 .14	.32 .19 .15 .15 .14

* Eq. (1)
** See Fig. 4

TABLE IV. Cost of electricity produced by Detroit Diesel generator sets.

Diesel generator set / Cost data	100 kw 4-71 T with dummy load					100 kw 4-71T with part-load package					100 kw 2-3-71N (50 kw) in parallel operation				
Investment cost -- C_m \$/kw	\$220/kw					\$243/kw					\$320/kw				
Life -- L, years	5 years														
Interest -- i, %	15%														
Annual usage -- U, hours	8,322 hrs (95% availability)														
Annual Mnt. & Opr. Cost -- M+O, \$/kw	\$222/kw														
Fuel cost -- K_r, \$/gal	\$1.26/gal														
Fuel heating value -- T, Btu/gal	138,618 Btu/gal														
Capacity -- F, %	10	25	50	75	100	10	25	50	75	100	10	25	50	75	100
Efficiency** -- r_F, %	5.1	12.8	25.6	28.4	29.5	8.6	15.9	25.6	28.4	29.5	13.4	21.8	25.6	25.1	25.6
Electricity cost* -- C_E, \$/kwh	.73	.31	.17	.15	.14	.49	.26	.17	.15	.14	.39	.22	.18	.17	.16

* Eq. (1)
** See Fig. 4

Figure 2

COST vs. CAPACITY for Caterpillar Diesel Gen. Sets

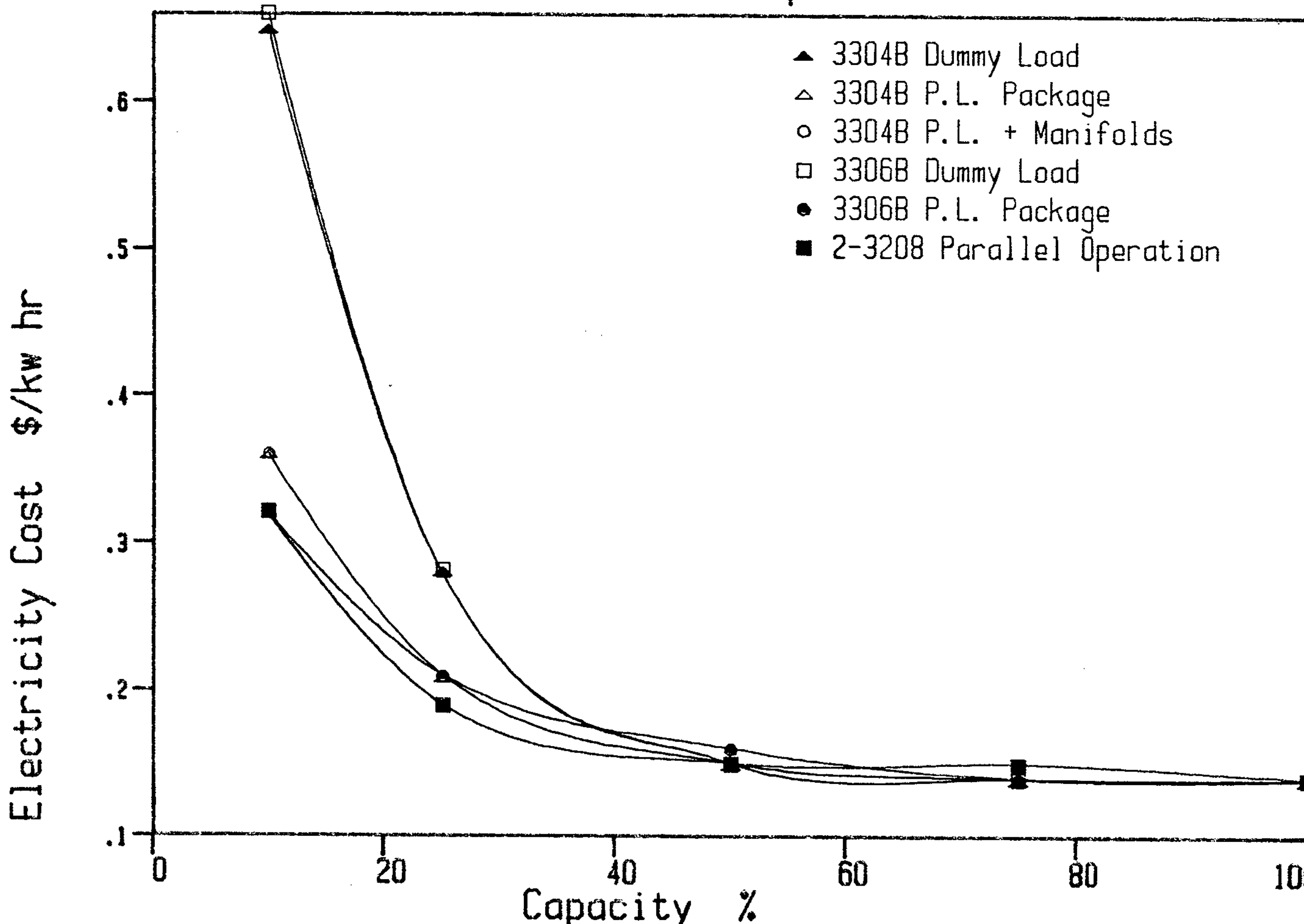
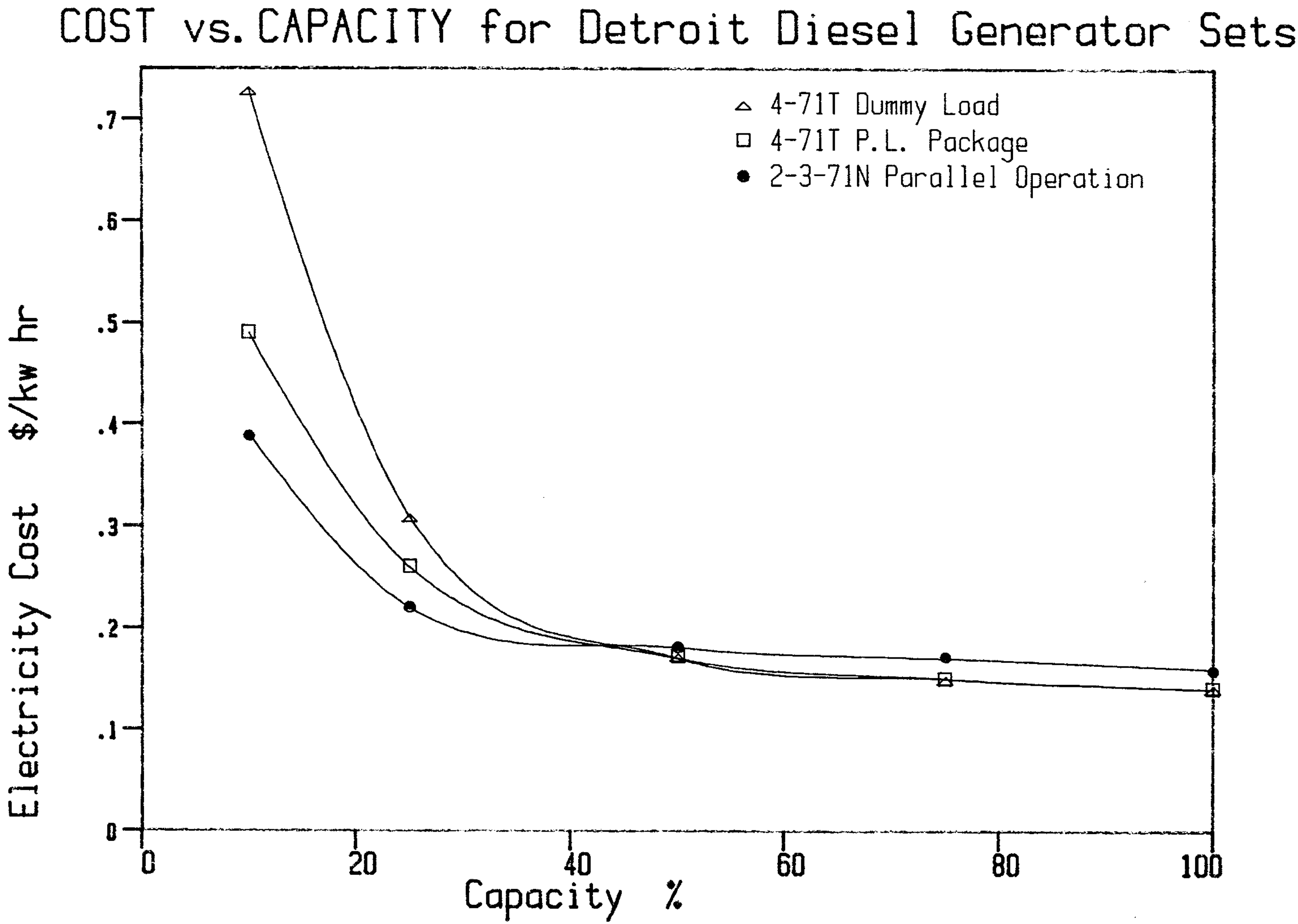


