FINAL REPORT

DESIGN, FABRICATION, DELIVERY, OPERATION AND MAINTENANCE
OF A
GEOTHERMAL POWER CONVERSION SYSTEM

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ABSTRACT

This effort involves the design, fabrication, delivery, operation and maintenance of an HPC 1250 KVA geothermal power conversion system using a helical screw expander as the prime mover. The delivery of the power conversion system was made to the Jet Propulsion Laboratory for evaluation and demonstration with geothermal energy consisting of hot, untreated, corrosive scale-forming brines and/or vapors, including the total flow from geothermal wells of such brines and/or vapors.
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SUMMARY

This effort relates to the design, fabrication, delivery, operation and maintenance of a Hydrothermal Power Co., Ltd. (HPC) 1250 KVA Geothermal Power Conversion System, suitably adapted by HPC for testing and evaluation by the Jet Propulsion Laboratory, California Institute of Technology (JPL).

The system was designed, engineered, and patterned after a 62.5 KVA Power Conversion System previously developed and successfully tested by HPC. The design incorporated Background Patents, Know-how, and Proprietary Rights previously developed and owned by Roger Sprankle and HPC. HPC staff and personnel participated in a preliminary system design review held at JPL covering the 1250 KVA Geothermal Power Conversion System.

The Power Conversion System fabrication included the planning of a fabrication sequence starting with the early issuance of purchase orders for long lead time items and concluding with satisfactory acceptance testing by JPL. The issuance of purchase orders followed competitive bidding. Fabrication included: (1) securing of a Vibration and Torsional Analysis; (2) establishment of a Quality Assurance Program; and (3) the development of a Property Control Procedure, acceptable to the U.S. Government.

To assist in the evaluation process, Calibration and Performance data for both the Speed Reducer and Alternator were obtained.

Copies of the manufacturers' manuals or instructions for each major assembly or sub-assembly were obtained in so far as available.
HPC also provided engineering services to JPL for the purpose of: (1) planning for support and interface equipment to be provided by JPL to be used in testing and evaluation; (2) the selection of a geothermal test site suitable for performance evaluation; and (3) the development of detailed plans for site preparation and performance evaluation of the Power System.

Following fabrication of the Power System, hydrostatic testing of the process piping and prime mover housing was successfully accomplished at the HPC facilities, after which acceptance testing was commenced. During the acceptance testing procedures, four equipment failures were experienced. Acceptance testing was successfully concluded and the System formally delivered on December 4, 1977.

A survey of geothermal well sites was concluded with the selection of well No. 54-3, owned by Phillips Petroleum Co., and located at Roosevelt Hot Springs, near Milford, Utah.

Following on-site inspection of the well and test facilities at Roosevelt Hot Springs, a pre-engineered metal "Butler Building" was ordered, and the Power Conversion System was shipped to Utah. The Power System was then installed and assistance given to the JPL Principal Investigator, Dr. Richard A. McKay, covering details of the testing and evaluation. The operation of the Power System in Utah for the purposes of testing and evaluation by JPL was concluded on November 14, 1979. The Power System and related support and test equipment was shipped to Cerro Prieto, Mexico, on December 1, 1979.
INRODUCTION

The exploitation of Geothermal Energy is included among the efforts of the U.S. Government to resolve the critical energy needs of its citizens. Geothermal Energy is known to exist in the form of dry-steam which is rare and easily developed. However, Geothermal Energy exists more abundantly in the form of hot mineralized water wells. Until the development of the Helical Screw Expander, exploitation of hot water resources had been seriously hampered because no suitable prime mover was available for use with the fluids from these wells. It has been necessary to produce a vapor to drive a turbine, either by flashing part of the brine to steam, as is done at Cerro Prieto, Mexico, or by boiling a secondary fluid in a heat exchanger. In the steam flashing process, much energy is lost in the waste hot brine which flows from the steam separators. Although hot mineralized water wells are common, advanced technical development is required to overcome not only the scaling, corrosive, erosive characteristics of the waters, but also the hostile environment in which most of these hot waters are found.

New technology has been developed by Hydrothermal Power Co., Ltd. (HPC) in extensive research resulting in Patents, Know-how, and Proprietary Rights developed in connection with a prototype 62.5 KVA Power System. The prototype HPC Power System utilizes the helical rotary screw expander design as a prime mover driving a conventional 62.5 KVA generator at speeds controlled by a governor. The prototype HPC Power System is portable and
intrinsically self-cleaning in the rotor areas. It is capable of using the liquid-vapor mixture as it comes directly from the well. The prototype unit was successfully tested by operating directly on hot, untreated, corrosive scale forming brines and vapors from wells located at: Cerro Prieto, Mexico (M-7) (M-10); East Mesa, near El Centro, California (62-1); and a geothermal well near Niland, California (Sinclair #4).

The HPC prototype 62.5 KVA power system was the first known power generator to use the total flow of hot untreated brine and vapors directly from a geothermal well. The HPC prototype power system disclosed some interesting and useful technology which HPC believed would assist in the early utilization of energy from geothermal brines. The following observations and conclusions were offered in support of this belief. Paragraphs 2 through 5 of the following were taken from the writings of R. McKay, JPL.

1. The helical screw expander is a pure rotary, positive displacement machine. The positive displacement feature allows the machine to operate effectively over a broad range of geothermal conditions. The pure rotary motion allows operation in a much higher speed range than reciprocating machines allow. Thus, helical rotary screw expanders up to the fifty MW size range are readily feasible and are ideally suited to geothermal applications.

2. As a geothermal prime mover, the HPC helical screw expander is a total flow machine which can expand directly the vapor that is continuously being produced
from the hot saturated liquid as it decreases in pressure during its passage through the expander. (See Appendix E for cutaway view of prime mover.) The effect is that of an infinite series of stages of steam flashers, all within the prime mover. Thus, the mass flow of vapor increases continuously as the pressure drops throughout the expansion process and the total fluid is carried all the way to the lowest expansion pressure. The process approximates an isentropic expansion from the saturated liquid line for the total flow. The geothermal fluid flows through an internal nozzle control valve and at high velocity enters the high pressure pockets formed by the meshed rotors, the rotor case bore surfaces, and the case end face. As the rotors turn, the pocket elongates, splits into a V, and moves away from the inlet port. With continued rotation, the V lengthens, expanding successively as the point of meshing of the scres appears to retreat axially from the expanding fluid. The expanded fluid at low pressure is then discharged into the exhaust port.

3. Conditions for mineral precipitation from saturated brines within the expander occur for several interrelated reasons, including temperature decrease, pressure decrease, solvent removal, turbulence and the presence of nucleation sites. The internal surfaces of the expander serve as mineral deposition sites. Mineral deposition on these surfaces accomplishes several
beneficial results. The thickness of the mineral layer increases until the rotor-to-rotor and rotor-to-case leakage clearances disappear and the mineralized surfaces are continually lapped; steady state is reached. The loss of leakage clearances results in substantial increase in the efficiency of the expander. This clearance removal mechanism makes possible the use of less expensive fabrication and machining procedures during manufacture, and also makes the expander self-healing in the event that scarring of the case or rotors should occur. Moreover, the mineral layer has been demonstrated to provide excellent protection of the case and rotors against corrosion. This protection provides greater flexibility in the selection of relatively low cost materials of construction. Similarly erosion is minimal, either because the scale layer forms a protective coating or because the fluid velocities within the machine are not high, or both.

4. The lapping process associated with the minerals which are deposited on the machine surfaces within the expander is a source of suspended nuclei for additional mineral deposition and crystallization within the expander. In an experimental investigation of mineral deposition carried out in October, 1971, while operating a prior helical screw expander on Well M-10 at Cerro Prieto, HPC staff observed that mineral deposition occurred either almost exclusively within the expander or on the seed particles traveling with the exhaust brine.
After 307 hours of operation, the deposits ranged from 5/32 in. at the expander exhaust port to 1/64 in. 50 feet downstream. In the absence of the expander, the same well and feedline plugged shut a 12 in. exhaust pipe in approximately 80 hours. This characteristic of mineral precipitation occurring preferentially within the expander, either on the expander surfaces which are self-cleaning, or harmlessly in suspension, is highly beneficial. The tendency to deposit scale downstream appears to be negligible, at least along an isothermal path. This is important, not only for interstaging, but also in waste lines.

5. Essential to high engine efficiency is small leakage past the rotors. This requires small clearances, both rotor-to-rotor and rotor-to-case. The minute clearances brought about by the wet lapping of the mineral deposits in the geothermal expander leads to maximum efficiencies in this new unique application.

Three energy conversion concepts -- the Flashed Steam System, the Binary Cycle System, and the Total Flow System -- are present contenders for producing electricity from hot-water geothermal resources. In the Total Flow System, as represented by the HPC Helical Rotary Screw Expander Power System, the hot wellhead product follows an isentropic expander directly from the wellhead through the prime mover to the exhaust pressure and temperature. The system is thermodynamically the simplest and is theoretically optimum.
The successful operation of the HPC 62.5 KVA prototype system led HPC to the conclusion that the design and construction of a commercial size system was possible. In April of 1973, two engineers from the Jet Propulsion Laboratory toured the geothermal site at Cerro Prieto, Mexico, and observed the 62.5 KVA power plant in operation. They agreed with the conclusions of HPC staff.

A project proposal calling for the construction and evaluation of an HPC designed 1250 KVA Geothermal Power System was prepared by the Jet Propulsion Laboratory in consultation with HPC, and submitted to, and eventually approved by, The National Science Foundation. The project was thereafter preempted by the Energy Research and Development Administration (ERDA) and then by the U.S. Department of Energy, (DOE), Division of Geothermal Energy, present sponsors of the project.

The project plan called for the construction of a modular HPC 1250 KVA Geothermal Power System, incorporating the helical rotary screw expander as the prime mover, to be operated on total flow brine with an evaluation of the power system's mechanical and thermodynamic performance by JPL. An interagency agreement between ERDA and NASA resulted in the authorization of and financing for the project. Dr. Richard A. McKay, proposal author, was assigned to plan, co-ordinate and manage the project as technical manager and principal investigator on behalf of JPL and NASA.
Jet Propulsion Laboratory contracted with HPC for design, fabrication, delivery, operation and maintenance of an HPC 1250 KVA Geothermal Power Conversion System, with testing and evaluation to be carried out by JPL. An impartial mechanical and thermodynamic performance report and evaluation are the responsibility of JPL.
The design and engineering for the 1250 KVA Power Conversion System built during the effort being reported were based upon a prototype 62.5 KVA Power Conversion System previously designed, engineered and constructed by Hydrothermal Power Co., Ltd. (HPC). The design incorporated Background Patents, Know-How and Proprietary Rights previously developed and owned by HPC. Appendix A is a Descriptive Specification of the 1250 KVA Power Conversion System.

The following discussion has been arranged in chronological order for ease of understanding. The time period is from start of plant construction, January 16, 1976, through shipment from the Roosevelt Hot Springs, Utah test site to Cerro Prieto, Mexico, on December 1, 1979.

Immediately following contract execution, various manufacturers were contacted for current quotations covering price and availability for major long-lead time items. Consistent with competitive bidding, "Requests for Quotations," were issued. A copy of the face sheet of the HPC, "Request for Quotation," form is attached as Appendix B.

The planned method of construction of the prime mover housing was changed from casting to fabricating. A meeting at the Cerro Prieto Geothermal Plant was conducted with the CFE Dept. of Geothermal Studies covering their recommended materials of construction. Their recommendations were co-ordinated with material availability from suppliers. Their recommendations also covered materials of construction for the entire plant.
A basic layout of the expander housing was drafted. The layout was detailed into shop drawings soon after rotor details were finalized. Appointments were arranged with shaft seal and bearing manufacturers. Appendix C contains facsimile copies of records of the chemical analysis, mechanical analysis, and non-destructive testing records relative to the rotor forging. Appendix D contains facsimile copies of chemical and mechanical analysis of material used in the prime mover housing. Appendix E shows a cutaway view of the prime mover.

A meeting with a bearing supplier covered the thrust and journal bearings. Their quotation included strain gauges and thermocouples in the thrust bearing pads and thermocouples in the journal bearing babbitt. All main bearings were sized with a unit loading of 150 psi or less. A meeting was held with a shaft seal supplier. Various designs were discussed, including the shaft seal design in the existing HPC 62.5 KVA Power System.

In March, 1976, a meeting was held with JPL personnel covering the electrical interfacing between the power System and Jet Propulsion Laboratory evaluation equipment. All major electrical equipment belonging to the Power System and supplied by HPC was made ready for purchase. Minor details of interfacing were scheduled for accomplishment during assembly. Suggestions concerning the alternator details were made by the JPL technical staff and these details incorporated into the alternator design. Also, the raw data for the vibration and torsional analysis of the main drive train was assembled and made ready for the actual analysis. In addition, the shop layout and supplies were organized and prepared for the delivery of the first raw materials.
In the following three (3) months, details of the prime mover were attended to and prepared for shop drawings. Items covered included the shaft seals, bearings, O-rings, shims and gaskets, bolt size and loading, and the housing fabrication sequence. Items addressed with respect to the entire power plant included the skid pad, protective coatings, minor electrical details, and the governor control response characteristics. Governing of the plant is achieved by controlling the position of a moveable nozzle component which forms part of the high pressure port of the prime mover. The hydraulic coupling between the governor and the control nozzle is identical to the existing 62.5 KVA power plant linkage, except for a second stage hydraulic amplifier to handle the greater work load of the larger control nozzle component.

In order to assure quality and conformity between purchase orders and purchased parts, an approved Quality Control Procedure was adopted. A record has been maintained of all significant purchased parts. Appendix F sets forth the established Quality Control Procedure and a copy of the form for records maintained.

While construction of the prime mover housing progressed routinely, attention was also directed to the safety shutdown system and engineering data for the lubrication console.

The basic safety shutdown system consists of a gate valve located in the inlet pipeline to the prime mover. This gate valve is held open by a double acting cylinder which, on loss of electrical signal, will close the valve automatically. Various sensing switches throughout the plant control this electrical signal. In addition the governor control nozzle trips to
the closed position on loss of electrical signal due to a fault. The gate valve construction was chosen with the assistance of engineers from Cerro Prieto, Mexico, and contains both design and materials known to be tolerant to corrosive geothermal brines. Appendix B shows material used for gate valve construction.

The requirements to the lubrication system involve the prime mover, speed reducer, and governor system. The prime mover requirements entail the bearings, seals, timing gears, and the heat transfer through the housing. The speed reducer requirements involve the bearings and gears. The governor system requirements include the governor, hydraulic servo, hydraulic amplifier and double acting cylinder. A small requirement is also necessary for the automatic gate stop valve. After these items were defined, and with their requirements known, the lubrication console was sized accordingly and construction started.

The main drive couplings are of the flexible gear type. The high speed coupling is a spacer type gear coupling with a NEMA standard diametric taper hub on the expander side for ease of removal. Both hubs have puller holes. The low speed coupling is an overload type gear coupling. Both of these hubs have puller holes. The puller holes allow the easy removal of the hubs for gear interchange in the speed reducer.

Following design completion of the main drive train couplings, a vibration and torsional analysis of the main drive train was performed. Appendix G contains the vibration and torsional analysis.
Concurrently with the plant construction, assistance was given to JPL in a site selection survey for plant evaluation. Various potential sites were visited in August, October, December, and January, 1977. As part of the site selection survey, a tour was made of the Roosevelt Hot Springs area in Utah, being developed by Phillips Petroleum Co. This site was eventually chosen as having the best potential of fulfilling the needs of the evaluation project. Major factors affecting this choice were the availability of effluent disposal, high wellhead flow and enthalpy, potential continuous operation of the well, and well flow stability.

From January through March, 1977, a major effort was extended to the welding, grinding, machining, and fabrication of the prime mover. The housing midsection advanced through numerous steps, including the surfacing of the end faces, finish welding to the exhaust section, and set-up for boring. The inlet port and nozzle area was organized, prepared for shaping, and shaped for acceptance of the control nozzle component. The housing was aligned and pinned and the midsection finish machined. The inlet port flange and foot pads were welded to the housing and the housing was assembled in preparation for hydrostatic testing. Numerous minor items were fabricated such as special tools for assembly and disassembly of the prime mover, an alignment fixture to position the prime mover on the skid pad, and hydrostatic test pump equipment.

The hydrostatic testing of the prime mover housing involved two regions, the high pressure region and exhaust region. For
hydrostatic testing, the high pressure region was isolated from the exhaust region with a bulkhead fixture. On April 7, the mid and low pressure regions were hydrostatically tested to 450 PSIG, following the *ASME Boiler and Pressure Vessel Code*. On June 29, the high pressure region was hydrostatically tested to 1080 PSIG, following the *ASME Boiler and Pressure Vessel Code*. A hydrostatic test was also conducted on all onboard inlet piping prior to installation.

Concurrently with hydrostatic testing, numerous other items were completed. Inspection and acceptance testing was made on the speed reducer. Appendix H contains efficiency and performance curves for the speed reducer. The alternator had been tested and inspected earlier. Appendix I contains efficiency and performance curves relating to the alternator.

The prime mover was assembled for an alignment, clearance check, and pinning of mating parts. Rotor machining and hard-facing were completed and the rotors balanced with bearing, seal, and coupling parts attached. Residual imbalance is shown in Appendix J. Hydraulic plumbing was completed for the shaft seals, governor, bearings, and buffer grease system. Installation of electrical switchgear, wiring, and instrumentation was partially completed with calibration of safety stop sensors.