Figure 3



COST vs. CAPACITY for Detroit Diesel Generator Sets
4-71T Dummy Load
4-71T P.L. Package
2-3-71N Parallel Operation
Electricity Cost $/kw hr
.7
.6
.5
.4
.3
.2
.1
0
0
20
40
60
80
100
Capacity %

TABLE V. Annual cost savings for Caterpillar 100 kw units

(a)

F capacity (%)	Output $\frac{kw\ hr}{yr}$ (1)	Annual Costs: 3304B with dummy load — Cost-C_E (2) \$/kwh	Cost (3) \$/yr	3304B with part-load package — Cost-C_E \$/kwh	Cost \$/yr	Annual savings (4) \$/yr
10	83,220	0.65	54,176	0.36	30,292	23,884
25	208,050	0.28	57,630	0.21	44,523	13,107

Notes: (1) Output $\frac{kw\ hr}{yr}$ = 8,322 $\frac{hr}{yr}$ x F% x 100 kw

(2) From Table III

(3) Cost \$/yr = Output $\frac{kw\ hr}{yr}$ x C_E \$/kwhr

(4) Annual savings = difference in costs

(b)

F capacity (%)	Output $\frac{kw\ hr}{yr}$ (1)	Annual Costs: 3304B with dummy load — Cost-C_E (2) \$/kwh	Cost (3) \$/yr	3304B with part-load package and manifolds — Cost-C_E \$/kwh	Cost \$/yr	Annual savings (4) \$/yr
10	83,220	0.65	54,176	0.37	30,375	23,801
25	208,050	0.28	57,630	0.21	44,523	13,107

TABLE VI. Annual cost savings for Caterpillar 150 kw units

(a)

F capacity (%)	Output kw hr/yr (1)	Annual Costs: 3306B with dummy load: Cost-C_E (2) \$/kwh	Annual Costs: 3306B with dummy load: Cost (3) \$/yr	Annual Costs: 3306B with part-load package: Cost-C_E \$/kwh	Annual Costs: 3306B with part-load package: Cost \$/yr	Annual savings (4) \$/yr
10	124,830	0.66	82,263	0.32	40,320	41,943
25	312,075	0.28	87,693	0.21	64,912	22,781

Notes: (1) Output - 8,322 hr/yr x F x 150 kw

(2) From Table III

(3) Cost \$/yr = Output $\frac{\text{kw hr}}{\text{yr}}$ x C_E \$/kwhr

(4) Annual savings = difference between costs

(b)

F capacity (%)	Output kw hr/yr (1)	Annual Costs: 3306B with dummy load: Cost-C_E (2) \$/kwh	Annual Costs: 3306B with dummy load: Cost (3) \$/yr	Annual Costs: 2 x 3208 units in parallel: Cost-C_E \$/kwh	Annual Costs: 2 x 3208 units in parallel: Cost \$/yr	Annual savings (4) \$/yr
10	124,830	0.66	82,263	0.32	39,946	42,317
25	312,075	0.28	87,693	0.19	59,294	28,399

about $9,000 to $20,000. The parallel operation saved about $28,000 at 10 percent load and $18,000 at 25 percent load. This was also the result of the low efficiencies for the dummy load package in spite of the increased switchgear costs for parallel operation.