Subsequent to the hydrostatic testing, the assembled prime mover, speed reducer, and alternator were mounted and aligned on the main skid pad. The alternator was mounted first and bolted directly to the skid pad and aligned with studs to the alternator feet. Next, the speed reducer was mounted to the main
skid. Alignment was effected by using thermoplastic grout, brass shims and alignment studs to the speed reducer feet. Finally, the prime mover was aligned to the speed reducer in the same fashion. With the main drive train mounted and aligned, the drive couplings were installed and attention directed towards the completion of sub-systems in preparation for dynamic plant testing.

Prior to dynamic testing, planning was done by staff from HPC and JPL and a procedure formulated entitled, "System Test and Acceptance Procedure". The procedure followed by both JPL and HPC staff is set forth in Appendix K.

Dynamic plant testing was scheduled for August 13, 1977. The first half of the month involved preparation for this testing. A faulty overspeed switch was replaced, and a design improvement was made to the governor override solenoid valves involving the hydraulic port location on the governor.

For dynamic testing, compressed air was used as the motive fluid to drive the prime mover. The dynamic testing was terminated early, after a spline drive to the governor sheared, and in the process destroyed much of the governor. The problem was later diagnosed as a tight fitting spline, allowing no radial misalignment between the governor input drive and female rotor shaft. Arrangements were made with the governor manufacturer for a repaired governor, and the clearances on the spline coupling were increased to allow for radial run-out.

The dynamic testing was re-scheduled for September 14. Preparation included general check-out, replacement of a hand pump with an electric drive pump, and adjustments to the response time.
in the governor hydraulic system. The acceptance testing was not completed due to a seal failure on the male rotor high pressure end seal assembly. Subsequent to inspection and consultation with the seal manufacturer it was concluded that the failure was due to an extreme overpressure in the supply oil to the seals and lack of proper relief valves for that pressure. It is believed that the extreme overpressure was caused by normal seal heating and subsequent fluid expansion within the seal assembly. Relief valves were installed on the supply oil lines to each of the seals. In addition, the male rotor high pressure end seal assembly was re-installed with only 4 of its original 7 seals. This reduced frictional heating.

On October 20, the power plant was again operated on air. After approximately forty (40) minutes of operation and acceptance testing, rotor contact was noticed. The test run was terminated and re-scheduled for the following week after the timing gears were re-set. It is believed that a contributing factor to the rotor contact was housing distortion due to the cooling effect of the air as it expanded across the prime mover.

On October 27, the power plant was again operated on air. The plant was operated for approximately 1 hour, 45 minutes, during which most of the acceptance testing procedure was completed. The testing was again terminated by a failure on the male rotor high pressure end seal assembly. Subsequent investigation revealed inadequate clearances between the stationary and rotating part due to thermal growth. Added clearances were machined into the seals and acceptance testing scheduled for December 4, 1977.
On December 4, acceptance testing was successfully completed after approximately four (4) hours of continuous operation and satisfactory completion of all items covered in the "System Test and Acceptance Procedure".

As specified in the contract, construction of the Power Conversion System was scheduled for 15 months at a cost of $477,791. Actual construction time was 22 months and 19 days at an approximate cost of $481,000. The schedule variation is attributed essentially to delays in issuance of initial purchase orders and mechanical problems during acceptance testing.

Following successful delivery of the plant, effort was given to: modifications to the plant needed for operation on Phillips Well 54-3; packaging; and site preparation. The modifications to the plant involved the re-design, ordering and installation of electrical switchgear suitable for the re-injection pumps required for this particular test site. The site preparation involved grading, placement of cross timbers onto which the plant was positioned, and site layout for the location of major items such as the data van, load bank, auxiliary power plant, exhaust holding tanks, shop facilities and living quarters. Appendix L contains a schematic of the Utah test site layout.

Prior to shipment of the Power Conversion system, it became evident to Hydrothermal Power Co. that shop facilities and support at the remote Roosevelt Test Site were unavailable for the project needs. To fill this need, HPC constructed a mobile shop trailer. The shop was well equipped with tools to provide a wide range of services such as welding, cutting, grinding, threading, cleaning,
and painting. In addition, the shop contained a broad selection of fittings such as valves, tubing, gaskets, and packing materials. The shop trailer proved to be a tremendous asset at the test site.

The Power Conversion System was delivered to the test site on February 1, 1978. The balance of the month was expended in off-loading the system, site preparation for and placing of the exhaust holding tanks, and erecting a protective steel building for the power system. Assistance was given in the planning for the inlet and exhaust piping, placement of the test van and other test facilities.

Prior to running the Power System, a procedure for logging and recording various important plant parameters, such as oil flows, pressures and temperatures was developed. The recording and logging procedure was planned to compliment the testing data to be recorded by the computer system housed in the JPL Data Van. As a part of the logging and recording procedures, forms were prepared suitable for manual logging and subsequent filing. Appendix M is a copy of the logging form. The initial time period for recording was every one-half hour, but was soon changed to one hour intervals as confidence increased in the process and equipment. Items concerning the plant status were also logged in the data van as part of the test data. In addition, periodic recordings were taken of the main drive train vibration level at eight (8) marked locations. A vibration meter was used for this purpose (Sonidet Meter, Cardwell Condenser Corp.). Also spot visual checks were continually made during operation.
The first half of March, 1978, was expended in assisting the Principal Investigator, Dr. Richard McKay, in the completion of the inlet and exhaust piping and data acquisition system. The first run was on March 16. After approximately fifteen (15) minutes running, a governor spline broke. Repairs were made to the governor and the system was again run on March 21. During the balance of the month, the system was run at intervals, being shut down frequently while changes in the inlet piping and inlet piping controls were made under the direction of the Principal Investigator.

Operation and testing at the Utah test site can be broken into two (2) categories: Power System Operation and Site Process Operation. The Power System involves only the process from the inlet flange to the exhaust flange of the HPC Power System. The Site Process includes everything from the wellhead through the Power System to the disposal well located one and four tenths (1.4) miles from the wellhead.

Initial operation of the Power System involved becoming familiar with the site process and then adjusting the process controls for stable, steady operation; a critical requirement for testing. A significant improvement was made to the site process operation when the wellhead separator level was instrumented and proper level maintained.

A problem that persisted throughout all the testing involved the inlet piping from the point where the steam and water were mixed to the point where the mixture entered the prime mover. The problem manifested itself in the form of unstable flow and
slugging which prevented stable 60 cycle operation, forcing the plant to vary at times ± 2% in frequency. This unstable flow was most noticeable between an inlet quality of 1% and 10% steam. With qualities greater than 10% steam, the higher flow velocities appeared to assist in mixing. Different diameters of inlet piping were tried with some success, in an attempt to prevent unstable and slugging flow. With zero steam quality or all liquid fase, the plant operation was surprisingly smooth and steady. However, under some conditions, where the inlet control valve was partially open, water hammer would occur in the inlet piping.

Concurrently with the effort to improve the unstable inlet flow, efforts were made to improve the governor system performance. Some success was obtained by cutting throttling notches into the spool for the hydraulic amplifier.

Another problem area during plant operation involved silica scale buildup in the waste disposal pump strainers. Part of the pipeline between the waste holding tanks and the pump inlets took advantage of an existing used pipe, previously installed for other purposes by Phillips Petroleum Co. This pipe length continuously shed scale which clogged the strainer to the pumps along with new scale which was continuously precipitating during plant operation. Much of the used pipe was removed with some improvement to this problem. By alternately switching between the duplex pumps, plant operation was maintained with repetitive strainer cleaning as required.

Another problem of a more serious nature involved the prime mover shaft seals. As testing and plant operation progressed, the
seal leakage rate continued to increase. On April 23, inspection revealed that the male low pressure seal leakage rate was excessive. Subsequent removal revealed a cracked seal sleeve and serious erosion, with silica scale build-up. The seal assembly was replaced. In the hope of preventing another failure, air was injected through pre-existing ports to the high pressure end seals. Pre-existing ports were not available to the low pressure end seals and could not be machined into the housing in the time available. Well shut-in was scheduled for June 1, 1978. The decision was made to continue testing with the recognized risk of another seal failure.

On May 31, 1978, one day before the scheduled termination of the Utah testing, the same shaft seal failed in a catastrophic manner. The seal failure friction welded the seal sleeve to the shaft, ruptured and demolished the seal assembly, bent the shaft, and due to excessive heating, melted the adjacent bearing babbitt.

Repair of the plant began subsequent to the post calibration of the evaluation instrumentation, preservation and storage of process equipment, and well site cleanup. Repair of the power plant was centered around repair and re-designing of the shaft seals and improvement of other plant aspects for better all around performance.

The fundamental design change to the shaft seals involved the addition of a fresh water flow across the seal area exposed to the brine process. This fresh water acts as a shield, or buffer, preventing mineral build-up in the seal assemblies.
To accommodate the new seal design, the safety shutdown system was changed. The change involved the installation of flow switches to each seal flush water line. The change also involved differential pressure switches and gauges installed on the oil/flush water system on each seal assembly. These switches are all wired in series with the existing shaft seal pressure relay. In addition, to handle the additional power requirements of the 24 VDC system, the batteries and battery charger were changed to a larger size.

At the Utah test site, there was no source of fresh water for use across the shaft seals. For the continued Utah testing, the most readily available source of flush water was determined to be steam condensate. The equipment involved is a steam/exhaust brine heat exchanger located in the exhaust holding tanks and then a condensate/air heat exchanger to supply a holding tank with condensate at a temperature \( \leq 160^\circ F \). The holding tank is used to supply a metering pump which feeds each seal assembly.

During the 1978 spring testing in Utah, the power plant experienced an abrupt load loss of more than 500 KW with subsequent overspeed and automatic shutdown. Proper governor design should be responsive enough to allow full load changes without overspeed or underspeed shutdown. A design improvement of the plant involved a custom built hydraulic amplifier and increasing the hydraulic oil supply for quicker governor response and greater work rating.

Also during the 1978 testing, water hammer was experienced at some control valve positions with all liquid inlet feed. The inlet port configuration was subsequently changed to eliminate this problem.
In addition, during the spring testing, it was determined that there was one major source of noise, the alternator cooling fan. In an attempt to attenuate the noise, a quieter fan was installed, shrouded and lined with a sound absorbent material, and ducted away from direct ear contact.

With resumption of well flow by Phillips Petroleum Co., in the spring of 1979, and mid July completion of the plant repair, efforts were directed to the evaluation equipment re-installation, calibration, and general test site preparation. Equipment calibration and site preparations were hindered somewhat by a well blow-out in June 1979, which deposited salts and scale over the entire test site, causing numerous electrical problems.

Checkout of the fresh water system revealed that the steam condensate contained large amounts of iron carbonate, which precipitated probably as siderite. Various methods were attempted to solve this problem. The solution involved changing the design, to first aerate and mix the hot condensate with bentonite and then hold the mixture in a large tank where the bentonite and newly formed iron oxide would settle out. The resulting water was then filtered to 25 microns and fed to the seal metering pump.

Plant operation for testing commenced on August 29, 1979. As testing continued, it became apparent that naturally formed mineral depositions would not close the clearances internal to the prime mover. The rate of deposition was too slow to close these clearances in the time allowed for testing. Recognizing the importance of internal clearances to prime mover performance, an
attempt was made to chemically force mineral deposition to occur at an accelerated rate.

The method used to force mineral deposition to occur involved the injection of a calcium chloride solution directly upstream of the prime mover inlet. The necessary equipment involved mixing tanks for the solution, a metering pump, and an injection line to the prime mover inlet. Various combinations of concentration and flow rates were attempted with some success. However, the resulting calcium carbonate deposition that did occur deposited preferentially in some areas and not others, and continually broke off in large scales. The attempt to force mineral deposition to occur was subsequently terminated and attention given to other aspects of the evaluation.

One incident did occur, however, that demonstrated the need for a jacking motor to slowly rotate the plant immediately after stopping and before starting. Upon stopping the plant after a test run, during which a particularly concentrated solution was injected, the rotors became locked as the housing was allowed to cool to ambient temperatures. In order to free the rotors, it was necessary to block the exhaust port and fill the housing with a mild solution of hydrochloric acid and metal pickling inhibitor. After approximately 24 hours of soaking, the rotors became free and testing was continued. A jacking motor has subsequently been installed and appears to have solved this problem.

During continued testing, water build-up was noticed in the main lube oil reservoir. Inspection revealed that flush water was migrating back across the shaft seals into the bearing areas, and
to the oil reservoir at a rate of approximately 100 cc/min. This leakage was recognized as a seal short-coming and that the water would have to be periodically removed at the reservoir. For the short term and continuation of testing, bleed steam was used to dry the reservoir during periods of plant shut down. For the longer term a water/oil separating centrifuge was ordered for continuous water removal.

Concurrently, with the test activities in Utah, many visitors observed the plant in operation. During one visit, a group of foreigners, some of whom were involved in geothermal activities in their respective countries, toured the test site. They were impressed with the plant operation and test activities. Their interest led to an International Energy Agency (IEA) agreement, whereby the Power System and support test equipment would travel abroad for demonstration purposes. First on the demonstration schedule is Mexico, where the plant would be operated in the geothermal field at Cerro Prieto.

Utah plant operation and testing was terminated on November 14, 1979. Post calibration, packing, and site clean-up followed, with loading and shipment to Cerro Prieto, Mexico, on December 1, 1979.

The support activities in Utah involved a time period of 24 months from plant delivery on December 4, 1977, through shipment to Mexico on December 1, 1979. Total cost for Hydrothermal Power Co. efforts during this time period was $530,927.
CONCLUSIONS

As a result of the reported effort, we conclude:

1. Problems associated with the initial plant operation are considered incidental and should be viewed as a normal debugging process for new equipment.

2. Varied geothermal well production characteristics put a large demand on the governor system. Control needs to be maintained over a wide range of inlet pressures, flows, and electrical loads. Design improvements to the governor system should satisfy these control needs.

3. That substantially all of the conclusions from the testing of the 62.5 KVA Prototype Power System are confirmed. In particular, the following conclusions were verified.
   A. The helical screw expander is a useful, efficient, total flow prime mover;
   B. The scaling or mineral deposits reduces leakage, between rotor-to-rotor and rotor-to-case, resulting in a substantial increase in machine efficiency.

4. That internal inspection of the prime mover has revealed nothing to prevent long term maintenance free operation.

5. The nature of the equipment, including the fault and safety shut down system, points to a Power System capable of extended periods of continuous, unattended operation.
6. That a Geothermal Power System could be built from a standard set of materials, adaptable to a large variety of geothermal wells and fields, and developing mechanical efficiencies greater than 70%.

7. That adoption of the recommended modifications would enhance the efficiency and overall attractiveness of the HPC Power System to the Geothermal Industry.

8. Test results have shown that the power conversion system does have an application for power recovery from geothermal brines having an extremely broad range of qualities.

9. The prime mover can be characterized as having a weight to power ratio somewhere between turbines and reciprocating prime movers. For example, with an installed prime mover weight of 100 tons, a diesel would produce 12 MW, a helical screw 30 MW, and a steam turbine 200 MW. This will limit the single shaft power output from a helical screw to about 50 MW utilizing existing heavy industry. This size may be increased by utilizing fabricated hollow rotors. An attractive size appears to be approximately 5 MW where the entire power plant can still be maintained easily transportable on skids and located near the wellhead.
RECOMMENDATIONS

The following recommendations are based upon operating experience. If adopted, they should result in reduced maintenance and simpler future operation.

We recommend:

1. a H₂S removal system be installed in all electrical enclosures;
2. a longer and wider main skid-pad for easier equipment access for servicing and maintenance;
3. that the safety shut-down electrical system be isolated in its own enclosure;
4. that the hydraulic actuator to the automatic stop-gate valve be located in a vertical position;
5. that the hydraulic actuator of the automatic stop-gate valve have an adjustable stroke cushion to reduce mechanical stresses on the main drive train during fault shut-down;
6. that the inlet pipe to the prime mover be welded to the main skid pad to reduce stresses to the prime mover feet, which could lead to misalignment;
7. that provisions be built into the lube oil console for additional cooling capacity when the plant is operated in hot desert environments;
8. that additional inspection ports be built into the prime mover housing;
9. improvements be made to the governor control system to allow stable plant operation at various inlet pressures and electrical loads;
10. a larger lube oil reservoir capacity to accommodate oil loss due to nominal shaft seal leakage;
11. that the manual start hand pump be changed to electrical drive;
12. that an event recording system be installed to monitor the plant and record the failure sequence in a fault shutdown;
13. that additional testing be done at different speeds, and with various field parameters;
14. that an HPC Power Conversion System, with a nominal capacity of 5 MW be constructed, incorporating the above design changes.
NEW TECHNOLOGY

Prior to the issuance of the subject contract, Hydrothermal Power Co., Ltd. (HPC), had developed New Technology through extensive research, resulting in patents, know-how, and proprietary rights. The research culminated in the successful operation of a prototype 62.5 KVA Power System.

Following the execution of the subject contract, HPC petitioned the U.S. Department of Energy for and received an "Advance Waiver" on New Technology developed during the performance of the contract.

No reportable items of New Technology were identified or developed during the fulfillment of the contract terms.
APPENDICES
DESCRIPTIVE SPECIFICATION

for

GEOTHERMAL POWER CONVERSION SYSTEM

supplied by

HYDROTHERMAL POWER CO., LTD.

Pasadena, California

May 9, 1980

The Geothermal Power Conversion System consists of a Lysholm type expander with sixteen and one-half (16.5) inch diameter rotors, a speed reducer and an alternator, complete with all necessary auxiliary equipment and accessories required for use as a geothermal wellhead electrical generating plant. The drive train is a skid mounted, factory assembled unit, susceptible of transport without dismantlement. Heavy tarpaulins are provided for protection of the System during shipment or site storage. The Contractor's predictions of System performance are set forth in Appendices 1 and 2 herewith. The System includes the following assemblies, sub-assemblies and components:

I

Main Drive Train

The main drive train is mounted and aligned on a structural steel base pad or frame. The basic envelope is 6 ft. in width, 8 ft. 1" in height, and 25 ft. in length; the weight is approximately 25,000 lbs. The main drive train is exposed for ease of interfacing with process piping, lubrication oil console, and electrical switchgear. The equipment is designed for outdoor, unattended operation for extended periods. The main drive train consists of the following sub-assemblies:

(Prime Mover)

The prime mover is a Lysholm-type machine designed for operation as a high enthalpy brine expander having the following features:

1. A fabricated steel housing with porting to provide for a variable volume ratio. The housing incorporates a gate-type governing valve that controls this variable volume ratio. The inlet port is an 8-inch. 300 lb., ANSI raised-face flange. The maximum allowable operating condition is 625 psig at 500° F.
2. The low-pressure end is of stainless steel with a 24-inch, 150 lb., ANSI raised-faced flange.

3. The shaft seal assemblies consist of a combination of segmented carbon seals, floating ring seals, and labyrinth seals. Oil is maintained behind the segmented carbon seals at a pressure slightly higher than the flush water pressure to prevent water intrusion into the oil system.

4. Radial bearings are pressure-lubricated, tilt-pad type sized for moderate to low specific bearing pressure. Thrust bearings are large, sturdy, self-equalizing type of conservative design for long life. One hundred ohm platinum resistance temperature detectors are provided on all bearings.

5. Two 1 1/4-inch, threaded, plugged, inspection holes are provided in the rotor bores with provisions for measuring rotor wear.

6. Rotors are machined from solid, one-piece forgings to provide the maximum practical bending strength.

7. Rotor construction is suitable for 100 psi pressure differentials at rotor speeds up to 5,000 RPM.

8. Hard-surfaced rotor tips and end faces are provided.

9. A jacking motor is provided to slowly rotate the prime mover during periods of startup and shutdown.

The prime mover housing is hydrostatically tested according to the ASME Boiler and Pressure Vessel Code. The inlet and high pressure regions are tested to meet or exceed a 300 lb. ANSI rating. The exhaust and low pressure regions are tested to meet or exceed a 150 lb. ANSI rating.

(Speed Reducer)

A suitable speed reducer is provided and is flexibly coupled to the prime mover and to the alternator. The speed reducer is a parallel shaft horizontal offset design having sleeve type bearings. Lubrication is provided from the main lubrication console. The high and low speed couplings are self-aligning gear type with sealed grease lubrication. The low speed coupling is of the shear-pin type. The couplings are designed to operate for 20,000 hours before recommended disassembly for an alignment check and re-lubrication. The speed reducer is generously sized for an extended life of greater than ten years before overhaul. Gear sets for three gear ratios, 5000/1800, 4000/1800 and 3000/1800 rpm (approx.) are supplied with the gearbox.
The alternator is a continuous duty 1000 KW, 1250 KVA, 0.8 p.f., 1800 rpm., 3 phase, 60 HZ, 480/277 volt, 4 lead, 2 bearing, drip proof, enclosed machine suitable for operation in a desert environment, and having a directly connected brushless exciter and a solid state voltage regulator. The alternator bearings are of the antifriction type with double shields and are lubricated at the factory. The alternator bearing is of a design capable of ten years of continuous operation. Two 100 ohm platinum resistance temperature detectors are installed in each phase of the windings to make possible a continuous indication of alternator temperature. A 100 ohm platinum resistance temperature detector is installed on each bearing. To reduce noise, the cooling fan is ducted and shrouded away from direct ear contact.

II

Oil System

The oil system provides bearing lubrication as well as cooling for the prime mover and the speed reducer. It also provides oil for the shaft seal needs and the hydraulic needs for the speed governor and safety shutoff mechanisms. The oil system also includes a heat exchanger and other provisions necessary to maintain the prime mover and the speed reducer at proper operating temperatures by transfer of heat from the oil to the surrounding atmosphere. A fully automatic greasing system is provided for the lubrication of all critical surfaces or bearings within the brine inlet and governor control valve. The oil system includes the following subassemblies and components:

(Lubrication Console)

1. 300-gallon reservoir with sight gauge, breather, and fill cap
2. Duplex filter and transfer valve
3. Forced draft oil-to-air heat exchanger
4. Oil pump directly connected to speed reducer at 1800 rpm
5. All associated piping, temperature and pressure regulators, gauges, and switches

(Shaft Seals)

1. Booster oil pump, filter, accumulator and regulators to shaft seals
2. A flush water pump, duplex filter with transfer valve, and flow meters to feed one GPM of suitable flush water to each shaft seal
3. A water-oil centrifuge to remove water from the seal oil discharge

(Auxiliary Functions)

1. Sufficient oil capacity and accessories are provided to assure proper operation of the governor and its hydraulic amplifier.

2. Sufficient oil capacity and accessories including an accumulator are provided for hydraulic operation of the automatic gate shutoff valve.

III

System Control

(Speed Governor System)

The governor system has the following features and characteristics:

1. The governor is a mechanical flyball-type, flexible spline connected to the female rotor of the prime mover.

2. The governor output is amplified through a hydraulic servo mechanism for operation of the governing valve located in the prime mover inlet port.

3. There is a means for adjustment of the governor with provision for remote control from the electrical control box.

4. The governor control mechanism provides means for either isochronous control or droop control at the election of the operator. The accuracy of control in either case is within plus or minus one quarter (1/4) of 1% of the speed set or selected by the operator.

(Automatic Gate Shutoff Valve)

The automatic gate shutoff valve is wired for automatic fail-safe operation whenever there is a dropout of the electrical signal required to hold it open. The generator output breaker trips open also with a dropout of the electrical signal due to underspeed.

Provisions are made for actuation of the automatic shutoff valve in consequence of any one or more of the following conditions, any one of which will trip and fully close the automatic gate shutoff value within fifteen (15) seconds:

1. Underspeed
2. Oil supply overtemperature
3. Oil supply underpressure
4. Shaft seal low differential pressure
5. Shaft seal low flush water flow
6. Excessive vibration
7. Actuation of manual stop switch
Provisions are also made for actuation of the automatic shutoff valve in consequence of any one or more of the following conditions, any one of which will trip and fully close the automatic stop gate valve within one (1) second:

1. Overspeed

Relays are provided for remote actuation of both the stop and emergency stop switches.

IV

Electrical Systems

The Geothermal Power Conversion System is designed for starting without any external electrical power source. Batteries are provided to energize the safety shutoff circuit during startup and during normal operation. During operation, all necessary electrical energy, including that for battery charging, is provided by the System itself. All of the electrical lines, connections and contacts are protected from the corrosive salts and gases prevalent in geothermal environments. Protection for all instrumentation and signal wires is provided by conduit, gutter or tray as appropriate for the protection and isolation of such circuits within the perimeter of the Geothermal Power Conversion System. The electrical system includes the following subassemblies and components:

(Alternator Control and Protection)

The alternator is provided with all necessary or required protective and control devices requisite for safe operation. Accordingly, an output circuit breaker complete with solid state protective devices for circuit fault, ground fault and thermal overload conditions is provided for the main load. The output circuit breaker has a 120V AC shunt trip coil. In addition, a 400 amp., 480 V., 3 phase breaker panel is provided for possible power needs at the geothermal plant site. A separate 120 volt output breaker is provided for all inhouse usage.

The alternator is provided with a control box or console having provisions for the measurement of alternator frequency, voltage, current, power output, and kilowatt hours. A current transducer and a power transducer each provide 4 to 20 MA output. Indicating meters are provided within the control box. Means are also provided there for the convenient connection for external recording of amperage and voltage. The control box also contains an elapsed time meter, necessary relays and timers, as well as the voltage regulator and a remote governor control switch. A 10 KVA single-phase transformer with 110/240 volt output together with output circuit breakers for the control of all electrical energy.
(station power) used for operation of the System is also provided. The arrangement of the control box panel is generally in accord with JPL Drawing No. SE/60-0 that appears in the JPL ELECTRICAL STANDARDS published in June 1975 by the JPL Facilities and Engineering Construction Office.

Remote Monitoring

A terminal box containing a terminal strip is provided to facilitate the remote monitoring of the following:

1. Alarm and sensor contacts giving indications of improper speeds, pressures, temperatures or vibrations
2. Remote circuit breaker trip mechanism
3. Station power (120/240 volt)
4. Temperature sensors
5. Bearing load sensors
6. Amperage transducer
7. KW transducer
8. KWH pulse
9. Voltage
10. Frequency
11. 24 Volt DC Supply.

Remote Control

A terminal box containing a terminal strip is also provided to facilitate the remote control of the following:

1. Voltage
2. Frequency
3. Normal stop
4. Emergency stop.
Inlet Piping

The System includes adequate means for support and flexible coupling of the upstream piping so as to minimize any mechanical loading of the prime mover. The inlet piping is capable of safe handling of geothermal fluids at pressures up to 625 psig and temperatures up to 500°F. All inlet piping is hydrostatically tested to the ASME Boiler and Pressure Vessel Code to meet or exceed a 300 lb. ANSI rating. The inlet piping of the System includes the following components:

1. 8-inch, 300 lb. ASA gate start and stop valve
2. 8-inch, 300 lb. ASA automatic gate stop valve, pneumatically-hydraulically actuated
3. Flex-coupling at prime mover inlet, 8-inch, 300 lb. ASA rating
4. Burst-type bypass plus relief valve.

Drawings

The Geothermal Power Conversion System is furnished in conformity with the following drawings as prepared by the Hydrothermal Power Co., Ltd.

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<th>Issue Date</th>
</tr>
</thead>
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<td>As revised 1-18-78</td>
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<tr>
<td>2. B-14</td>
<td>As revised 5-9-80</td>
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<tr>
<td>3. B-20</td>
<td>As revised 5-11-80</td>
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### APPENDIX 1

**HYDROTHERMAL POWER SYSTEM PERFORMANCE**

**1250 KVA PLANT**

<table>
<thead>
<tr>
<th>CASE I</th>
<th>CASE II</th>
</tr>
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<tbody>
<tr>
<td><strong>SIZE</strong></td>
<td></td>
</tr>
<tr>
<td>16.5&quot; Rotor diameter</td>
<td>same</td>
</tr>
<tr>
<td>25&quot; Rotor length</td>
<td></td>
</tr>
<tr>
<td><strong>POWER</strong></td>
<td></td>
</tr>
<tr>
<td>1000 KW Prime Mover</td>
<td>same</td>
</tr>
<tr>
<td>Shaft Output</td>
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</tr>
<tr>
<td><strong>RPM</strong></td>
<td></td>
</tr>
<tr>
<td>4000; = 288 ft/sec</td>
<td>same</td>
</tr>
<tr>
<td>tip velocity</td>
<td></td>
</tr>
<tr>
<td><strong>FLOW RATE</strong></td>
<td></td>
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<tr>
<td>135,000 lb/hr.</td>
<td>85,000 lb/hr.</td>
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<tr>
<td><strong>ENTHALPY</strong></td>
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<tr>
<td>424 Btu/lb. inlet</td>
<td>same</td>
</tr>
<tr>
<td><strong>TEMPERATURE</strong></td>
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<tr>
<td>444°F</td>
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<tr>
<td><strong>PRESSURE</strong></td>
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<tr>
<td>400 PSIA inlet</td>
<td>400 PSIA Inlet</td>
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<tr>
<td>14.7 PSIA exhaust</td>
<td>3 PSIA exhaust</td>
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<tr>
<td><strong>QUALITY</strong></td>
<td></td>
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<tr>
<td>0 at inlet</td>
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<tr>
<td><strong>EXPANSION RATIO</strong></td>
<td></td>
</tr>
<tr>
<td>347/1</td>
<td>1500/1</td>
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<tr>
<td><strong>PRIME MOVER EFF.</strong></td>
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</tr>
<tr>
<td>70% of isentropic</td>
<td>65% of isentropic</td>
</tr>
<tr>
<td><strong>SPECIFIC CONS.</strong></td>
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<tr>
<td>135 lb/KWhr.</td>
<td>85 lb/KWhr.</td>
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APPENDIX 2

Exhaust Pressure = 14.7 psia
Assume Efficiency = 70%

SPECIFIC POWER OUTPUT $\frac{KW}{10^5\text{ lb/hr}}$

HYDROTHERMAL POWER SYSTEM
PRIME MOVER PERFORMANCE
HYDROTHERMAL POWER CO., LTD.
2031 Woodlyn Road • Pasadena, California 91104 • (213) 798-1005
27022 Via Callado • Mission Viejo, California 92673 • (714) 837-3081

REQUEST FOR QUOTATION

RFQ NO. 76-F-2 DATE April 21, 19
PRIORITY RATING W-A2
CERTIFIED UNDER DHS REG. 1
TAXABLE NO [X] YES [ ]
CALIF. RESALE NO. SR AP 17-668216

TO BE CONSIDERED YOUR QUOTATION MUST BE RECEIVED BY HPC NO LATER
THAN May 17, 1976 DATE MATERIAL REQUIRED Sept. 15, 1976

DESCRIPTION OF ITEM(S)

AUTOMATIC GATE VALVE

(1) One 8" 300# ASA flanged, hydraulically actuated, Gate Valve.
    Body, bonnet, and yoke of ASTM A216 grade WCB; seats and wedges
    of ASTM 182-F6 and with Stellite No. 6 coating; and the stem
    of ASTM 182-F9. The valve shall be controlled by two input signals
    either one of which will automatically close the gate valve upon
    signal loss. Both signals shall be 12 VDC with 2 amp. maximum
    current. Signal loss from one of the inputs shall close the gate
    valve within one second, and a signal loss from the other input
    shall close the gate valve in approximately 15 seconds.

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<table>
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<th>O.B.</th>
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<th>Terms</th>
<th>Date Material Will Be Shipped</th>
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Hereby Submit the Above Quotation Phone No. By (Typed Name) Signature Date

(The Contractor)

GOVERNMENT SUBCONTRACT

Any Purchase Order issued by HPC as a result of your quotation will constitute a
subcontract under Contract NAS7-100 between the United States of America and the

Page 1 -B-
This report is in addition to Ultrasonic Report dated Sept. 17, 1976. Using the 80300 Test Block there is Continuous Clusters up to 85% (avg. - 25%) from #2 to 1" off #2, continuous for 15%" from the end in the 7.12" arm. Indications from #1 thru #5 are as follows: using the 80300 Test Block as 100%,

#1 - 70% Indication
#2 - 50% Indication
#3 - 85% Indication
#4 - 50% Indication
#5 - 20% Indication

For locations of Indications see attached sketch.
2.25 MHz 1" dia. Indication 100% - 5% loss of B.R.
  1/2 dia.  100% - 60%

2.25 MHz 1" dia. Indication 30% - no loss of B.R.
  1/2 dia.  40%

2.25 MHz 1" dia. Indication 20% - no loss of B.R.
  1/2 dia.  30%

2.25 MHz 1" dia. Indication 15% - no loss of B.R.
  1/2 dia.  20%

2.25 MHz 1" dia. Indication 10% - no loss of B.R.
  1/2 dia.  15%

Calibration - 100% seven light back reflection
RESULTS:  
When tested in accordance with the above Procedure, these parts were found to be acceptable. (No reportable or unacceptable indications found.)

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### CUSTOMER SPECIFICATION

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<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
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<td>.12</td>
<td>.50</td>
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### MECHANICAL PROPERTIES

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<th>DIA.</th>
<th>YIELD P.S.I.</th>
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<th>ELONG.</th>
<th>RED. AREA %</th>
<th>HARNESS</th>
<th>JOMINY HARDENABILITY</th>
<th>GRAIN SIZE</th>
<th>IMPACT FT. LBS</th>
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<tr>
<td>1</td>
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<td></td>
<td>76,500</td>
<td>100,000</td>
<td>23.0</td>
<td>73.9</td>
<td>229/229/223/248</td>
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**MELT SOURCE**: ARMCO

**PER A-418, REPORT ATTACHED**

*This is to certify that to the best of our knowledge and belief the above material has been manufactured in accordance with the drawings, purchase orders and specifications, and complies with the dimensional requirements and workmanship.*

**C6**

*McINNES STEEL COMPANY*

*CHIEF METALLURGIST*
# STEEL COMPANY
Corry, Pennsylvania 16407

NUCLEAR - AIRCRAFT - ALLOY - CARBON - FORGINGS
COMPLETE HEAT TREATING, LABORATORY & TESTING FACILITIES
ULTRA SONIC INSPECTION

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<td>A11304</td>
<td>10-1-76</td>
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SOLD TO

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SHIP VIA CONSOLIDATED - COLLECT - COMPLETE

CUSTOMER'S SPECIFICATION

<table>
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<tr>
<th>TYPE</th>
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<th>WEIGHT</th>
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<td>410</td>
<td>1 PC.</td>
<td>2482#</td>
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SUP NO. | SIZE | SERIAL NO.
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<tbody>
<tr>
<td>12073-524</td>
<td>PER DWG.</td>
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CONDITION
NORMALIZED & TEMPERED

<table>
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<tr>
<th>ITEM NO.</th>
<th>HEAT NO.</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Fe</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>Cu</th>
<th>PE</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>656451</td>
<td>.11</td>
<td>.44</td>
<td>.014</td>
<td>.021</td>
<td>.41</td>
<td>12.79</td>
<td>.21</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

MECHANICAL PROPERTIES

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>SERIAL NO.</th>
<th>DIA.</th>
<th>YIELD P.S.I.</th>
<th>ULTIMATE TENSILE %</th>
<th>ELONG. %</th>
<th>RED. AREA %</th>
<th>HARDNESS</th>
<th>JOHNNY HARDENABILITY</th>
<th>GRAIN SIZE</th>
<th>IMPACT FT. LBS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>.2</td>
<td>76,000</td>
<td>100,000</td>
<td>20.0</td>
<td>68.8</td>
<td>201/207/207/207</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MELT SOURCE
ARMCO

ULTRA-SONIC INSPECTION: PER A-418, REPORT ATTACHED

MACRO RESEARCH CLASSIFICATION: REND TEST
INTERSECT: LIQUID PENETRENTH
COMBINATION RESULTS: INSPECTION RESULT:

THIS IS TO CERTIFY THAT, TO THE BEST OF OUR KNOWLEDGE AND BELIEF, THE ABOVE MATERIAL HAS BEEN MANUFACTURED IN ACCORDANCE WITH THE DRAWINGS, PURCHASE ORDERS AND SPECIFICATIONS, AND COMPLIES WITH DIMENSIONAL REQUIREMENTS AND WORKMANSHIP.