Cost Data and Assumptions

Referring to Tables III and IV; the life, interest rate, annual usage, annual maintenance and operating cost, fuel cost and fuel heating value were assumed to remain the same for all comparisons. All but the fuel heating value was taken from the Alaska cost data in Appendix D. The life given in the appendix was around 3.4 years. A five year life was used, assuming one top end rebuild on the engine. An interest rate of 15 percent was considered a typical value for Alaska banks. The usage was calculated on the availability of 95 percent, assuming the unit was down 5 percent of the year for maintenance and other unforeseen problems. The maintenance and operating cost was calculated from data in Appendix D. It includes the cost of an operator, but does not include a savings due to decreased maintenance resulting from a part-load package. For units much larger or smaller than those considered here, the operating and maintenance cost per kw would change. The fuel cost was the typical amount that DOT&PF pays for fuel. The fuel heating value was calculated from data in the Caterpillar handbook (see References).

The investment cost was based on data from Appendix D. This figure is the vendor's price for the unit in $/kw, plus the installation cost and cost of accessories, such as the part-load package or extra switch gear for parallel operation. The Caterpillar base price is 240 $/kw and the Detroit Diesel base price is 206 $/kw. These figures are used for all units of the same manufacturer, regardless of size. Added to that is a $1,400 installation cost calculated from Appendix D data. The cost of the building is not included in this figure. The cost of the part-load package is presented in Appendix E. The cost of the manifolds is estimated at $2,000 per set. The cost for switch gear for parallel operation was approximately $10,000, according to Williams & Lane, a

TABLE VII. Annual cost savings for Detroit Diesel 100 kw units.

(a)

F capacity (%)	Output $\frac{kw\ hr}{yr}$ (1)	Annual Costs: 4-71T with dummy load		Annual Costs: 4-71T with part-load package		Annual savings (4) $/yr
		Cost-C_E (2) $/kwh	Cost (3) $/yr	Cost-C_E $/kwh	Cost $/yr	
10	83,220	0.73	60,584	0.49	40,944	19,640
25	208,050	0.31	63,663	0.26	54,717	8,946

Notes: (1) Output $\frac{kw\ hr}{yr}$ = 8,322 $\frac{hr}{yr}$ x F% x 100 kw

(2) From Table IV

(3) Cost $/yr = Output $\frac{kw\ hr}{yr}$ x C_E $/kwhr

(4) Annual savings = difference in costs

(b)

F capacity (%)	Output $\frac{kw\ hr}{yr}$ (1)	Annual Costs: 4-71T with dummy load		Annual Costs: 2 x 3-71N units in parallel		Annual savings (4) $/yr
		Cost-C_E (2) $/kwh	Cost (3) $/yr	Cost-C_E $/kwh	Cost $/yr	
10	83,220	0.73	60,584	0.39	32,456	28,128
25	208,050	0.31	63,663	0.22	45,771	17,892

generator set fabricator in San Leandro, California. This figure was used for both the Caterpillar and Detroit Diesel units.

The total investment cost in \$/kw was determined by adding the total base price plus the installation cost and accessory cost, and then dividing the sum by the capacity.

To complete the calculations, the relationship between efficiency and capacity must be determined. This can be calculated from manufacturers technical data. Figure 4 summarizes the results of these calculations. It is a plot of efficiency versus output from both the Caterpillar and Detroit Diesel generator sets. For the dummy load calculations, the efficiencies at 50 percent loading were extracted from Figure 4 and then scaled linearly to account for useful output of less than 50 percent.

In the calculation of electricity cost for the diesel generators with the part-load package, the efficiencies were calculated from Figure 4 by adding the extra load per Appendix E to the abcissa on Figure 4. This extra load raises the engine to a higher efficiency level. Then, this efficiency was scaled linearly to take into account the fact that only part of the total load is usable output. Even though there may also be an increased efficiency due to the higher operating temperatures associated with the part-load package, we do not have sufficient data to quantify this.

The final annual costs with and without part-load packages appear in Tables VI and VII for the Caterpillar and Detroit Diesel generator sets, respectively. The system lifetimes and annual M+O costs are assumed to be the same for both the dummy load and part-load options. Hence, whatever cost savings result from the part-load package are due entirely to the increased efficiency of the latter which results from much less power being needed to drive the part-load package than to maintain the dummy load. This effect is more important than the higher capital cost of the part-load package.

The addition of the tuned, low restriction manifolds does increase the efficiency. From the work of Cser (1978) and Kleinberg and Schmeichel (1981), a 3.5 percent increase in efficiency is deemed typical for such equipment, and is used in these calculations. This would result in an increase in overall efficiency, say, from 20.5 to 21.2 percent.

These cost figures must be considered approximate and should only be used to provide relative costs between various options. The costs of backup systems and distribution systems are not included. Due to limited available data, the low load efficiencies assumed are uncertain. Since much of the cost of electricity is associated with fuel costs, the uncertainties in efficiencies lend to comparable uncertainties in projected electrical costs.

RECOMMENDATIONS

The economic analysis showed that the part-load package was attractive from the standpoint of reducing electricity cost assuming an existing unit was already oversized. Since it contains the kinds of electrical equipment that in some cases are already present on many diesel generators, the maintenance and personnel skill level requirements will be minimally affected. Because commercially available components are used in the part-load package, parts availability problems should not increase. This is presently the most feasible method of solving the part-load performance problem and the efficacy of this approach should be proven with long-term full-scale tests on a diesel generator.

The use of acoustically tuned, aerodynamically efficient intake and exhaust systems are also an attractive approach to improving diesel generator economy for two reasons. The first is that a definite documented increase in part-load efficiency is attainable with these systems; and second, they are passive devices that require no maintenance or personnel skill level increases once they are installed on the engine. Further research, full-scale testing and development should be done on these systems. The Caterpillar 3304 is a common power plant for which a tuned system could be developed and subsequently installed on every such DOT&PF installation.

Parallel operation of smaller generating units has the advantage of redundant reliability. However, the economic analysis did not show them to be less costly than single units especially if one already had an operational single unit on site. There is also the problem of increased maintenance associated with multiple units. Also, at low loads, the same problems associated with single units such as wet-stacking, etc., may also occur. This may be a feasible method of solving part-load problems in some instances, but careful detailed economic analysis may be necessary to demonstrate the benefits.

All of the other methods of improving part-load performance except alcohol fumigation may become feasible in the future. An example of this is microprocessor-controlled injection pumps with light-load advance. The development of these items should be monitored closely in the event they become commercially available. The development of an electro-mechanical injection pump with light-load advance should also be pursued. These kinds of devices might, however, increase the maintenance and skill level requirements for the installation.

CONTINUING RESEARCH

Since none of the proposed methods of improving part-load performance have been definitely shown to reduce the major problems such as wet-stacking, etc., more research is needed to thoroughly evaluate these methods.

A small scale test facility to begin this research using the University of Alaska-Fairbanks Mechanical Engineering Department's 17 hp Deutz diesel engine with a new dynamometer and data logger would cost from $11,000 to 26,000 (see Appendix F). This is not a good arrangement because the engine is not matched with the dynamometer.

A better small scale test facility is shown in Table VIII. This uses the Deutz engine, but instead of a dynamometer, it uses an AC generator and load bank to absorb power. The total price for initiating this test facility if $47,250 and includes personnel costs.

This is the most economical approach to continuing research on part-load performance, but the size and type of engine casts doubts on the transferability of technology to the larger, more common diesel generator sets. The engine is only 17 hp (13 kw) and it is air cooled. The typical units are 100 kw and are liquid cooled.

To be assured of the validity of the results, a full scale test facility should be used. Table IX summarizes the cost for a full-scale diesel engine dynamometer test set-up. The total cost for this arrangement is $70,000. A full scale diesel generator test facility is described in Table X and would cost $73,000. Although this set-up is slightly more costly, it would be better for long-term evaluation under part-load conditions.

If it is desirable to test the part-load package, the additional cost of this equipment should be added to the cost estimates. Appendix E contains the cost data for the part-load package for both 2 cycle and 4 cycle engines. The total cost of the part-load package for these engines is $2,375 and $2,125, respectively.

TABLE VIII. Summary of cost estimate for initiation of proposed small scale diesel-electric generator test facility.

	Item	Cost
1.	Deutz Mod. F2L411D diesel engine	$ -0-
2.	Kurz & Root Mod. KR4BD286 15 kw generator	1,750
3.	Avtron Mod. K7-75 30 kw outdoor load bank (for Arctic Service)	2,500
4.	Superflow turbine airflow meter	500
5.	Hewlett-Packard Mod. 3054 data logger	7,500
6.	Principle investigator for two man-months with technician and student help	35,000
	TOTAL	$ 47,250

TABLE IX. Summary of cost estimate for initiation of proposed full scale diesel engine test facility.

	Item	Cost
1.	Detroit Diesel Mod. 4-71T diesel engine	$ 8,000
2.	Superflow model SF 901 dynamometer set-up including data logger	26,000
3.	Engine stand	1,000
4.	Principle investigator for two man-months with technician and student help	35,000
	TOTAL	$ 70,000

TABLE X. Summary of cost estimate for initiation of proposed full scale diesel-generator test facility.

	Item	Cost
1.	Detroit Diesel Mod. 4-71T 100 kw diesel-generator set	$ 24,000
2.	Avtron Mod. K 675 100 kw outdoor load bank	4,000
3.	Hewlett-Packard Mod. 3054 data logger with misc. airflow and temperature instrumentation	10,000
4.	Principle investigator for two man-months with technician and student help	35,000
	TOTAL	$ 73,000

IMPLEMENTATION STATEMENT

With this research project we have begun to develop concrete information concerning performance of diesel-electric systems as they are most commonly used in Alaska. While specific problems and solutions are addressed in this report the results are not expected to be immediately implementable into departmental routine design and construction or maintenance and operation. We recommend further work in two areas before a direct implementation effort is undertaken.

1. Research should work with Standards and Technical Services to gather more field operational data on existing systems while developing an outline design specification for diesel-electric systems.

2. A field test project should be undertaken to test and verify the recommendations and conclusions of this report.

We would anticipate that concurrent performance of these tasks could lead to a specific cost effective implementation strategy within one and a half to two years.

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APPENDIX A

ALASKA FIELD SURVEY QUESTIONNAIRE

AND

INDEX OF VENDORS AND PERSONAL CONTACTS

SURVEY

1) How many diesel-electric generator sets are on site? ______________

2) What make is the diesel engine(s)? ______________________________
____

3) Who is the generator manufacturer(s) and what size is the generator(s) in kilowatts? ______________________________________ _____kw
______________________________________ _____kw

4) If there is a stand-by unit, which one is it? ____________________

5) Does the primary generator set run continuously? _______________

6) Is the generator(s) running at full capacity? ____________________

7) If not, what percentage would you estimate is being used of the total possible output?______________________________________%

8) If the generator set is NOT always being run at full-load:

   a. Have you had any mechanical problems with the diesel engine? (i.e. plugged injectors, rings sticking, carbon buildup, etc.) ________
   b. If so, what are they? ____
   ____
   ____
   ____
   ____
   c. How often does the engine get rebuilt? ________________________
   d. Do you use dummy loads? ______________________________________
   e. Do you have any recommendations to help prevent or alleviate problems due to running the engine at part-load?
   ____
   ____
   ____
   ____

9) What is your name and job title? ______________________________
____

10) Any comments or suggestions not specifically covered by this questionaire: ____
____
____
____

Thanks again!