C 7.

[Signature] (Chief Metallurgist)
**SHIP TO:** SAMAX FORGE DIE CO  
MONTEREY PARK CALIF  

**CHARGE TO:** HYDROTHERMAL POWER CO LTD  
27032 VIA CALLADO  
MISSION VIEJO CALIF 92675 35  

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>MATERIAL</th>
<th>WEIGHT</th>
<th>PRICE</th>
<th>EXTENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EF-4142 VAC. DEGASED, QUENCHED AND DOUBLE TEMPERED TO 269/302 BHN, 28/32 RC FINISHED SIZES</td>
<td>10 X 32.5 X 38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D1  
SAW FOR YOUR PRINT  
GRIND TOP & BOTTOM CLEAN UP  

**Customer Copy**
METALLURGICAL REPORT

STOMER: A. Finkl & Sons Co. (CA.)

DATE: November 2, 1976

QTY: 1 Pcs.

No. 9/28/76/01

SM: 10" x 32.5" x 38". Finish Sizes


FORGED SURFACE

Heat No. | Mill | Class | C | Mn | P | S | Si | Ni | Cr | Mo | V | Cu | Grain Size
--------|------|------|---|----|---|---|----|----|----|----|---|---|------
.60576   | X    | BE   | .42| .88| .015| .021| .30| -  | .83| .19|    |   |      

Jominy: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 20 22 24 26 28 30 32

Test No. | Test Dia. | Test Direction or Location | Yield Strength PSI | Tensile Strength PSI | Elongation % in 2" | Reduction of Area % | Fracture Rating | Brinell Hardness (HB) | Impact Ft. Lbs. | Serial No.
squired:  |           |                            |                  |                   |                   |                    |               |                    |               |          

269/302  
293/293  

WITNESSED

above agrees with the official company records.

PHYSICAL FOR DATE

SURFACE FOR DATE

Subscribed and sworn to before me this day of November 3, 1976

Notary Public

D2

A. Finkl & Sons Co.
2 cop./C.A.R.

DATE 11-2-76

CUSTOMER Firms (call.)

CUSTOMER ORDER NO.9/24/76/01

DESCRIPTION 10X32.5X30°

SHOP ORDER NO. 15645

HEAT NO. 160578

QUANTITY TESTED 1pc

SONIC UNIT SPERRY UNI 715

SEARCH UNIT SPERRY
2.25 MHz - 1.125 Dia. Qtz

COUPLANT 30 OIL

TEST BAR 4/64" F.B. HOLE

TEST BAR

SENSITIVITY ADJUSTMENT:

SCAN FACE 4/64" F.B. HOLE =2"pip (Swp/pk) on SCOPE

RESULTS:

No indications found & loss in a full screen
back ref. reflection did not exceed 10%.

J. P. Wirth
Q. C. Manager
# Nippon Steel Corporation
## Mill Sheet

**Contract No.:** S-BAR-H1-S-0-006
**Community:** Hot Rolled Stainless Steel Plates
**Specification:** ASME SA-240 Type 304A, As Welded

<table>
<thead>
<tr>
<th>Size (inches)</th>
<th>Width x Thickness</th>
<th>Weight (lbs)</th>
<th>Heat No.</th>
<th>Test Plate No.</th>
<th>Inspection No.</th>
<th>Tensile Test</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3/4&quot; x 96&quot; x 240&quot;</td>
<td>11482</td>
<td>34257501</td>
<td>.32300</td>
<td>.023000640</td>
<td>125</td>
<td>0.076103</td>
<td>31</td>
</tr>
<tr>
<td>2-1/2&quot; x 96&quot; x 120&quot;</td>
<td>8448</td>
<td>33304101</td>
<td>.32700</td>
<td>.05600620</td>
<td>130</td>
<td>0.044102</td>
<td>30</td>
</tr>
<tr>
<td>2-1/4&quot; x 96&quot; x 120&quot;</td>
<td>8350</td>
<td>33304501</td>
<td>.32900</td>
<td>.05500650</td>
<td>125</td>
<td>0.047903</td>
<td>30</td>
</tr>
<tr>
<td>2&quot; x 96&quot; x 240&quot;</td>
<td>8350</td>
<td>33307601</td>
<td>.32700</td>
<td>.05500630</td>
<td>125</td>
<td>0.044102</td>
<td>30</td>
</tr>
<tr>
<td>3-1/2&quot; x 60&quot; x 144&quot;</td>
<td>9800</td>
<td>33071001</td>
<td>.32700</td>
<td>.05500650</td>
<td>125</td>
<td>0.044102</td>
<td>30</td>
</tr>
</tbody>
</table>

**Total:** 23059.6 lbs

**Chemical Composition:***
- C: 0.076%
- Si: 0.076%
- Mn: 0.327%
- P: 0.055%
- S: 0.055%
- Co: 130%
- Ni: 30%
- Cr: 5%
- Mo: 30%

**Hydro Thermal Power Co.,**
25721 Oberdo Unit B
Mission Viejo, CA. 92692

**PO#76-M-1-C-5-A, ESCO 5005829592 W10-4-76**

---

**Remarks:**
- Material treated: 1/2" x 96" x 240" ASME SA-240 with BURGER '74 ADDENDUM QQ-S-766C and MSC-5035C.
- Exceptions: Packed and marked items to be deleted.
- Production process, test item and test method.

---

**Original Page:**

---

**Signature:**

---
### Material Specifications

**Design:** 76-M-1-C-2A

**Ship To:**
- A. Finkl and Son
  - C/O Bud Finkl
  - 10735 Sessler Street
  - Southgate, CA.

**Sold To:**
- HYDROTHERMAL POWER CO LTD
  - 25721 Obrea UNIT B
  - MISSION VIEJO, CA 92675

**Type and Specification:**
- 304 ASME SA-240, WINTER 1975
- HRAP

<table>
<thead>
<tr>
<th><strong>Item</strong></th>
<th><strong>QTY</strong></th>
<th><strong>Heat</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>656673-1</td>
</tr>
</tbody>
</table>

**Chemical Analysis**

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>.060</td>
<td>1.44</td>
<td>.019</td>
<td>.012</td>
<td>.49</td>
<td>18.50</td>
</tr>
</tbody>
</table>

**Notes:**

- ORIGINAL PAGE IS OF POOR QUALITY

**Dimensions:**

- 569 LA 2 S 76-M-1-C-2A
**U.T. PROCEDURE**: (✓) LONGITUDINAL: PER ASTM - A435  

**SCAN SPEED**: 6"/Sec.  
**Max OVERLAP**: 10% Min.  
**METHOD**: CONTACT  
**COUPLANT**: WATER & DETERGENT  
**EQUIPMENT**: SPERRY UM 775  
**PULSER**: 10-S #2  
**SCANNING**: 100% ONE MAJOR SURFACE

<table>
<thead>
<tr>
<th>PART IDENTIFICATION</th>
<th>DESCRIPTION</th>
<th>TRANSUCER</th>
<th>SETTINGS</th>
<th>CALIBRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM QUAN HEAT</td>
<td>SIZE</td>
<td>MAKE BEAM</td>
<td>FREQ.</td>
<td>SENS.</td>
</tr>
<tr>
<td>1 1 656673-1</td>
<td>5.250 Ga. SKETCH</td>
<td>AERG STR</td>
<td>1&quot;Ø</td>
<td>MHZ</td>
</tr>
</tbody>
</table>

**RESULTS**: THE ABOVE MATERIAL WAS TESTED BY THE LONGITUDINAL WAVE METHOD AND FOUND TO BE ACCEPTABLE TO THE ABOVE PROCEDURE.

**INSPECTOR(S)**: [Signature]  
**QUALIFIED**: SNT-TC-1A(✓) LEVEL II (✓) MIL-STD-271E  
**CUSTOMER REP.**

FORM ULT Rev. 2
HYDROTHERMAL POWER CO., LTD.

QUALITY CONTROL PROCEDURE

In order to assure the absolute conformance of incoming materials, purchased parts, machining or processing of materials and purchased parts, each such incoming item received by HPC secured for integration into the HPC Power Conversion System, is to be checked against the purchase order and purchase order drawing as to both quantity and quality.

A record will be maintained by HPC showing the results of checking, inspection, and measurement upon receipt of incoming materials, purchased parts, machining or processing of materials and purchased parts.

Such record shall be in the following form:

A. PART NO. or PURCHASE ORDER NO.
B. DESCRIPTION of PART or TASK
C. DRAWING NO.
D. (1) DATE of PURCHASE ORDER
    (2) DATE of RECEIPT by HPC
    (3) DATE of INSPECTION
E. MANUFACTURER, VENDOR or SUPPLIER
F. CRITICAL MEASUREMENTS TAKEN BY:
G. CRITICAL MEASUREMENTS TAKEN DATE:
H. SHOP DRAWING or COPY of PURCHASE ORDER
    (1) BY:
    (2) DATE:
I. ACCEPTANCE DATE
J. COMMENTS

F

PART NO. or P. O. NO. ____________________
Brief Summary of Torsional Frequency Analysis

A lumped-mass mass model was constructed for the entire system. This model consists of five "inertias" (actually moments of inertia) which represent respectively:

Female & Male Rotors & Shafting of the Compressor
The First Coupling
The Speed Reducer
The Second Coupling
The Alternator (Fan, Rotor & Exciter)

These five inertias are coupled by four uniform shafts. The numerical values of the inertias and of the torsional rigidities of the shafts were determined from values on the blueprints or were calculated from the physical dimensions provided. All calculations were made with reference to the Male Rotor Axis.

The analysis of the Free-free torsional vibrations of the system is accordingly reduced to an eigenvalue problem. The eigenvalues are found to be the roots of a tenth-order algebraic equation in the circular frequency $\omega^*$. One root, as expected, is $\omega=0$, which corresponds to a rigid body rotation of the entire system. Thus the determination of the eigenvalues amounts to the determination of the roots of a fourth order equation in $\omega^2$. The four roots correspond to the frequencies $n$ (Hz) of the four principal modes of torsional vibration of the system which have one, two, three or four modes corresponding to the increasing numerical value of the frequency. Usually the lower frequencies are those of particular interest in practice. The natural frequencies of the higher order modes are generally beyond the operating frequencies of a system.

*The tenth order equation can be treated as a fifth order equation because only even powers of $\omega$ occur in it.
The four frequencies \( n_i \) \( (i = 1, 2, \ldots) \) were determined for three different speed ratios for the five mass system. The results are as follows:

**Case I; Speed Ratio 1800/3000**

\[
\begin{align*}
  n_1 &= 64 \text{ Hz} \\
  n_2 &= 189 \text{ Hz} \\
  n_3 &= 315 \text{ Hz} \\
  n_4 &= 609 \text{ Hz}
\end{align*}
\]

**Case II; Speed Ratio 1800/4000**

\[
\begin{align*}
  n_1 &= 52 \text{ Hz} \\
  n_2 &= 191 \text{ Hz} \\
  n_3 &= 294 \text{ Hz} \\
  n_4 &= 574 \text{ Hz}
\end{align*}
\]

**Case III; Speed Ratio 1800/5000**

\[
\begin{align*}
  n_1 &= 47 \text{ Hz} \\
  n_2 &= 209 \text{ Hz} \\
  n_3 &= 308 \text{ Hz} \\
  n_4 &= 629 \text{ Hz}
\end{align*}
\]

These values have been determined subject to certain approximations which should be noted:

1) Continuous mass distributions have been lumped

2) Continuous parameter distributions e.g. torsional rigidities have been lumped

3) Gear assembly is assumed to be rigid. Gear & tooth flexibility is neglected and gear backlash is ignored

4) Frictional energy dissipation e.g. in flexible couplings is considered to be negligible throughout the system

5) Flexural vibrations have not been considered

A lengthier and more detailed analysis would be needed to include the effects of these approximations.
References:

Two basic works of reference are "Practical Solution of Torsional Vibration Problems" by W. E. Wilson, Wiley, New York, 1956 (Two volumes) and "Handbook on Torsional Vibrations" by E. J. Nestorides, Cambridge University Press, 1958.
November 15, 1977

Hydrothermal Power Company, Ltd.
25721 Obrero, Unit B
Mission Viejo, California 92675

Attention: Mr. J.A. Sprinkle

Subject: Your P.O. #76-M-4
Our Order #489254
Efficiency curves

Gentlemen:

To confirm our meeting of 11-9-77, the efficiency curves that were delivered to you on 10-25-77 were derived in a similar fashion explained to you in a July 21, 1977 letter from our Michael Hardman. The empirical data on the above order has indicated about an 8% error in the calculated constant that we used in our heat-balanced equation. This error, in all probability, is caused by aeration of the oil. The empirical formula accounts for this and includes radiant heat losses as well.

Hopefully, this is the information that Dr. McKay is looking for. Please advise us if there is anything else we can do to bring this matter quickly to a close.

Very truly yours,

PHILADELPHIA GEAR CORPORATION

Mark M. Alter
Sales Representative

MMA/fj

cc: Dr. R.A. McKay - Jet Propulsion
cc: John L. Gillaspy - Anaheim
July 21, 1977

Hydrothermal Power Co., Ltd.
2051 Woodlyn Road
Pasadena, California 91104

Attention: Mr. J. A. Sprankle,
Business Manager

Reference: Your P.O. #76-M-4.
Our Order #489254.
Your Letters of 1/12/77 and 6/14/77

Gentlemen:

I appreciate your concern in receiving the required efficiency data as well as your demonstration of good faith with the trustee account. As you know, we have submitted one set of efficiency data but unfortunately, the inlet oil temperature has been changed rendering this data unusable for your purposes. Also, you must realize that the calculation tools available today are not sophisticated enough to guarantee the 1/2 of 1% maximum error you have requested.

A telephone conversation between Dr. McKay and myself indicated that an explanation of our testing/calculating heat loss method may suffice in satisfying this requirement.

I have attached three sheets covering the derivation of our heat balance equation and the particular lubricant used at our test stands. As you will note, empirical data has indicated about an 8% error in the calculated constant. This error, in all probability, is caused by aeration of the oil. The empirical formula accounts for this and includes radiant heat losses as well.
Hydrothermal Power Co., Ltd.
Mr. J. A. Sprinkle
July 21, 1977

If possible, Dr. McKay should run both loaded and unloaded tests using a torque cell and tachometer to verify the accuracy of our conscant under his test stand conditions. Once this is established, the accuracy he requires for his testing should be attainable.

I hope this data will suit your requirements. If there are any questions, please contact me.

Very truly yours,

PHILADELPHIA GEAR CORPORATION

Michael J. Hardiman, Manager
Special Products Division

enc.
rc
cc: Dr. R. A. McKay/Calif. Institute Tech.
J. Gillaspy/P.G.C., Anaheim, Calif
DERIVATION OF HEAT BALANCE EQUATION

Req: 462140

Type of Lubricant: Mobil Die Light (spec. sheet attached)

Dimensionally

\[ \text{HP} = \frac{\text{GAL}}{\text{MIN}} \times \frac{\text{BTU}}{\text{GAL}} \times \frac{\text{BTU}}{\text{GAL}} \times \frac{\text{F}^\circ}{\text{F}^\circ} \]

Mobil reports the following with reference to die light:

- Weight per gallon = 7.251 lb
- Specific heat = \(0.481 \text{ BTU} / \text{lb} \cdot \text{F}^\circ\)

Insertion into the dimensional equation yields

\[ \text{HP} = \frac{(\text{GPM})(7.251)(0.481)(\Delta T)}{42.45} \]

Collecting all constants

\[ \text{HP} = 0.0822 \ (\text{GPM})(\Delta T) \]

By monitoring several units on test using a torque cell to measure input torque and an electronic tachometer to monitor speed, the constant 0.0822 was empirically found to be excessive. Using a broad range of sizes and/or type of unit, the constant 0.0762 was found to yield more accurate results. This accounts for churning, aeration, etc.

Empirically

\[ \text{HP} = 0.0762(\text{GPM})(\Delta T) \]
Mobil D. T. E.®
20 Series
Hydraulic Oils

The Mobil D.T.E. 20 series of high quality oils has been developed specifically to satisfy the requirements of hydraulic systems using the newer, high-pressure, high-output pumps. The large growth in hydraulic operation of systems on mobile equipment has resulted in the development of pumps that are smaller, yet deliver greater volumes of fluid at higher pressures than were thought practicable a few years ago. Since response time is improved when a smaller volume of fluid at higher pressure is used, high pressure pumps are also being applied increasingly in hydraulic systems of machine tools and other industrial applications. Pump vanes or pistons, control valves, and linear and rotary actuators of hydraulic systems all operate with boundary or mixed film lubrication so that wear protection must be provided by thin oil films. As pressures and operating speeds are increased, the loading on these thin films is increased, and the fluid must provide greatly enhanced antwear or film strength characteristics to protect against excessive wear. At the same time, oxidation and foaming resistance, demulsibility, and rust and corrosion protection must be maintained at high levels to avoid other operating problems.