INDEX OF VENDORS AND PERSONAL CONTACTS

Alaska Diesel Electric, Inc., 1200 West International Airport Road, Anchorage, Alaska. David Rowland, generator salesman.

Alaska Generator and Engine Sales, 100 East International Airport Road, Anchorage, Alaska. Jim Renk, salesman.

Alaska Power Authority, 334 West 5th Avenue, Anchorage, Alaska
Jerry Larsen, Project Manager
Peter Hansen, mechanical engineer

Alaska Village Electric Coöperative, 4831 Eagle, Anchorage, Alaska.
Robert Brouillette, Manager of Operations and Maintenance
Lloyd Hodson, General Manager.

Bedrock Mining Company, Fox, Alaska.
Cacy Patton, owner.

Bethel School District, Bethel, Alaska.
Joe Sullivan, mechanical engineer.

Chena Hot Springs Resort, Chena Hot Spring, Alaska.
Phil Panaritus, employee.

Craig Taylor Equipment Company, 733 East Whitney Road, Anchorage, Alaska. Hans Jensen, Product Support Manager.

Cummins Northwest-Diesel, Inc., 2618 Commercial Drive, Anchorage, Alaska. Frank Papasavas, Alaska Sales Representative.

DOT&PF Central Region, 4111 Aviation Drive, Anchorage, Alaska.
Harry Dullinger, Building Maintenance Manager
Erwin Koorenny, Building Management Specialist.

DOT&PF Northern Region, 2301 Peger Road, Fairbanks, Alaska.
Dennis Moen, Building's Superintendent
Fred Barrett, Building Maintenance Manager
Dick Kaiser, Building Maintenance Assistant Manager
Tom Bowdre, foreman, Gardiner Creek Unit
Richard Burton, HML51 foreman, South Fork Unit and O'Brien Creek Unit
Richard Symons, highway maintenance foreman II, Central Unit
Scott Butterfoss, remote buildings worker, Chandalar Unit
John Merrill, remote buildings worker, Jim River unit
Vern Carlson, operator-mechanic, Cantwell and East Fork Units
Don Bascom, foreman, 80 Mile Steese Camp.

Emerson GM Diesel, 3061 Peger Road, Fairbanks, Alaska.
Fred Henkel, Branch Manager.

Evans Equipment Company, 720 East Whitney Road, Anchorage, Alaska.
Tom Cowden, salesman.

Generator Systems and Technology, 2205 Hanson Road, Fairbanks, Alaska. R.M. "Rusty" Foyle, owner.

Gibson Placer Mines, 1610 Southern Street, Fairbanks, Alaska. Wayne Gibson, owner-operator.

Kem equipment Company, 6900 Arctic Blvd., Anchorage, Alaska. Don Kling, salesman.

Lake and Boswell Consulting Electrical Engineers, Inc., 543 - 3rd Avenue, No. 206, Fairbanks, Alaska. Jim Lake, electrical engineer.

N C Machinery, .25 Mile Steese Highway, Fairbanks, Alaska. Mickey Allen, mechanic.

Northwest Exploration, Ruby Creek Mine, Ruby, Alaska. Jon Holmgren, supervisor.

Sandiford, Brendan and Wade, Christopher. "Improving Part-load Performance of Diesel-electric Generators," May 1984, Mechanical Engineering Department, University of Alaska-Fairbanks, Fairbanks, Alaska.

Waukesha Alaska Corporation, 1301 Huffman Road, Anchorage, Alaska Mary Haxby, sales representative.

APPENDIX B

INDEX OF VENDORS

AND

PERSONAL CONTACTS FOR ALASKAN EQUIPMENT SURVEY

INDEX OF VENDORS AND PERSONAL CONTACTS

Alaska Department of Transportation and Public Facilities - Central Region, 4111 Aviation Drive, Anchorage, Alaska. Harry Dullinger, building maintenance manager. Erwin Koorenny, building management specialist

Alaska Department of Transportation and Public Facilities - Northern Region, 2301 Peger Road, Fairbanks, Alaska. Dennis Moen, building's superintendent. Fred Barrett, building maintenance manager. Dick Kaiser, building maintenance assistant manager

Alaska Diesel Electric, Inc., 1200 West International Airport Road, Anchorage, Alaska. David Rowland, generator salesman

Alaska Generator and Engine Sales, Inc., 100 East International Airport Road, Anchorage, Alaska. Jim Renk, salesman

Bedrock Mining Company, Fox, Alaska. Cacy Patton, owner

Craig Taylor Equipment Company, 733 East Whitney Road, Anchorage, Alaska. Hans Jensen, product support manager

Cummins Northwest-Diesel, Inc., 2618 Commercial Drive, Anchorage, Alaska. Frank Papasavas, Alaska sales representative

Emerson GM Diesel, 3061 Peger Road, Fairbanks, Alaska. Fred Henkel, branch manager

Evans Equipment Company, 720 East Whitney Road, Anchorage, Alaska, Tom Cowden, salesman

Fessler Equipment Services, Inc., 2400 Commercial Drive, Anchorage, Alaska. Louie Fessler, owner

Generator Systems and Technology, 2205 Hanson Road, Fairbanks, Alaska. R. M. "Rusty" Foyle, owner

Hayden Electric Motors, Inc., 4109 Seward Highway, Anchorage, Alaska. Chuck Igou, salesman

Industrial Engine Specialists, 2130 East Dimond Blvd., Anchorage, Alaska. Esther Creech, sales representative

Kem Equipment Company, 6900 Arctic Blvd., Anchorage, Alaska. Don Kling, salesman

Kenworth Alaska, 2838 Porcupine Drive, Anchorage, Alaska. Roger Nafts, salesman

N C Machinery, Inc., .25 Mile Steese Highway, Fairbanks, Alaska. Mickey Allen, mechanic

Northern Hydraulics, Ltd., 4510 Stuart Way, Anchorage, Alaska.