PRODUCT DESCRIPTION

The Mobil D.T.E. 20 series was developed in cooperation with pump and hydraulic system component manufacturers to provide the superior antwear and film strength characteristics necessary for the new high pressure hydraulic pumps that are coming into wide use. They are formulated from high quality, chemically stable, high VI base stocks combined with additives chosen to provide the specific properties required in hydraulic fluids. Compared to the best automotive oils, they provide superior performance characteristics including demulsibility, rust prevention, and resistance to deposit formation, and equal antwear protection. In addition, the viscosities are chosen to accurately meet the requirements of hydraulic pump builders and coincide with the new ASTM viscosity grades. Furthermore, their functional characteristics permit a wide range of industrial applications other than in hydraulic systems.

In the development of the Mobil D.T.E. 20 series, extreme care was given to the selection of antwear agents and rust inhibitors which will not interfere with water separating characteristics. The combination of additive components was carefully balanced with the base stocks to ensure that the final products provide the best obtainable combination of antwear, demulsibility, oxidation resistance, rust protection and foam resistance properties. A protective barrier is provided by a thin film of oil which prevents the rusting of metal parts in the presence of small

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mobil D.T.E. 24</th>
<th>Mobil D.T.E. 25</th>
<th>Mobil D.T.E. 26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity, API</td>
<td>31.7</td>
<td>30.6</td>
<td>29.9</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.857</td>
<td>0.873</td>
<td>0.877</td>
</tr>
<tr>
<td>Pour Point, max. F (C)</td>
<td>0 (−18)</td>
<td>0 (−18)</td>
<td>0 (−18)</td>
</tr>
<tr>
<td>Flash Point, min. F (C)</td>
<td>385 (232)</td>
<td>400 (204)</td>
<td>400 (204)</td>
</tr>
<tr>
<td>Viscosity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUS at 100 F</td>
<td>153</td>
<td>225</td>
<td>300</td>
</tr>
<tr>
<td>SUS at 210 F</td>
<td>43</td>
<td>49</td>
<td>53</td>
</tr>
<tr>
<td>cSt at 38 C</td>
<td>33</td>
<td>48.5</td>
<td>65</td>
</tr>
<tr>
<td>cSt at 99 C</td>
<td>5.1</td>
<td>7.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Viscosity Index</td>
<td>95</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>Color, ASTM, Max.</td>
<td>2.0</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Cincinnati Millacron, Inc.</td>
<td>C M Co Heat Test</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>1 Week at 275 °F (135 °C)</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>
amounts of water or condensed moisture from the air. They have shown superior fluid durability (resistance to deposit formation) and exceptional service performance.

**TYPICAL CHARACTERISTICS**

Physical and chemical characteristics of the Mobil D.T.E. 20 oils are shown in the data sheet table. Those values which are not shown as maximums or minimums are typical characteristics which may vary slightly.

**APPLICATION**

Mobil D.T.E. series oils are recommended for hydraulic applications in industrial, marine and mobile service. These oils are Mobil’s primary recommendation for all hydraulic applications including the newer, high-pressure systems in industrial service, especially when the equipment manufacturer specifies the use of antiwear type hydraulic fluids.

Since Mobil D.T.E. 20 series oils are the primary hydraulic recommendation at all times, application consists mainly of selecting the proper grade for the particular system. Selection of the correct viscosity is based on ambient and bulk fluid temperatures, as well as the operating pressure and design characteristics of the pump and system. Mobil D.T.E. 24 is recommended frequently for small gear pumps, vane pumps and both radial and axial piston pumps. Mobil D.T.E. 25 meets the viscosity requirements for many vane pumps and is an excellent product to simplify plant inventory, when a single oil is desired to replace one of 150 SUS (32 cSt) at 100 F (38 C) and another oil of 300 SUS (65 cSt) at 100 F (38 C). Some hydraulic equipment manufacturers specify a preferred viscosity (at 100 F) for vane and axial piston pumps. Mobil D.T.E. 24 is recommended where a 150 second oil is specified; Mobil D.T.E. 25 for a 250 second oil and Mobil D.T.E. 26 for a 300 second oil. Other manufacturers base their recommendations on pump pressures. When this pressure is below 1000 psi (70 kg/cm²), Mobil D.T.E. 24 is recommended; below 1500 psi (105 kg/cm²), Mobil D.T.E. 25; and over 1500 psi (105 kg/cm²), Mobil D.T.E. 26.

Mobil D.T.E. 20 series oils are also recommended for many circulation, splash, bath and ring oiling systems supplying lubricant for the bearings and gears of industrial machinery. Their adaptability to these applications can greatly reduce inventory and lubrication costs where these oils are required for hydraulic use. They are not recommended for steam turbine nor ammonia refrigeration compressor service. Where no unusually high temperatures are involved, Mobil D.T.E. 25 may be used as the lubricant in single-stage reciprocating compressors up to 80 psig (5.6 kg/cm²) or in two-stage reciprocating compressors up to 150 psig (10.5 kg/cm²) of the type normally used for producing “plant” air.

**ADVANTAGES**

Mobil D.T.E. 20 series oils offer the following advantages and benefits:

- Outstanding antiwear performance
- High resistance to oxidation degradation
- Good protection against rust corrosion
- Good foam resistance
- Good water separation in hydraulic systems
- Correct grades for hydraulic service
- Worldwide availability
## UNIT TEST REPORT

**PH** 
**DELPHELIA GEAR CORPORATION**

### ORDER

- **PARTIAL FINAL UNIT**
- **ORDER NUMBER** 489254
- **5/4/77**

### DEPARTMENT

- **ENGINEERING**
- **TECH LAB.**
- **QUALITY CONTROL**

### TEST CONDITIONS

- **Total Running Time**: *
- **H.S. Shaft Speed**: *
- **H.S. Shaft Rotation**: CW
- **Shaft Which Was Driven**: HS
- **Amount of Load Applied**: None
- **Method**: 50 HP Reeves
- **Type of Lubrication System**: External force feed
- **Location of Oil Level**: None maintained
- **Bearings & Seal(s) Which Require Grease**: None
- **Type of Lubricant used on test**: Mobil Vaprotec Light
- **Oil Pressure Cold**: 25 PSI
- **Oil Pressure Hot**: 25 PSI
- **Ambient Temperature**: 75
- **Oil Inlet Temp.**: *
- **Unit Sump Temp. F.**: *
- **Seal Temp. HSS**: LSS
- **Bearing Temp's**: HSS LSS INT.
- **Oil Leakage**: Piping None Caps None Seals None
- **Splits**: None
- **Housing**: None
- **Note all leaks and corrective measures**:

### VIBRATION (MILS)

- **H.S.**: LSS
- **Vertical**: NM
- **Axial**: NM

### SOUND LEVEL

- **Ambient Sound**: NM
- **Overall Sound**: NM
- **High Octave**: NM
- **Freq.**: NM

### NOTES, REJECTIONS, CORRECTIONS, ETC.

- **Note 1**
- **Group**: Input Speed
- **Ratio**: 1.666:1
- **1**: 3000 RPM
- **2**: 4000 RPM
- **3**: 5000 RPM

### TEST PERSONNEL

- **ASSEMBLER**: J. Gordon, B. Bailey, R. Scheler

### APPROVAL

- **H7**

### ADDITIONAL DATA SHEETS ATTACHED: 4
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DATA MUST BE ACTUAL, NOT RATED VALUES; IF NOT MEASURED, LEAVE BLANK

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DATA MUST BE ACTUAL, NOT RATED VALUES.
IF NOT MEASURED, LEAVE BLANK
Combining Advanced Design with Proven Performance

RELATIONSHIPS OF SPEED, CAPACITY, PRESSURE, POWER CONSUMPTION

Table "A" below shows the capacity and suggested driving motor size for different speeds and pressures. These figures are based upon pumping a liquid of about 200 SSU viscosity with a 15" maximum vacuum. While Tuthill Series C pumps will develop as high as 27" of vacuum, it is sound engineering to reduce the vacuum to a minimum.

The speed of the pump must be reduced when handling liquids of high viscosity, and the size of lines increased to prevent cavitation, loss of capacity and high power requirements. For typical performance with liquids of varying viscosities kindly see chart "B" below. For speeds above 1800 rpm and fluid temperatures above 200°F, consult factory.

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Based on pumping liquids of 200 SSU viscosity.
TEST REPORT

ALTERNATOR

Manufacturer: Kato Engineering Co.
Buyer's P.O. #: 14612-P.245-A
Specification #: 
Buyer's Serial #: 
Manufacturer's Ser. #: SN 74526
I hereby certify that to the best of my knowledge all tests were performed in accordance with test specifications in and true data representing these tests is contained in this report.
### LIST OF SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACV</td>
<td>Generator output voltage</td>
</tr>
<tr>
<td>ACI</td>
<td>Generator output current</td>
</tr>
<tr>
<td>KVA</td>
<td>Kilovolt-amperes</td>
</tr>
<tr>
<td>KW</td>
<td>Power output or input in kilowatts</td>
</tr>
<tr>
<td>PF</td>
<td>Power Factor</td>
</tr>
<tr>
<td>GFV</td>
<td>DC voltage generator field</td>
</tr>
<tr>
<td>GFI</td>
<td>Generator field amps</td>
</tr>
<tr>
<td>V_{rp}</td>
<td>Rated phase voltage</td>
</tr>
<tr>
<td>I_{rp}</td>
<td>Rated phase current</td>
</tr>
<tr>
<td>m</td>
<td>Ammeter reading</td>
</tr>
<tr>
<td>L-L</td>
<td>Line to Line</td>
</tr>
<tr>
<td>L-N</td>
<td>Line to Neutral</td>
</tr>
<tr>
<td>RPM</td>
<td>Revolutions per minute</td>
</tr>
<tr>
<td>~</td>
<td>Ohms</td>
</tr>
<tr>
<td>Lbs.</td>
<td>Pounds</td>
</tr>
<tr>
<td>Ft.</td>
<td>Feet</td>
</tr>
<tr>
<td>Dyn</td>
<td>Dynamometer</td>
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<tr>
<td>CT</td>
<td>Current Transformer</td>
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<tr>
<td>X_d</td>
<td>Direct axis synchronous reactance</td>
</tr>
<tr>
<td>X'd</td>
<td>Direct axis transient reactance</td>
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<tr>
<td>X''d</td>
<td>Direct axis subtransient reactance</td>
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<tr>
<td>SCR</td>
<td>Short Circuit Ratio</td>
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<tr>
<td>X_2</td>
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<tr>
<td>HFV</td>
<td>Motor Field Volts</td>
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<td>Motor exciter field current</td>
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<tr>
<td>Motor EFV</td>
<td>Motor Exciter field volts</td>
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<td>P_{N}</td>
<td>Frequency no load</td>
</tr>
<tr>
<td>F_{N}</td>
<td>Frequency full load</td>
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<tr>
<td>V_{N}</td>
<td>Voltage no load</td>
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<tr>
<td>V_{F}</td>
<td>Voltage @ full load</td>
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<tr>
<td>I_{F}</td>
<td>Line current @ full load</td>
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<tr>
<td>1-2,2-3,3-1</td>
<td>Three phase terminal to terminal readings</td>
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<tr>
<td>1-2-3</td>
<td>Three phase line currents</td>
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<tr>
<td>Wave</td>
<td>Average of the three phase voltages</td>
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<tr>
<td>Iave</td>
<td>Average of the three line currents</td>
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<tr>
<td>CC res</td>
<td>Cross current resistor</td>
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<tr>
<td>CC Comp</td>
<td>Cross current compensation</td>
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<tr>
<td>EFI (Gen.)</td>
<td>Exciter field amps</td>
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<td>EFV (Gen.)</td>
<td>Exciter field volts</td>
</tr>
<tr>
<td>NA</td>
<td>Not applicable</td>
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<tr>
<td>CWFDE</td>
<td>Clockwise facing drive end</td>
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<tr>
<td>CCWFDK</td>
<td>Counterclockwise facing drive end</td>
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<td>EFF</td>
<td>Efficiency</td>
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<td>T'do</td>
<td>Direct axis transient open circuit time constant</td>
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<tr>
<td>T'd</td>
<td>Direct axis transient short circuit time constant</td>
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<td>W&amp;F</td>
<td>Windage &amp; Friction</td>
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<td>CL</td>
<td>Core loss</td>
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<td>SLL</td>
<td>Stray load loss</td>
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KATO ENGINEERING COMPANY
SYNCHRONOUS MACHINE COMMERCIAL TEST

<table>
<thead>
<tr>
<th>KW</th>
<th>KVA</th>
<th>P.F.</th>
<th>RPM</th>
<th>PHASE</th>
<th>FREQ.</th>
<th>VOLTS</th>
<th>AMPS</th>
<th>SERIAL NO.</th>
<th>UNIT</th>
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<td>0.81</td>
<td>1800</td>
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<td>60</td>
<td>430</td>
<td>150</td>
<td>74526</td>
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CUSTOMER: SWEHART ELECTRIC CO. INC  DATE: 11/23/76

TESTED BY: M. HUNTER PD KAULKE

RESISTANCE:

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<tr>
<th>CODE</th>
<th>TYPE</th>
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<td>10006896</td>
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SATURATION CURVE

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<th>ACI</th>
<th>KVA</th>
<th>KW</th>
<th>P.F.</th>
<th>DCV</th>
<th>EFI</th>
<th>HZ</th>
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<td>0</td>
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EXCITATION

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<th>EXC POLARITY</th>
<th>RES. VOLT.</th>
<th>CONNECTED</th>
<th>ROTATION</th>
<th>SEQUENCE</th>
<th>COMM RUNOUT</th>
<th>COMMUTATION</th>
<th>RADIO SUPPRESSION</th>
<th>BEARINGS</th>
<th>MECH. BAL.</th>
<th>DR. END</th>
<th>OPP. END</th>
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<td>F = -7</td>
<td>39.0</td>
<td>Y</td>
<td>CW FDE</td>
<td>T = T</td>
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<td>BAUHEU</td>
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<td>OK</td>
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</tbody>
</table>

AIR GAP (MINIMUM)

| EXCITER | 0.0034 |
| P.M. FLD. | |

DIELECTRIC STRENGTH

| GEN ARM | Volt |
| GEN FLD | Volt |
| EXC ARM | Volt |
| EXC FLD | Volt |
| PM FLD | Volt |

INSULATION RESISTANCE

<table>
<thead>
<tr>
<th>PM GENERATOR</th>
<th>VOLT</th>
<th>AMP</th>
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<th>ACV</th>
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<td>T12</td>
<td>950</td>
<td>1-N</td>
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<tr>
<td>T23</td>
<td>450</td>
<td>2-N</td>
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<tr>
<td>T31</td>
<td>450</td>
<td>3-N</td>
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REMARKS

ORIGIN IS OF POOR QUALITY
# KATO ENGINEERING COMPANY
## SYNCHRONOUS MACHINE COMMERCIAL TEST

<table>
<thead>
<tr>
<th>KW</th>
<th>KVA</th>
<th>P.F.</th>
<th>RPM</th>
<th>PHASE</th>
<th>FREQ.</th>
<th>VOLTS</th>
<th>AMPS</th>
<th>SERIAL NO.</th>
<th>UNIT</th>
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<td>1000</td>
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<td>0.8</td>
<td>1500</td>
<td>3d</td>
<td>57</td>
<td>177/480</td>
<td>1506</td>
<td>74526</td>
<td>I</td>
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</table>

**CUSTOMER:** SWENHART ELECTRIC CO  
**DATE:** 11-30-76

**RESISTANCE:**  
**TESTED BY:** J. MROZ, W. T. BECK, C. LEIFERMAN

| ARM 1-2 | 0.00293 | ±0.25 % | GEN FLD | 1.366 | ±0.25 % |
| ARM 2-3 | 0.00293 | ±0.25 % | EXC FLD | 11.444 | ±0.25 % |
| ARM 3-1 | 0.00293 | ±0.25 % | PM FLD |  | ±0.25 % |

**CODE:** 426-2175  
**TYPE:** 18856  
**MODEL:** 1000 EIR 9E

### SATURATION CURVE

<table>
<thead>
<tr>
<th>ACV</th>
<th>ACI</th>
<th>KVA</th>
<th>KW</th>
<th>P.F.</th>
<th>DCV</th>
<th>EFI</th>
<th>HZ</th>
</tr>
</thead>
</table>

### EXCITATION
- **POLARITY:** Eo = 1
- **RES. VOLTS:**
- **CONNECTED:** Y
- **ROTATION:** CW FDE
- **SEQUENCE:**
- **COMM. RUNOUT:** BRUSHLESS
- **RADIO SUPPRESSION:**
- **BEARINGS:**
  - MECH. BAL: (P-P)
  - DR. END = 0
  - OPP. END = 0

### AIR GAP (MINIMUM)

**EXCITER:** OVER 0.054
**P.M. FLD:**

### DIELECTRIC STRENGTH

<table>
<thead>
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<th>GEN ARM</th>
<th>2000 VOLT</th>
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<tr>
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<td>1500 VOLT</td>
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<td>1500 VGLT</td>
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<tr>
<td>PM FLD</td>
<td>1500 VOLT</td>
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</table>

### INSULATION RESISTANCE

**GENERATOR**

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<th>VOLT</th>
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**PH | ACV | ACI |
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<tbody>
<tr>
<td>T1 1</td>
<td>150.0</td>
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<tr>
<td>T2 2</td>
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<td>2-N</td>
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<td>T3 3</td>
<td>930</td>
<td>3-N</td>
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</table>

**REMARKS**

- ORIGINAL PAGE IS OF POOR QUALITY

**INSULATION RESISTANCE**

<table>
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<th>GEN ARM</th>
<th>OVER 100 MEGA</th>
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<td>GEN FLD</td>
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<tr>
<td>EXC ARM</td>
<td>OVER 100 MEGA</td>
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<td>OVER 100 MEGA</td>
</tr>
<tr>
<td>PM FLD</td>
<td>OVER 100 MEGA</td>
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</table>

**ORIGINAL PAGE IS OF POOR QUALITY**
**TEST RECORD**

**KATO ENGINEERING CO.**

**MANKATO, MINNESOTA U.S.A.**

**CUSTOMER:**

**SWEINHART ELECTRIC**

**P.O. OR CONTRACT NO.:**

**TESTED BY:**

**J. MROZ**

**D. HOEL**

**C. LEIFERMAN**

**TEST EFFICIENCY**

**DIRECT LOADING**

**SELF EXCITED**

**REPEAT TEST**

**GOVT. INSPECTOR:**

**DATE:** 11-30-76

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<th>GET</th>
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<th>EFF</th>
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<th>W2</th>
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<th>RPM</th>
<th>LD</th>
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</table>

**VOLTAGE A.D.R. 5:1 **

**READ MRA MRR 1.5:1**

**FLW X TQ = (157-3.15) X 3.5 x 175 X 746 = 157**

**K = 25.2**

**WATT INPUT = FLW X TQ X = 157 X 3.5 X 175 X 746 = 157**

**Where Drive Loss = 3.15 LBS @ 3.5 FT**

**EFFICIENCY =**

\[
\text{Efficiency} = \frac{\text{Output Power (WT)}}{\text{Input Power (WT)}} \times 100 = 73.4\% 
\]
<table>
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<tbody>
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</tr>
<tr>
<td>GOVT. INSPECTION</td>
<td>D. HOFEL</td>
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**Test Record**

**Kato Engineering Co.**

**Mankato, Minnesota U.S.A.**

**TEST EFFICIENCY TEST**

**Segregated Losses Method**

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**Open Circuit Core Loss**

**Repeat Test**

**Segregated Losses Method**

**A Core Loss @ Rated Voltage**

**Sheet 2 of 3**
# Test Record

**Kato Engineering Co.**

**Mankato, Minnesota** S.A.

**Customer:** Supervisory Electric

**Test Efficiency:** 11-30-76

**Method:**

**Test:** Segregated Losses Method

## Test Data

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**Remarks:**

- Main gen field separately excited
- W.P. 1000 = Static, Electric load
- A positive or negative 90° gen. exc. Dyna and operate Dyna

Sheet 3 of 3
A. Friction & Windage Loss (No Excitation)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

Where:
- \( F \) = Net Force in lbs.
- \( L \) = Lever Arm in ft.
- \( N \) = Speed of Dynamometer in RPM

\[ \frac{(30.35 \times 3.5 \times 1795)}{5252} \times 746 = 27083 \text{ WATTS} \]

B. Core Loss + Windage and Friction (@ Rated Voltage)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

\[ \frac{(39.9 \times 3.5 \times 1795)}{5252} \times 746 = 35585 \text{ WATTS} \]

Core Loss B-A

\[ 35585 - 27083 = 8502 \text{ WATTS} \]

C. Armature Copper Loss (Stray Load Loss Test)

\[ \text{Watts} = I^2_{\text{arm}} \times R \times 3 \]

Where:
- \( I \) = Rated Armature Current
- \( R \) = Armature Resistance Per Phase at Time of the Stray Load Loss Test

\[ (1504)^2 \times (0.0155) \times (3) = 10518 \text{ WATTS} \]

D. Stray Load Loss + \( I^2 R \) Loss + Friction & Windage (@ Rated Armature Current)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

\[ \frac{(410.5 \times 6.6 \times 1793)}{5252} \times 746 = 41048 \text{ WATTS} \]

Stray Load Loss = D-(A + C)

\[ 41048 - (27083 + 10518) = 2447 \text{ WATTS} \]
100 % LOAD

EFFICIENCY CALCULATIONS

KATO ENGINEERING CO.
Mankato, Minnesota

S/N 74524
MODEL 1060ER9E
MIL-STD-705
METHOD 415.0
DATE

E. Armature $I^2R$ Loss

Watts = $I_{arm}^2 \times R_{75} \times 3$

= $(1504)^2 \times 0.001755$ (3)

= 11,912 Watts

Where: $I_{arm}$ = RATED ARMATURE CURRENT

$R_{75}$ = RESISTANCE PER PHASE Corrected to 75°C

$R_{75} = \frac{234.5 + 75}{234.5 + 23.8} \times 0.001755$ ohms

= $0.001755 \times \frac{234.5 + 75}{234.5 + 23.8}$ ohms

F. Generator Field $I^2R$ Loss

Watts = $(60)^2 \times 1.366$

= 5892 Watts

Where: $I_f$ = FIELD CURRENT AT RATED LOAD

$R_{75}$ = RESISTANCE OF THE FIELD CORRECTED TO 75°C

$R_{75} = \frac{234.5 + 75}{234.5 + 23.8} \times 1.366$ ohms

= $1.366 \times \frac{234.5 + 75}{234.5 + 23.8}$ ohms

Total Losses (Watts)

1. Friction & Windage Loss = 2708.3
2. Core Loss = 860.2
3. Stray Load Loss = 347.7
4. Armature $I^2R$ Loss = 11912
5. Field $I^2R$ Loss = 5892
6. Exciter Losses = 800

Efficiency:

\[
\% \text{ Eff.} = \frac{\text{Output} \times 100}{\text{Losses}} = \frac{100 - \left(5763.6 \times 100\right)}{1000000 \times 5763.6} = \frac{100 - 5763.6}{5763.6} = 94.55\%
\]
75% LOAD

EFFICIENCY CALCULATIONS

KATO ENGINEERING CO.
Mankato, Minnesota

S/N 74526
MODEL 1000 ER2E
MIL-STD 705
METHOD 115.0
DATE 11-30-77

A. Friction & Windage Loss (No Excitation)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

Where:  
\( F \) = NET FORCE IN LBS.  
\( L \) = LEVER ARM IN FT.  
\( N \) = SPEED OF DYNAMOMETER IN RPM

\[ \frac{F \times L \times N}{5252} \times 746 = 27083 \text{ WATTS} \]

B. Core Loss + Windage and Friction (0 Rated Voltage)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

\[ \frac{F \times L \times N}{5252} \times 746 = 6502 \text{ WATTS} \]

Core Loss B-A

\[ \frac{F \times L \times N}{5252} \times 746 = 8502 \text{ WATTS} \]

C. Armature Copper Loss (Stray Load Loss Test)

\[ \text{Watts} = I_{\text{Arm}}^2 \times R \times 3 \]

Where:  
\( I \) = RATED ARMATURE CURRENT  
\( R \) = ARMATURE RESISTANCE PER PHASE AT TIME OF THE STRAY LOAD LOSS TEST

\[ I_{\text{Arm}}^2 \times R \times 3 = \text{WATTS} \]

D. Stray Load Loss + I^2R Loss + Friction & Windage (0 Rated Armature Current)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

\[ \frac{F \times L \times N}{5252} \times 746 = 11 \text{ WATTS} \]

Stray Load Loss = D-(A + C)

\[ \left(3447 \left(\frac{2}{3}\right)\right)^2 = 1939 - \left(\frac{27083}{27083} + \frac{6502}{6502}\right) \]
E. Armature $I^2R$ Loss

\[
\text{Watts} = I_{\text{arm}}^2 \times R_{75} \times 3 = \left( 16.91 \right)^2 \times \left( \frac{3}{4} \right) = 6700 \text{ Watts}
\]

F. Generator Field $I^2R$ Loss

\[
I_{\text{fld}}^2 \times \frac{3}{4} \text{ Load} = (I_{\text{fld}}^2 - I_{\text{NL}}^2) \times \left( \frac{3}{4} \right) + I_{\text{NL}}^2
\]

\[
= \left( 51.8 \right)^2 \times \left( \frac{3}{4} \right) + 27.2
\]

\[
= 51.8 \text{ Watts}
\]

\[
\left( 16.91 \right)^2 \times \left( \frac{3}{4} \right) = 4390 \text{ Ohms}
\]

Total Losses (Watts)

1. Friction & Windage Loss
2. Core Loss
3. Stray Load Loss
4. Armature $I^2R$ Loss
5. Field $I^2R$ Loss
6. Exciter

Efficiency:

\[
\% \text{ Eff.} = \frac{100 \times \text{Output} - \text{Losses}}{\text{Output}}
\]

\[
= 100 - \left( 49209 \right) \times \left( \frac{49209}{750,000} \right)
\]

\[
= 100 - 6.157
\]

\[
\% \text{ Eff.} = 93.84 \%
\]
A. Friction & Windage Loss (No Excitation)

\[
Watts = \frac{FLN}{5252} \times 746
\]

Where: 
- \( F \) = NET FORCE IN LBS.
- \( L \) = LEVER ARM IN FT.
- \( N \) = SPEED OF DYNOFLOROMETER IN RPM

\[
= \frac{5252}{5252} \times 746
\]

= 27083 WATTS

B. Core Loss + Windage and Friction (\( \theta \) Rated Voltage)

\[
Watts = \frac{FLN}{5252} \times 746
\]

\[
= \frac{5252}{5252} \times 746
\]

= 8502 WATTS

Core Loss B-A

\[
= \frac{5252}{5252} \times 746
\]

= 8502 WATTS

C. Armature Copper Loss (Stray Load Loss Test)

\[
Watts = I^2_{Arm} \times R \times 3
\]

Where: 
- \( I \) = RATED ARMATURE CURRENT
- \( R \) = ARMATURE RESISTANCE PER PHASE AT TIME OF THE STRAY LOAD LOSS TEST

\[
= (3447)^2 (\frac{1}{2}) \times 3
\]

= 862 WATTS

D. Stray Load Loss + \( I^2R \) Loss + Friction & Windage (\( \theta \) Rated Armature Current)

\[
Watts = \frac{FLN}{5252} \times 746
\]

\[
= \frac{5252}{5252} \times 746
\]

= 113 WATTS

Stray Load Loss = \( D-(A+C) \)

\[
(3447)(\frac{1}{2})^2 = 862
\]
E. Armature $I^2R$ Loss

\[
\text{Watts} = I^2_{\text{arm}} \times R_{75} \times 3
\]

\[
= \left( \frac{1}{2} \right)^2 \left( \frac{1}{2} \right) \left( \frac{27}{11} \right)
\]

\[
= 29.78 \text{ Watts}
\]

F. Generator Field $I^2 \times R$ Loss

\[
I_{FL0.5\%} = (I_{FL} - I_{NL}) \frac{1}{2} + I_{NL}
\]

\[
= (60 - 37.2) \frac{1}{2} + 37.2
\]

\[
= 43.6
\]

\[
\text{Watts} = I^2 \times R
\]

\[
= (43.6)^2 \times (1.62 \Omega)
\]

\[
= 3110
\]

Total Losses (Watts)

1. Friction & Windage Losses = 2708.3
2. Core Loss = 850.2
3. Stray Load Loss = 862
4. Armature $I^2R$ Loss = 29.78
5. Field $I^2R$ Loss = 3110
6. Exciter Loss = 42.5

Efficiency:

\[
\% \text{ Eff.} = \frac{100 \times \text{Output} - \text{Losses}}{\text{Output}}
\]

\[
= 100 - \frac{42960}{42960}
\]

\[
= 100 - 7.912
\]

\[
% \text{ Eff.} = 92.08
\]
A. Friction & Windage Loss (No Excitation)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

Where:
- \( F \) = Net Force in lbs.
- \( L \) = Lever Arm in ft.
- \( N \) = Speed of Dynamometer in RPM

\[ \text{Watts} = \frac{27085}{5252} \times 746 \]

B. Core Loss + Windage and Friction (@ Rated Voltage)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

\[ \text{Watts} = \frac{8502}{5252} \times 746 \]

Core Loss B-A

\[ \text{Watts} = \frac{8502}{5252} \]

C. Armature Copper Loss (Stray Load Loss Test)

\[ \text{Watts} = I^2 \times R \times 3 \]

Where:
- \( I \) = Rated Armature Current
- \( R \) = Armature resistance per phase at time of the stray load loss test.

\[ \text{Watts} = \frac{(3^2)(3)}{5252} \times 746 \]

D. Stray Load Loss + \( I^2R \) Loss + Friction & Windage (@ Rated Armature Current)

\[ \text{Watts} = \frac{F \times L \times N}{5252} \times 746 \]

\[ \text{Watts} = \frac{115}{5252} \times 746 \]

Stray Load Loss = \( D-(A+C) \)

\[ (\frac{1}{2}) \left( \frac{3^2 \times 746}{734.47} \right) = 138 - \left( \frac{-2}{-1} \right) \]
E. Armature $I^2R$ Loss

$$Watts = I^2_{arm} \times R_{75} \times 3$$

$$= (1.1)^2 (234.5) (3)$$

$$= -76$$ Watts

F. Generator Field $I^2XR$ Loss

$$I_{FL} = (I_{FL} - I_{NL}) \times (2) + I_{NL}$$

$$= (100 - 27.2) \times (2) + 27.2$$

$$= 33.76$$

$$Watts = I^2R$$

$$= (33.76)^2 (1636)$$

$$= 429.88$$ Watts

Total Losses (Watts)

1. Friction & Windage Loss ——— 2728.3
2. Core Loss ——— 850.2
3. Stray Load Loss ——— 13.8
4. Armature $I^2R$ Loss ——— 7.6
5. Field $I^2R$ Loss ——— 1566
6. Exciter Loss ——— 224

Efficiency:

$$\% \text{ Eff.} = 100 - \frac{\text{Losses} \times 100}{\text{Output} + \text{Losses}}$$

$$= 100 - \frac{(3828) (100)}{400,000 + 3828}$$

$$= 100 - 16.06$$

$$\% \text{ Eff.} = 83.93$$
A. Friction & Windage Loss (No Excitation)

\[ \text{Watts} = \frac{F \cdot L \cdot N}{5252} \times 746 \]

Where:

- \( F \) = Net Force in lbs.
- \( L \) = Lever Arm in ft.
- \( N \) = Speed of Dynomometer in rpm

\[ \frac{27083}{5252} \times 746 \]

\[ = 27083 \text{ WATTS} \]

B. Core Loss + Windage and Friction (@ Rated Voltage)

\[ \text{Watts} = \frac{F \cdot L \cdot N}{5252} \times 746 \]

\[ = \frac{8502}{5252} \times 746 \]

\[ = 8502 \text{ WATTS} \]

Core Loss B-A

\[ = \frac{8502}{5252} \times 746 \]

\[ = \frac{2518}{5252} \times 746 \]

\[ = 8502 \text{ WATTS} \]

C. Armature Copper Loss (Stray Load Loss Test)

\[ \text{Watts} = I^2 \cdot \text{arm} \times R \times 3 \]

Where:

- \( I \) = Rated Armature Current
- \( R \) = Armature Resistance per phase at time of the stray load loss test

\[ (1.2)^2 (1) (3) \]

\[ = \frac{1.44}{3} \text{ WATTS} \]

D. Stray Load Loss + \( I^2 \cdot R \) Loss + Friction & Windage (@ Rated Armature Current)

\[ \text{Watts} = \frac{F \cdot V}{5252} \times 746 \]

\[ = \frac{117}{5252} \times 746 \]

\[ = \frac{117}{5252} \times 746 \]

\[ = 117 \text{ WATTS} \]

\[ \text{Stray Load Loss} = \frac{2}{7} \left( \frac{1}{10} \right) \left( \frac{3447}{3} \right) = \frac{25}{1} \text{ - (____ + ____)} \]
E. Armature $I^2R$ Loss

$$\text{Watts} = I_{arm}^2 \times R_{75} \times 3$$

$$= \left( \frac{2}{(1.1912)} \right) \times (3)$$

$$= 119 \text{ Watts}$$

F. Generator Field $I^2R$ Loss

$$I_{FL0} = (I_{FL0} - I_{NL}) + I_{NL}$$

$$= (60 - 27.2) + 27.2$$

$$= 30.48 \text{ Watts}$$

Where:

- $I_{arm}$ = RATED ARMATURE CURRENT
- $R_{75}$ = RESISTANCE PER PHASE Corrected to 75°C
- $R_{FL0}$ = RESISTANCE OF THE FIELD Corrected to 75°C

Total Losses (Watts)

1. Friction & Windage Loss = 270.83
2. Core Loss = 850.2
3. Stray Load Loss = 35
4. Armature $I^2R$ Loss = 119
5. Field $I^2R$ Loss = 152.0
6. Exciter = 188

Efficiency:

$$\% \text{ Eff.} = 100 - \frac{\text{Losses} \times 100}{\text{Output} + \text{Losses}}$$

$$= 100 - \frac{270.83 \times 100}{100,000 + 37442}$$

$$= 100 - 27.24$$

$$\% \text{ Eff.} = 72.75$$
A. Friction & Windage Loss (No Excitation)

\[
\text{Watts} = \frac{F \times L \times N}{5252} \times 746
\]

Where:  
- \(F\) = Net Force in Lbs.  
- \(L\) = Lever Arm in Ft.  
- \(N\) = Speed of Dynamometer in RPM  

\[
= \frac{270 \times 746}{5252} \times 746
\]

\[
= 8502 \text{ Watts}
\]

B. Core Loss + Windage and Friction (@ Rated Voltage)

\[
\text{Watts} = \frac{F \times L \times N}{5252} \times 746
\]

\[
= \frac{270 \times 746}{5252} \times 746
\]

\[
= 8502 \text{ Watts}
\]