Northwest Exploration, Ruby Creek Mine, Ruby, Alaska. Jon Holmgren, supervisor

Waukesha Alaska Corporation, 1301 Huffman Road, Anchorage, Alaska. Mary Haxby, sales representative

APPENDIX C

LOWER-48 STATES MANUFACTURERS AND VENDORS SURVEY QUESTIONNAIRE

AND

INDEX OF VENDORS AND PERSONAL CONTACTS

QUESTIONNAIRE

A Survey of Ways of Improving Part-Load Fuel Economy
of Diesel Electric Generators
Funded by
Alaska Department of Transportation and Public Facilities

This is a joint research project with the University of Alaska-Fairbanks to study ways of reducing electric power costs in rural Alaska.

COMPANY NAME:____________________________________

ADDRESS:____________________________________
____

PHONE:____________________________________

1. Does your firm sell diesel generators for service in arctic or sub-arctic climates such as the Alaskan bush?
   yes_____ no_____

2. If so, how many per year?_____

3. What are the optimum or recommended operating conditions for these units?
   Fuel Temperature?_____°F
   Jacket Water Temperature?_____°F
   Combustion Intake Air Temperature?_____°F
   Lube Oil Temperature?_____°F
   Minimum Continuous Operating Load?_____%

4. What modifications do you perform on a standard diesel generator set to make it more suitable for service in arctic or subarctic climates? If you have a "standard arctic package", please describe its important features.
   ____
   ____
   ____
   ____
   ____
   ____

5. What is the additional cost of your arctic package installed on a 100kw unit?___________

6. Does your arctic package allow long term operation of the diesel generator at part load?
   yes_____ no_____

7. If not, what is the maximum recommended time for operation below the recommended minimum load? (Please answer this question even if you do not have an "arctic package".)

____

8. Do you have a design document that provides guidance and recommendations in the application of your generator sets?
yes_____ no_____
(If you do, please send us a copy.)

9. What mechanical problems have you observed in diesel generators that operate at light loads for extended periods?

____
____
____
____
____

10. What is the climate where the problems are most severe?
cold_____ temperate_____ tropical_____

11. Are you aware of any modifications that will allow the diesel generator to operate at low loads without sustaining any long-term mechanical problems?
yes_____ no_____
If yes, please explain______________________________
____
____
____
____
____

12. Who are the vendors of these items and what are the prices?

____
____
____

13. Would you install retrofit devices on diesel-generators if they successfully improved part-load fuel economy?
yes_____ no_____

14. How would you solve the problem of supplying power with a diesel generator(s) when the load can vary between 20% and 100% and may stay at 20% for long periods (2 months)?

____
____
____
____
____

15. Do you have any other comments pertaining to part-load fuel economy of diesel-electric generators?

____
____
____
____
____
____

16. Would you like an executive summary of the results of this study?
yes_____ no_____

Please return this questionaire to:

Dr. James B. Malosh, P.E.
25 Drumm Street, Suite 203
San Francisco, CA 94111
Phone: 415/391-2158

(A stamped, self-addressed envelope is included.)

INDEX OF MANUFACTURERS, VENDORS, AND PERSONAL CONTACTS

Allis Chalmers Engine Division
(Diesel Generator Set Manufacturing)
P.O. Box 1563
Harvey, IL 60426
312/339-3300
Mr. Ray Klaxton

AVTRON Manufacturing, Inc.
(Load Bank Manufacturing)
10409 Meech Avenue
Cleveland, OH 44105
216/641-8310
Mr. Jeff Thompson

Barber Coleman Company
Precision Dynamics Division
(Generator Set Control Manufacturing)
1300 Rock Street
Rockford, IL 61101
815/877-0241
Mr. Patrick W. Cavanagh

Con-Select, Inc.
(Load Bank Manufacturing)
202 E. Robert
P.O. Box 2804
Hammond, LA 70404
504/542-9390
Mr. Harvey Verette

Caterpillar Tractor Company
Engine Division Engineering
Peoria, IL 61629
309/578-6136
Mr. Jack Wellauer
Asst. Chief Engineer

Cummins West, Inc.
1960 Folsom Street
San Francisco, CA 94103
415/621-8930
Mr. John Boro

Empire Generator Corporation
(Diesel Generator Manufacturing)
Box 399
Germantown, WI 53022
414/255-2700
Mr. Ted McCabe

Ford Industrial Engine Operations
(Diesel Generator Set Manufacturing)
3000 Shafer Road
P.O. Box 6011
Dearborn, MI 48121
313/327-3971
Mr. Chuck Taylor

Go-Power Corporation
(Dynamometer Manufacturing)
1890 Embarcadero Road
Palo Alto, CA 94303
415/856-7676

Kurc & Root Company
(Generator Manufacturing)
P.O. Box 1119
Appleton, WI 54912
414/739-9441

Marathon Electric Corporation
(Generator Manufacturing)
100 East Randolph Street
Wausau, WI 54401
715/675-3311

Morrison-Knudsen, Inc.
Power Systems Division
(Diesel Generator Manufacturing)
101 Gelo Road
P.O. Box 1928
Rocky Mount, NC 27801
919/977-2720
Mr. Milton Sharpe

N C Machinery Company
(Caterpillar Dealer)
Engine Power Branch
16711 West Valley Hwy.
Seattle, WA 98188
206/251-5877
Mr. Gene Larson

The O'Brien Machinery Company
(Diesel Generator Set Dealer)
214 Power Drive
Downingtown, PA 19335
215/269-6600
Mr. Larry Yocum
Service Manager

Peterson Power Systems, Inc.
(Caterpillar Dealer)
2828 Teagarden Street
San Leandro, CA 94577
415/895-8400
Mr. Don Stroot, Chief Engineer

Racor Industries, Inc.
(Fuel Heater Manufacturing)
P.O. Box 3208
Modesto, CA 95353
209/521-7860

Stanadyne, Inc.
Diesel Systems Group
(Injection Pump and Fuel Heater Manufacturing)
P.O. Box 1440
Hartford, CT 06143
203/525-0821
Mr. Ed Bartus

SuperFlow Corporation
(Dynamometer Manufacturing)
3512 North Tejon
Colorado Springs, CO 80907
303/471-1746