Core Loss B-A

\[
= \frac{270 \times 746}{5252} \times 746
\]

\[
= 8502 \text{ Watts}
\]

C. Armature Copper Loss (Stray Load Loss Test)

\[
\text{Watts} = \frac{I^2}{\text{arm}} \times R \times 3
\]

Where:  
- \(I\) = Rated Armature Current
- \(R\) = Armature Resistance per Phase at Time of the Stray Load Loss Test

\[
= \left( \frac{2702}{1504} \right)^2 \times (3)
\]

\[
= 2202 \text{ Watts}
\]

D. Stray Load Loss + I^2R Loss + Friction & Windage (@ Rated Armature Current)

\[
\text{Watts} = \frac{F \times L \times N}{5252} \times 746
\]

\[
= \frac{270 \times 746}{5252} \times 746
\]

\[
= 8502 \text{ Watts}
\]

Stray Load Loss = D - (A + C)

\[
= \left( \frac{1202}{1504} \right) \times 3447 = \frac{2202}{5252} (\text{____ + ____})
\]

Where 1202 = \(I_{11\%} \times 1000 \text{ Kw} \times 1.0 \text{ PF} \)
E. Armature $I^2R$ Loss

\[
\text{Watts} = I_{\text{arm}}^2 \times R_{75} \times 3
\]

\[
= \left( \frac{1207}{1504} \right)^2 \times 1120 = 760.8 \text{ Watts}
\]

F. Generator Field $I^2R$ Loss

\[
\text{Watts} = I_{\text{Fg}}^2 \times R
\]

\[
= (37.3)^2 \times 0.634 = 2276
\]

Total Losses (Watts)

1. Friction & Windage Loss 2708.3
2. Core Loss 550.2
3. Stray Load Loss 220.2
4. Armature $I^2R$ Loss 760.8
5. Field $I^2R$ Loss 2276
6. Exciter 310

Efficiency:

\[
\% \text{ Eff.} = \frac{100 - \text{Losses} \times 100}{\text{Output} + \text{Losses}}
\]

\[
= \frac{100 - (4798.1 \times 100)}{1000,000 + 4798.1}
\]

\[
= 95.4\%
\]
A. Friction & Windage Loss (No Excitation)

\[
Watts = \frac{FLN}{5252} \times 746
\]

Where:
- \( F \) = Net Force in LBS.
- \( L \) = Lever Arm in FT.
- \( N \) = Speed of Dynometer in RPM

\[
= \frac{5252}{5252} \times 746
\]

\[
= 170.83\text{ WATTS}
\]

B. Core Loss + Windage and Friction (0 Rated Voltage)

\[
Watts = \frac{FLN}{5252} \times 746
\]

\[
= \frac{152}{5252} \times 746
\]

\[
= \frac{8502}{5252}\text{ WATTS}
\]

Core Loss B-A

\[
= \frac{8502}{746}
\]

\[
= 850.2\text{ WATTS}
\]

C. Armature Copper Loss (Stray Load Loss Test)

\[
Watts = I_{\text{arm}}^2 \times R \times 3
\]

Where:
- \( I \) = Rated Armature Current
- \( R \) = Armature Resistance per Phase at time of the Stray Load Loss Test

\[
= \left( \frac{889}{1504} \right)^2 \left( \frac{3447}{\text{Watts}} \right)
\]

\[
= \frac{1205}{\text{Watts}}
\]

D. Stray Load Loss + \( I^2R \) Loss + Friction & Windage (0 Rated Armature Current)

\[
Watts = \frac{FLN}{5252} \times 746
\]

\[
= \frac{5252}{5252} \times 746
\]

\[
= \frac{121}{\text{WATTS}}
\]

\[
= \frac{889^2}{1504} \times 3447 = \frac{1205}{\text{Watts}}
\]

Stray Load Loss = D-(A + C)
E. Armature $I^2R$ Loss

$$\text{Watts} = I_{\text{arm}}^2 \times R_{75} \times 3$$

$$= (\frac{889}{15.04})^2 \times 4162 \text{ Watts}$$

F. Generator Field $I^2R$ Loss

$$I_{F LD} = (3.73 - 26 \times 0.75) + 26$$

$$= \text{Watts} = I^2 R$$

$$= (34.4)^2 \times 0.636$$

$$= 1936$$

Total Losses (Watts)

1. Friction & Windage Loss 270.8
2. Core Loss 750.2
3. Stray Load Loss 120.2
4. Armature $I^2R$ Loss 4162
5. Field $I^2R$ Loss 1936
6. Excitation 263

Efficiency: 4314.8

\% Eff. = 100 - \frac{\text{Losses x 100}}{\text{Output} + \text{Losses}}

= 100 - \frac{(4314.8) (100)}{750,000 + 4314.8}

= 100 - 5.44

\% Eff. = 94.55
A. Friction & Windage Loss (No Excitation)

\[ \text{Watts} = \frac{F \times L}{252} \times 746 \]

Where: 
- \( F \) = Net Force in LBS.
- \( L \) = Lever Arm in FT.
- \( N \) = Speed of Dynomometer in RPM

\[ \text{Watts} = \frac{270.83}{252} \times 746 \]

B. Core Loss + Windage and Friction (0 Rated Voltage)

\[ \text{Watts} = \frac{F \times L}{252} \times 746 \]

\[ \text{Watts} = \frac{270.83}{252} \times 746 \]

Core Loss B-A

\[ \text{Watts} = \frac{270.83}{252} \times 746 \]

C. Armature Copper Loss (Stray Load Loss Test)

\[ \text{Watts} = I^2 \times R \times 3 \]

Where: 
- \( I \) = Rated Armature Current
- \( R \) = Armature Resistance per Phase at Time of the Stray Load Loss Test.

\[ \text{Watts} = \frac{(601)}{5252} \times 746 \]

D. Stray Load Loss + I^2R Loss + Friction & Windage (0 Rated Armature Current)

\[ \text{Watts} = \frac{F \times L}{252} \times 746 \]

\[ \text{Watts} = \frac{270.83}{252} \times 746 \]

\[ \text{Watts} = \frac{1.23}{550} \]

\[ \text{Stray Load Loss} = D - (A + C) \]

\[ (\frac{601}{5252})^2 \times 746 \times 550 \]
E. Armature $I^2R$ Loss

\[ \text{Watts} = I_{arm}^2 \times R_{75} \times 3 \]
\[ = \left( I^2 \right) \left( \frac{2}{15.04} \right) \left( \frac{119.2}{122} \right) = 190.2 \text{ Watts} \]

F. Generator Field $I^2R$ Loss

\[ I_{FLD} = (37.3 - 26)(5) + 26 = 31.65 \]
\[ \text{Watts} = I^2R \]
\[ = (31.65)^2 \times 1.636 \]
\[ = 1639 \]

Total Losses (Watts)

1. Friction & Windage Loss 27093
2. Core Loss 8502
3. Stray Load Loss 5530
4. Armature $I^2R$ Loss 1902
5. Field $I^2R$ Loss 1639
6. Exciter Losses 232

Efficiency:

\[ \frac{500000 \times 39898}{500000 \times 39898} = 92.61\% \]
A. Friction & Windage Loss (No Excitation)

\[ \text{Watts} = \frac{F \cdot L \cdot N}{5252} \times 746 \]

Where:
- \( F \) = Net Force in LBS.
- \( L \) = Lever Arm in FT.
- \( N \) = Speed of Dynometer in RPM

\[ \text{Watts} = \frac{27083}{5252} \times 746 \]

\[ = 27083 \text{ WATTS} \]

B. Core Loss + Windage and Friction (@ Rated Voltage)

\[ \text{Watts} = \frac{F \cdot L \cdot N}{5252} \times 746 \]

\[ = \frac{5252}{5252} \times 746 \]

\[ = 5252 \text{ WATTS} \]

Core Loss B-A

\[ = 9502 \text{ WATTS} \]

C. Armature Copper Loss (Stray Load Loss Test)

\[ \text{Watts} = I^2_{\text{arm}} \times R \times 3 \]

Where:
- \( I \) = Rated Armature Current
- \( R \) = Armature Resistance per Phase at time of stray load loss test

\[ = ( )^2 ( ) (3) \]

\[ = \text{WATTS} \]

D. Stray Load Loss + I^2R Loss + Friction & Windage (@ Rated Armature Current)

\[ \text{Watts} = \frac{F \cdot L \cdot N}{5252} \times 746 \]

\[ = \frac{5252}{5252} \times 746 \]

\[ = \text{WATTS} \]

\[ \text{Stray Load Loss} = D-(A+C) \]

\[ \left( \frac{240}{1504} \right)^2 \times 3447 = \frac{88}{1} - \]
E. Armature $I^2R$ Loss

Watts = $I^2_{arm} \times R_{75} \times 3$

\[
\left( \frac{240}{15^\circ C} \right)^2 \left( \frac{119\Omega}{12 \Omega} \right) = \left( \frac{1}{2} \right)^2 \left( \frac{1}{3} \right) (3)
\]

= 303 Watts

F. Generator Field $I^2X$ R Loss

\[
I_{FLV} = (37.3 - 26) \times 2 + 26
\]

= 28.26

Watts = $I^2R = (28.26)^2 \times (1.636)$

= 1306

Total Losses (Watts)

1. Friction & Windage Loss 2708.3
2. Core Loss 850.2
3. Stray Load Loss 88
4. Armature $I^2R$ Loss 303
5. Field $I^2R$ Loss 1306
6. Exciter Losses 177

Efficiency:

\[
\frac{3745.9}{1306}
\]

% Eff. = 100 - Losses $\times 100$

Output + Losses

= 100 - (3745.9) (100)

200,000 + 3745.9

= 100 - 15.77

% Eff. = 24.22
A. Friction & Windage Loss (No Excitation)

\[ \text{Watts} = \frac{F \times L}{5252} \times 746 \]

Where: \( F \) = NET FORCE IN LBS.
\( L \) = LEVER ARM IN FT.
\( N \) = SPEED OF DYNAMOMETER IN RPM

\[ = \frac{5252 \times 746}{5252} \times 746 \]

\[ = 27083 \text{ WATTS} \]

B. Core Loss + Windage and Friction (Rated Voltage)

\[ \text{Watts} = \frac{F \times L}{5252} \times 746 \]

\[ = \frac{5252 \times 746}{5252} \times 746 \]

\[ = \text{WATTS} \]

Core Loss B-A

\[ = \frac{5252 \times 746}{5252} \times 746 \]

\[ = 8502 \text{ WATTS} \]

C. Armature Copper Loss (Stray Load Loss Test)

\[ \text{Watts} = I^2 \text{arm} \times R \times 3 \]

Where: \( I \) = RATED ARMATURE CURRENT
\( R \) = ARMATURE RESISTANCE PER PHASE AT TIME OF THE STRAY LOAD LOSS TEST.

\[ = \left( \frac{I^2}{3} \right) \times 746 \times 3 \]

\[ = \text{WATTS} \]

D. Stray Load Loss + \( I^2R \) Loss + Friction & Windage (Rated Armature Current)

\[ \text{Watts} = \frac{F \times L}{5252} \times 746 \]

\[ = \frac{5252 \times 746}{5252} \times 746 \]

\[ = \text{WATTS} \]

\[ \text{Stray Load Loss} = D \times (A + C) \]

\[ \left( \frac{120}{160} \right)^2 \times 3447 = 22 \times \left( \frac{A}{9} \right) + \left( \frac{C}{3} \right) \]
E. Armature $I^2R$ Loss

$$\text{Watts} = I_{\text{arm}}^2 \times R_{75} \times 3$$

$$= \left( \frac{120}{1504} \right)^2 \left( 1.1912 \right) \times 76.0 \text{ Watts}$$

F. Generator Field $I^2X$ Loss

$$I_{FLD} = (37.3 - 20 \times 1) + 20$$

$$= 27.13$$

$$\text{Watts} = I^2X$$

$$= (27.13)^2 \times (1.636)$$

$$= 1204 \text{ Watts}$$

Total Losses (Watts)

1. Friction & Windage Loss 27083
2. Core Loss 1852
3. Stray Load Loss 22
4. Armature $I^2R$ Loss 76
5. Field $I^2R$ Loss 1204
6. Excess Field Losses 163

Efficiency = \frac{\text{37050}}{\text{37050}}

% Eff. = 100 - \frac{\text{Losses} \times 100}{\text{Output} + \text{Losses}}

= 100 - \frac{(27083)(100)}{100,000 + 37050}

= 100 - 27.03

% Eff. = 72.96

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**TEST RECORD**

**KATO ENGINEERING CO.**

**MANKATO, MINNESOTA U.S.A.**

**CUSTOMER: SWENHART ELECTRIC**

**P.O.C: CONTRACT NO.: 4573-R24864**

**TESTED BY: PHIL KROENER**

**GOV'T. INSPI.**

---

### Test Results

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**REMARKS**

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G. VOLTS | TEMP. RISE | ROTATION, FACING DRIVE END |
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KVA: 1250  KW: 1000  A.C. VOLTS: 480  Cycles: 60  RPM: 1800

Temp. Rise: 70°C  Rotation, Facing Drive End: CCW

Unit Specifications

Order Serial No.: 74536  Date: 11/23/76  Sold To: Swelhart Electric Co Inc.

Model: 1000E95  Type No.: 18856  Unit No.: 1  Tested By: L. K. Hewett

PD K. R. K. L. N.
KATO ENGINEERING CO.
HANKATO, MINNESOTA

ORDER SERIAL NO. 74576 DATES 11/23/76 SOLD TO: SWEIERT ELECTRIC CO. INC

MODEL 1000 SERIES TYPE NO. 18856 UNIT NO. 1 TESTED BY: PHHENTH
PD KRALOY

UNIT SPECIFICATIONS

KVA 1250 KW 1000 A.C. VOLTS 480 CYCLES 60 RPM 1800

- VOLTS TEMP. RISE 70° ROTATION, FACING DRIVE END CW

ZERO POWER SAT.

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OF POOR QUALITY
**KATO ENGINEERING CO.**

**HANKATO, MINNESOTA**

**ORDER SERIAL NO. 74586** **DATE 11/23/76** **SOLD TO: SWALBART ELECTRIC CO, INC.**

**MODEL 1000ER9E** **TYPE NO. 18856** **UNIT NO. 1** **TESTED BY: DA HESS**

**PD KRALOCEL**

**UNIT SPECIFICATIONS**

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<th>RPM</th>
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| 92 | 0 | — | — | 50.0 | 42.9 | 1.27 | 37.6 | 30.9 |

| 180 | 326 | 31.5 | 280 | 0.0 | 59.62 | 42.9 | 1.59 | 37.1 | 36.0 |
| 653 | 0 | — | — | 60.0 | 42.9 | 1.59 | 37.1 | 36.0 |
Small Impeller
6-7-77

A = Correction Plane
Drive End

B = Correction Plane
Other End

24\(\frac{1}{2}\)''

DISTANCE BETWEEN PLANES

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| ORIGINAL VIB. AMP. | 120 Gr. In. |
| FINAL VIB. AMP.   | 5 Gr. In.   |
| WEIGHT ADDED/REMOVED | 15 Grams |
| RADIUS             | 7\(\frac{1}{2}\)'' |
| PERMANENT CORRECTION MADE | BY ADDED/REMOVAL OF WEIGHT |

ELECTRONIC BALANCING CO.
2849 Long Beach Blvd.
Long Beach, Calif. 90806
GArfield 4-0739  NEvada 6-6538
Large Impeller
6-7-77

A = Correction Plane
B = Correction Plane
Large Gear End

Distance between planes

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ELECTRONIC BALANCING CO.
2849 Long Beach Blvd.
Long Beach, Calif., 90806
GARFIELD 4-0739 NEVADA 6-6538

WEIGHT ADDED/REMOVED 20 Grams
RADIUS 7½"
ACCEPTANCE AND INTERFACE TESTING

A. PURPOSES

1. To verify that the HPC Power System 76-1 (a) complies with the contract specifications as embodied in Contract 954404, Exhibit 1, and HPC Drawings B13 and B14, (b) is a complete and functioning subsystem in compliance with HPC Drawing B20, and (c) is ready for delivery to JPL.

2. To verify that the interfaces between the HPC Power System 76-1 and the JPL support system are correct and to demonstrate that the Power System and the JPL Control and Instrument Support Van function together as a system.

B. APPROACH

1. HPC assemble, prepare, and check the Power System in Mission Viejo. The preparation should include:
   a. Preset vibration switches \((V_1, V_2)\) to NC (normally closed) plus margin at rest. \(V_1 \quad V_2 \quad \)
   b. Preset underspeed switch \((US)\) to NO (normally open) at \(\sim 50\) Hz. 
   c. Preset high oil temperature \((OHT)\) switch to NC \(\sim 150^\circ F\).
   d. Preset low oil pressure \((LOP)\) switch to NO \(\sim 10-12\) psig.
   e. Preset shaft seal pressure \((SSP)\) switch to NO \(\sim 125\) psig.
   f. Preset overspeed \((OS)\) switch to NC \(\sim 2200\) RPM = 66 Hz.
   g. Preset Stop \((S)\) rate for Automatic Stop valve.
   h. Preset Stop \((S)\) rate for Governor Override.
   i. Preset Emergency Stop \((ES)\) rate for Automatic Stop valve.
   j. Preset Emergency Stop \((ES)\) rate for Governor Override.

2. JPL assemble and check the Control and Instrument Support Van equipment and associated cables in Pasadena.
3. When both assemblies are ready, transport Van to Mission Viejo. Park along curb toward front of 25721 Obrero and order air compressors for driving Power System. Compressors will arrive in seven days. When they arrive they will park along Obrero toward rear of 25721.