Taku Marine Industries, Inc.
(Diesel Generator Set Dealer)
P.O. Box 968
Friday Harbor, WA 98250
206/378-4181
Mr. Steve Raichlen

Tuban Industrial Supply Company
(Diesel Generator Set Dealer)
2003 Leghorn Street
Mountain View, CA 94043
415/968-243L
Mr. Dave Lobree

United Technologies Diesel Systems
(Injection Pump and Governor Control Manufacturing)
3664 Main Street
Springfield, MA 01107
413/785-6600
Mr. Pete Corcodilas

Wabash Power Equipment Company
(Diesel Generator Set Dealer)
444 Carpenter Avenue
Wheeling, IL 60090
312/541-5600

Williams and Lane, Inc.
(Detroit Diesel Dealer)
1975 Adams Avenue
San Leandro, CA 94577
415/632-2310
Mr. Hall Wondolleck

APPENDIX D

ALASKA-BASED FIGURES USED IN COST ANALYSIS

ALASKA-BASED FIGURES FOR USE IN COST ANALYSIS

1) Typical purchase costs:

Caterpillar 3304 Turbocharged (105 kw) ----------- $24,000
Nat. Aspirated (64 kw) ---------- 21,000
Detroit Diesel 4-71T Turbocharged (100 kw) radiator cooled
FOB Seattle ------------------ 20,562

Typical installation costs:
Per the Service Department at N C Machinery in Fairbanks:
The mechanic doing the installation gets paid:

Flight time ----------------------- $ 52.50/hr
or Driving time ----------------------- 1.00/mi
Actual Labor ----------------------- 59.00/hr
Overtime --------------------------- 120.00/hr

It normally takes anywhere from 4 hours to 2 days to install a generator set.

2) Typical life:

Per John Merrill, DOT remote buildings worker ----- 20,000 hrs
Per Mickey Allen, mechanic, N C Machinery --------- 30,000 hrs
(Allen has seen lifetimes range from 8,000 to 44,000 hrs.)

3) Current interest rates being charged in Alaska:

First National Bank: loans less than $25,000 ---------- 14%
loans greater than $25,000 ------- 16%

(These are the interest rates they would charge COT or other low risk organization. If a high risk village (i.e. Minto) wanted a loan, First National would be reluctant to charge more than the prime interest rate plus 3, so would probably not grant the loan. The above 16% for loans greater than $25,000 is just a ball park figure and is obtained from adding 3 onto the prime interest rate.)

National Bank of Alaska: prime interest rate plus 2 -- 15%

4) Annual unit usage:

Most of the DOT units surveyed (9 out of 10) said that their primary generator sets are run continuously, year round, 24 hrs per day ---- 8,760 hrs/yr.

5) Annual maintenance and operating costs for a typical unit:

Operator costs:

Per Dick Kaiser, Asst. Building Maintenance Manager, DOT&PF Northern Region: ---- $17/hr plus benefits, so approximately $32/hr for 2 hrs/day 5 days/wk. Therefore, annual operator costs -- $16,640/yr.

Maintenance costs:

Per Ernie Searing in Fairbanks, owner of Searing Repair: For a Caterpillar 3304 run continuously, he would estimate it would cost $0.12/kwh. This is allowing $20/hr pay with 1 hr/day labor and 20 hrs/yr for maintenance. This also is estimating that the fuel consumption is 8.3 gal/hr at $1.30/gal. Searing is also estimating that the oil will be changed once each week and that the engine has a 5 gallon sump. He estimates that the price of lube oil is $5.80/gal and that the oil filter is $3.60. Searing mentioned that the oil filter and lube oil costs amount to a maximum of one cent per kilowatt hour. The number one cost of running the generator set is the fuel and the number two cost is the labor. Searing also mentioned that you can throw all cost estimates out the window when it comes to bush villages because maintenance is sometimes little or nonexistent.

6) Typical on-site fuel costs:

Per Fred Barrett, Building Maintenance Manager, DOT&PF Northern Region: Average cost of No. 1 fuel in the Interior is $1.26/gal. Barrett said that DOT only uses No. 1 fuel for its diesel-electric generator sets.

Per Interior Energy Corporation in Fairbanks: No. 1 fuel is $1.12 at Livengood and $1.38 at Sag River.

Per Matomco Oil Company, Inc. in Fairbanks: The price of No. 1 and No. 2 fuel in Fairbanks is:

Amount	No. 1	No. 2
100-199 gal.	$1.21	$1.14
200-299	1.19	1.12
300-499	1.16	1.09
500-999	1.12	1.05
over 1000	1.09	1.03

Per Rob Blankenship, owner of Blankenship's Store in Kotzebue, No. 2 fuel costs $2.26/gal at the pump in Kiana and $1.41/gal at the pump in Kotzebue.

Per Ron Davena, an employee of DOT&PF Nome, No. 2 fuel is $1.65/gal if delivered, and $1.31/gal if purchased at the pump in Nome.

7) Annual fuel consumption:

Per Dennis Moen, Building's Superintendent, DOT&PF Northern Region: A good rule of thumb is 1 gpd per kw load.

Per Ernie Searing, owner of Searing Repair in Fairbanks: 72,708 gal/yr (for a Caterpillar 3304 operating 876,000 kwh/yr).

8) Annual delivered electrical output:

For a 90 kw Caterpillar generator set at DOT's Livengood Unit that is run at 50% during the summer and 90% load during the winter using no dummy loads, an estimated 551,880 kwh are delivered in one year.

90 x .5 = 45 kw (during the summer)

90 x .9 = 81 kw (during the winter)

(45 kw) (365/2 days/yr) (24 hrs/day) = 197,100 kwh

(81 kw) (365/2 days/yr) (24 hrs/day) = 354,780 kwh

Total: 197,100 + 354,780 = 551,880 kwh

For a 135 kw Caterpillar generator set used at DOT's Jim River Unit which is run continuously at 100% capacity during the winter and 35% capacity in the summer, the annual electrical output delivered is 798,255 kwh.

Note: All prices FOB Fairbanks unless noted otherwise.

APPENDIX E

PART-LOAD PACKAGE COSTS AND ELECTRICAL LOADS

APPENDIX E

COSTS AND ELECTRICAL LOADS FOR PART-LOAD PACKAGE

COMPONENT	4 CYCLE ENGINES		2 CYCLE ENGINES	
	ELECTRICAL LOAD -- kw	COST -- $ (2)	ELECTRICAL LOAD -- kw	COST -- $ (2)
INTAKE AIR USING EXHAUST WASTE HEAT	0	$750	5 (1)	$1000 (1)
FUEL HEATER (COMMERCIAL UNIT)	0.35	$175	0.35	$175
OIL & COOLANT HEATERS (TANK TYPE) WITH THERMOSTATIC CONTROL	4.3	$700	4.3	$700
INSTALLATION COSTS	--	$500	--	$500
TOTALS	4.65 kw	$2125	9.65 kw	$2375

NOTE: (1) A 2 Cycle engine requires more air than a 4 cycle engine. There is not enough exhaust energy available to heat this quantity of air. Therefore, supplemental heat is required.

(2) Costs were developed from commercial units such as Cummins or Katz assuming some custom fabrication would be involved. They are conservative estimates.

APPENDIX F

TESTING EQUIPMENT FOR 17 HP DEUTZ DIESEL

TESTING EQUIPMENT FOR 17 HP DEUTZ DIESEL

Superflow manufactures complete engine dynamometer systems. Their SF-901 system includes: control console with instruments, 6809 microprocessor system, complete engine test stand, 1,000 hp absorption unit, fuel flow measurement system, air flow measurement system, 80 column printer with table, engine cooling tower, and an exhaust temperature measurement system for a price of $21,900.

This system is compatible with the mechanical engineering department's 17 hp Deutz Diesel, but would probably not be cost effective unless a larger diesel engine were to be used. Interpolating from the chart given in a brochure by Superflow for the torque and rpm to find the minimum horsepower engine that can be used with the SF-901 absorption unit gives 3.4 hp at 10 to 12 ft. lb. operating at 1,800 rpm. This was confirmed by Mr. Harold Bettis, salesman for Superflow.

An accessory to the SF-901 system would have to be purchased so that the input drive would be dampened relative to torsional vibration. The drive plate that the SF-901 comes with needs softer coupling for the 17 hp Deutz than can be obtained with the stock coupling.

Lord Corporation - Industrial Products Division sells a coupling called Dynaflex LCR 275-400-009A (LCR 275-400-017A also can be used) that would probably provide the correct amount of vibration dampening, depending upon the inertia of the two-cylinder Deutz engine. The price of this Dynaflex is $17.

The SF-901 system can maintain either constant torque or a specific engine speed, but not constant load unless the throttle controller option, TH-1, is purchased and installed. The Superflow throttle option controller costs $3,500.

Go-Power Corporation also sells dynamometer systems. According to Mr. John Woodward, Go-Power's Dealer for the Northwest and Alaska, the absorption unit that would best fit our small engine is the D-316 model that sells for $4,150. The accompanying control system could either be: (1) The C-19 which controls torsion and rpm by water loading. The C-19 cannot control the torque and the engine speed simultaneously, but by operating the throttle manually, a constant load can be approximated by maintaining the rpm to plus or minus 20. The C-19 costs $4,500. (2) The GPS-2000, which can be fully programmed to maintain specified constant loads at various rpm's for computer-controlled intervals, sells for approximately $15,000. Woodward does not recommend using the GPS-2000 on an engine smaller than 50 hp. He also mentioned that for $4,000 or $5,000 a 453 Detroit Diesel (99-108 hp) could be purchased that would be a much better test engine. Woodward recommends that the dynamometer system be purchased that would best fit future needs also, rather than spending alot of money for a system that would only be good for the small 17 hp Deutz Diesel.

The S-801 engine stand from Go-Power would cost $990 and would probably have to be modified to fit the 17 hp Deutz Diesel for a minimal charge. A special adapter would need to be purchased so that the equipment could be fitted to the Deutz Diesel. This would cost $300 to $400. The only other device that would need to be purchased would be a torsional dampening assembly for the engine drive. This could probably be purchased for under $20 from the Deutz dealer or Go-Power could design one to fit, but this would, of course, cost quite a bit more than the stock part that could be purchased from the Deutz dealer.

General Electric was contacted, but no information was available on their dynamometers. General Motors Research Lab mentioned that G.E. only sells the larger and more expensive type dynamometers, so the matter was not pursued.

Froude Engineering in Livonia, Michigan was also contacted. They were asked to send information regarding their dynamometer systems and prices. No information has been received from them as of this time (8/24/84).

W. C. Dillon and Company, Inc. in California sent information concerning their complete line of dynamometers. After reviewing the brochures they sent, it was determined that their dynamometers would not be suitable for our purposes, as they are mostly force gauges and tensiometers.

The mechanical engineering department has access to a Hewlett-Packard 85 computer and an UP 3054 data logger. The system is fully programmable and is compatible with the current Deutz diesel engine set-up. The data logger could be hooked up to the engine system and used to scan and record experimental data at specified intervals. This could include output from thermocouples, hot wires, torque meters, and an rpm transducer. The HP 85 costs approximately $2,750 (1984 price) and the HP 3054DL about $5,100 (1982 price).

It would cost approximately $6,000 to purchase a new air velocity measurement system that would be much more accurate than what is currently being used on the Deutz diesel engine. This could be used to measure the air speed and hence infer flowrate for the inlet air.

TSI Incorporated sells an anemometer system that consists of:

1) 1053 A Anemometer
2) 1052 Polynomial Linearizer
3) 1051-2 Monitor and Power Supply
4) 1058-4 Cabinets for 4 single width modules
5) TSI 1210-T1.5 Hot Wires for use in air flow
6) TSI 1159-15 Probe Supports

Superflow produces an air flow turbine meter for less than $500 that could be used with the existing settling chamber set-up.