4. During wait for compressors, JPL will interface with the Power Systems at the terminal strips TB"EA", TB"EB", and TB"EC" in the junction boxes as shown on HPC Drawing B20. As part of the procedure of interfacing at the terminal strips, each function possible will be checked for end-to-end signal to verify that the JPL and HPC wiring diagrams are correct and correctly executed and that the nomenclature is mutually compatible. Static testing will then be carried out as described under Static Test Procedure, Section C, and the Power System will be checked against Exhibit 1 and HPC Drawings B13 and B14.

5. After the compressors arrive, the Dynamic Acceptance and Interface Testing will be performed as described under Dynamic Test Procedures, Sections D and E.

6. The Load Bank Interface Testing will not be included in Mission Viejo because of insufficient power. Also science data instrumentation testing for brine parameters, pressure, temperature, and flow rate will be postponed to the field, except that at least two unmouted temperature and pressure measuring devices will be wired and monitored.
ACCEPTANCE AND INTERFACE TESTING (Cont'd.)

C. STATIC TEST PROCEDURE

1. Check Batteries. _____


3. Reset Emergency Stop relay to energize the safety shutdown circuit. _____

4. Verify that the Exciter switch is in Underspeed Bypass position. _____

5. Activate Data Logger and Intercoms. _____ _____ _____ Log SSP fault. _____

6. Operate pump #1 to prime lube oil system. _____

7. Operate pump #2. _____ At 125 psig monitor no fault. _____ Pressurize to 150 psig. _____ Verify that bearing and winding temperatures, bearing thrust, and throttle position are being logged. See check-list in Appendix.

8. Momentarily turn (key) Start switch. _____ Throttle should open. Obse ve. _____ Log. _____ Stop relay should reset. _____

9. Operate pump #3 to open Automatic Stop valve fully. _____

10. Press Stop button at power plant. _____ Observe Throttle \(^b\) and Automatic Stop valve close slowly. _____ _____ Estimate closing time of Automatic Stop valve. _____ Log Throttle \(^b\) position. _____

11. Momentarily turn Start switch. _____ Throttle \(^b\) should open. Observe. _____ Log. _____ Stop relay should reset. _____

\(^b\) - Throttle response must be verified. It may be necessary to monitor the Governor Override Stop relay instead.

Date: ___________ Test Staff: ___________

Notes: ___________
12. Press Stop button in Van. Observe Throttle\textsuperscript{b} close and Stop relay trip. Estimate closing time of Throttle. Log Throttle\textsuperscript{b} position.

13. Momentarily turn Start switch. Throttle\textsuperscript{b} should open and Stop relay should reset. Log Throttle\textsuperscript{b} position.

14. Operate pump #3 to open Automatic Stop valve fully.

15. Press Emergency Stop button at power plant. Observe Throttle\textsuperscript{b} and Automatic Stop valve close rapidly. Estimate closing time of Automatic Stop valve. Log Throttle\textsuperscript{b} position.

16. Reset Emergency Stop relay. Observe Throttle\textsuperscript{b} open and Emergency Stop relay reset. Log Throttle\textsuperscript{b} position.

17. Press Emergency Stop button in Van. Observe Throttle\textsuperscript{b} close and Emergency Stop relay trip. Estimate closing time of Throttle\textsuperscript{b}. Log Throttle\textsuperscript{b} position.

18. Reset Emergency Stop relay. Observe Throttle\textsuperscript{b} open and Emergency Stop relay reset. Log Throttle\textsuperscript{b} position.

19. Underset or otherwise trip vibration switch $V_1$. Observe Throttle\textsuperscript{b} close and Stop relay trip. Log $V_1$ fault and Throttle\textsuperscript{b} position. Reset $V_1$. Log no fault. Turn Start switch momentarily. Throttle\textsuperscript{b} should open and Stop relay should reset. Log Throttle\textsuperscript{b} position.

\textsuperscript{b} - Throttle response must be verified. It may be necessary to monitor the Governor Override Stop instead.

\begin{tabular}{ll}
\hline
Date: & Test Staff: \\
\hline
\end{tabular}

Notes:
20. Underset or otherwise trip Vibration switch $V_2$. Observe Throttle$^b$
    close and Stop relay trip. Log $V_2$ fault and Throttle$^b$
    position. Reset $V_2$. Log no fault. Turn Start
    switch. Observe Throttle$^b$ open and Stop relay reset.

    Log OHT fault and Throttle$^b$ position. Restore OHT circuit.
    Turn Start switch. Observe Throttle$^b$
    open and Stop relay reset.

22. Turn Exciter switch to On position to open US bypass. Observe
    Throttle$^b$ close and Stop relay trip. Log US fault and
    Throttle$^b$ position. Turn Exciter switch to US bypass.
    Log no fault. Turn Start switch. Observe Throttle$^b$
    open and Start relay reset.

23. Remove jumper from LOP switch. Observe Throttle$^b$ close and
    Stop relay trip. Log LOP fault and Throttle$^b$ position.

24. Open battery circuit by pressing Emergency Stop button. Log all
    bearing and winding temperature data. Refer to check-list in
    Appendix.

25. Turn off Data Logger. Turn off Intercoms.

b - Throttle response must be verified. It may be necessary to monitor
    the Governor Override Stop instead.

Date: Test Staff:

Notes:
D. DYNAMIC TEST PROCEDURE: MODIFIED START, RUN, STOP

1. Deactivate Governor Override relay for Stop circuit. _____ Install circuitry with auxiliary switches to permit bypassing the OS switch and place a meter across the OS switch terminals. _____ Leave bypass circuit in safety position. _____

2. Inspect the Power Plant, Van, and Cables for readiness. _____ _____ Verify that Main Circuit Breaker is open. _____

3. Check Batteries. _____

4. Reset Emergency Stop relay to energize the safety shutdown circuit. _____

5. Verify that Exciter switch is in Underspeed Bypass position. _____

6. Verify that Automatic Stop and Manual 8" gate valves are closed. _____

7. Turn on compressors. _____ (Wear ear protection as necessary.)

8. Open Manual gate valve fully. _____

9. Operate pump #1 to prime lube oil system. _____

10. Open shaft guard #1. _____ Manually roll over power train. _____ Close guard. _____

---------------------------

c - This step permits OS switch bypass but retains manual ES shut-down via Governor Override from Power system and in Van.

_______ _______ _______ _______ _______
Date: Test Staff:

Notes: -6- K6
11. **Activate Data Logger and Intercoms.** Log LOP fault and SSP fault.


15. Verify that lube oil reservoir temperature is above 60°F. Otherwise, wait until it is. Then continue to open Automatic Stop valve to bring plant to standard operating speed. Observe Governor take over. Monitor RPM and adjust Governor as necessary. Open Automatic Stop valve slightly more.


Date: Test Staff:

Notes:
Transfer speed control to Manual gate valve with Governor adjusted for full Throttle.

17. Prop Automatic Stop valve about 7/8 open.

18. With Manual gate valve, adjust speed to standard operating RPM\(^d\). Check operation of \(V_1\) two or three times by adjusting sensitivity and adjust for normal plant operation. Log \(V_1\) fault and then no fault. Observe Automatic Stop valve close against the prop. Turn Start switch to reset Stop relay. Operate pump #3 to open Automatic Stop valve fully. Check operation of \(V_2\) two or three times by adjusting sensitivity and adjust for normal plant operation. Log \(V_2\) fault and then no fault. Observe Automatic Stop valve close against the prop. Turn Start switch to reset Stop relay. Operate pump #3 to open Automatic Stop valve fully.

19. Bypass OS switch and turn on meter. With Manual gate valve and tachometer, check OS trip RPM. Note RPM at which trip occurs. If RPM does not occur before 11\(\%\) overspeed, (see Rotor RPM table), set overspeed at 10\(\%\), (see table), and adjust OS trip to just open. Then reduce RPM gradually to determine RPM at which OS trip closes. Verify that OS trip opens on rising RPM. Reduce speed to close OS switch and terminate bypass of OS switch. During this step, continuously monitor RPM and press Emergency Stop if RPM exceeds 2400 RPM.

\(d\) - or adjust speed to a vibration node if one appeared during start-up.

Date: Test Staff:

Notes:
20. Adjust Manual gate valve so that speed cannot reach 10% overspeed (See Rotor RPM table) with Throttle wide open. Then reduce speed to standard RPM with Governor and Throttle.


23. Adjust voltage at Power Plant. Check remote voltage adjustment capability.

24. Adjust frequency to 60 Hz at Power Plant. Check remote frequency adjustment capability.

25. Check operation of oil cooler fan. Direction.

Date: Test Staff:

Notes:

K9
26. Check operation of ammeter at Power Plant.

27. Check Main Circuit Breaker remote trip operation.

28. Check greaser operation. Set pressure at $P_1 + 100$ psi.

   Observe Automatic Stop valve close and Plant stop. 
   Log US fault.

30. Press Emergency Stop button to open battery circuit.

31. Reactivate Governor Override relay for Stop circuit. 
   Remove meter and bypass circuit from Overspeed switch and replace leads on 
   NC terminals.

Date: 

Test Staff: 

Notes:
ACCEPTANCE AND INTERFACE TESTING (Cont'd.)

E. DYNAMIC TEST PROCEDURE: SEMI-NORMAL START, RUN, STOP

1. Walk around Plant inspection. _____ Verify that Main Circuit Breaker is open. _____
2. Check battery. _____
3. Reset ES relay. _____
4. Place Exciter switch in US Bypass position. _____ Verify that oil cooler fan is in On position. _____
5. Activate Data Logger and Intercoms _____ _____ Log LOP fault _____ and SSP fault. _____ Log engineering data. _____
6. Open Manual gate valve fully. _____
7. Operate pump #1 to prime lube oil system. _____
8. Operate pump #2 to provide 150 psig oil. _____ LOP fault only. _____
9. Hold Start switch on. _____ Observe Throttle open. _____
10. While holding Start switch on, operate pump #3 to open Automatic Stop valve part way. _____ Watch Tachometer and driving pressure. _____ Watch oil pressure to bearings. _____ Release Start switch when pressure exceeds LOP point (~12 psig). _____ Plant will continue to run, throttled by Start/Stop valve.
11. Verify that lube oil reservoir temperature is above 60°F. Otherwise, wait until it is. _____ Then continue. Open Automatic Stop valve to bring Plant to standard operating speed, shifting control to the Governor and Throttle. _____ Open Automatic Stop valve fully. _____ Monitor RPM and adjust Governor as necessary. _____

Date: Test Staff:

Notes:

K11
12 Turn on Exciter. Watch Volmeter and Frequency Meter at Power Plant. Look for Ammeter response. Adjust frequency to 60 Hz with Governor. Adjust voltage to 480 V.

13. Check Oil Cooler air flow.

14. Cycle the Exciter to check the Governor response. Monitor effect on frequency.

15. Operate plant three hours. Log engineering data. Refer to check-list in Appendix. Verify Grease operation.

16. Press Stop button in van. Observe Automatic Stop valve slowly close and bring Plant to a stop.

17. Turn off Data Logger. Turn off Intercoms.

18. Press ES button to open Battery circuit.


Date: Test Staff: Notes:

-12-
## APPENDIX

### CHECKLIST: ACCEPTANCE AND INTERFACE TESTING GUIDE

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<th>DYNAMIC TEST D</th>
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<td>B4</td>
<td>C7</td>
<td>D12</td>
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| Intercom                 | B4 | C5 | D11 | E5  |
| I. remote                | B4 |    | D12 | E15 |
| KW remote                | B4 |    | D12 | E15 |
ACCEPTANCE AND INTERFACE TESTING (contd)

D. DYNAMIC TEST PROCEDURE: MODIFIED START, RUN, STOP

1. Install circuitry with auxiliary switches to permit bypassing the OS switch. 
   (This is accomplished by placing a switched jumper across the OS relay output and an auxiliary switch in the OS switch output circuit. The switched jumper requires two switches in series, one at the start station and one at the backup RPM monitor station.)
   Place a meter across the OS switch terminals. Leave all three switches in closed (on) position.

2. Activate the data logger and intercoms.

3. Check for SSP fault, LOP fault, US fault, OS no fault.

4. Open auxiliary switch in OS switch circuit (near OS switch). Log OS fault.


6. Inspect the Power Plant, Van, and Cables for readiness. Verify that Main Circuit Breaker is open. Set inhouse breaker off. Record cumulative operating time.

7. Operate pump #1 to prime lube oil system.

Date: ____________________________ Test Staff: ____________________________

Notes:

K15
8. Open shaft guard #1. Manually roll over power train. Leave guard open to permit use of surface speed tachometer.


10. Reset Emergency Stop relay to energize the safety shutdown circuit.

11. Verify that Exciter switch is in Underspeed Bypass position.

12. Verify that Automatic Stop and Manual 8" gate valves are closed.

13. Turn on compressors. (Wear ear protection as necessary.)


15. Check nitrogen pressure. Recharge if necessary. Log engineering data. See checklist in Appendix.


Date: Test Staff:

Notes:
19. Verify that lube oil reservoir temperature is above 60°F. Otherwise, wait until it is. Then continue to open Automatic Stop valve to bring plant to standard operating speed according to the following schedule.


b. Transfer control to governor at 1800 RPM.

c. Adjust governor and automatic stop valve alternately to bring speed to 2500 RPM (50 Hz).

d. Excite governor. Bring speed to 2750 RPM. (55 Hz)

e. Turn on inhouse breaker. Check operation of oil fan.

f. With governor, slowly bring speed to 3000 RPM (60 Hz). Run 10 minutes under governor control. Start time. While running 10 minutes or more at normal speed, perform steps g through k.

g. Adjust voltage at power plant to 480 V. Check remote voltage adjustment capability.

h. Adjust frequency to 60 Hz at Power Plant panel. Check remote frequency adjustment capability.

i. Check operation of ammeter at Power Plant.

j. Check greaser operation. Set pressure at P1 to 100 psi.

k. Calibrate tachometer with frequency meter at 60.0 Hz. Tachometer reading. Calculate expected reading for 65.0 Hz and enter in step 24. Calculate expected reading for 66.6 Hz and enter in step 25a.

Date: Test Staff:

Notes:

K17

21. Hold speed to standard operating RPM or adjust speed to a vibration mode if one appeared during startup. Check operation of $V_1$ two or three times by adjusting sensitivity and adjust for normal plant operation. Log $V_1$ fault and then no fault. Turn Start switch to reset Stop relay. Check operation of $V_2$ two or three times by adjusting sensitivity and adjust for normal plant operation. Log $V_2$ fault and then no fault. Open Stop metering valve.

22. With speed adjusted to standard (60.0 Hz generator and 3000 RPM male rotor) cycle exciter to monitor speed change. Note tachometer speed change.

23. Turn on voltmeter to monitor OS switch.

24. Increase speed to 65.0 Hz and check tachometer for correct reading. Theoretical = 3250. Calculated. Observed.

25. If observed tachometer reading does not correlate well with the calculated value, step 23, leave exciter on and set OS switch at 65 Hz using frequency meter as speed reference. Adjust OS switch to open at high end of frequency meter. Reduce speed with governor and note speed at which OS switch closes. Increase speed until OS opens to verify setting. Repeat as necessary.

25a. If observed tachometer reading does correlate well with the calculated value, step 23, turn off exciter and set OS switch using tachometer as speed reference. During this step, continuously monitor RPM and trigger Emergency Stop if RPM exceeds 3450 RPM. Adjust speed to 11% overspeed equal to 3330 RPM male rotor shown on the tachometer as RPM calculated in step 19k.

Date: ___________________________  Test Staff: ___________________________

Notes: ___________________________
Set OS switch to just open at this speed. Reduce speed with governor and note speed at which OS switch closes. Increase speed until OS opens to verify setting. Reduce speed to close switch and repeat procedure as necessary.

26. Reduce speed to normal and excite generator.

27. Terminate bypass of OS switch by first closing bypass switch and then opening bypass jumper.


30. Open battery circuit.

31. Remove meter from Overspeed signal terminals.

32. Remove jumper from OS relay output. Reconnect lead to OS switch output terminal.


Date: Test Staff: Notes:

K19
ACCEPTANCE AND INTERFACE TESTING (Cont’d.)

E. DYNAMIC TEST PROCEDURE: SEMI-NORMAL START, RUN, STOP

1. Walk around Plant inspection. Verify that Main Circuit Breaker is open. Place Exciter switch in U.S. bypass position. Set inhouse breaker off.

2. Manually roll over power train and re-install guard.

3. Log engineering data.

4. Operate pump #1 to prime lube oil system.

5. Close battery switch.

6. Reset ES relav.


8. Check nitrogen pressure. Recharge if necessary.


10. While holding Start switch on, operate pump #3 to open Automatic Stop valve part way. Watch Tachometer and driving pressure. Watch oil pressure to bearings. Release Start switch when pressure exceeds LOP point (~12 psig.). Plant will continue to run, throttled by Start/Stop valve.

11. Verify that lube oil reservoir temperature is above 60°F. Otherwise, wait until it is. Then continue. Open Automatic Stop valve to bring Plant to standard operating speed, shifting control to the Governor and Throttle. Open Automatic Stop valve fully. Monitor RPM and adjust Governor as necessary.

Date: ____________________________  Test Staff: ____________________________

Notes:
12. Turn on Exciter. Watch Voltmeter and Frequency Meter at Power Plant. Look for Ammeter response. Adjust frequency to 60 Hz with Governor. Adjust voltage to 480 V.

13. Check Oil Cooler air flow.

14. Cycle the Exciter to check the Governor response. Monitor effect on frequency.

15. Operate plant three hours. Log engineering data. Refer to check-list in Appendix. Verify Greaser operation.


17. Turn off Data Logger. Turn off Intercoms.

18. Press ES button to open Battery circuit.


Date: Test Staff:

Notes:
PROCESS NOMENCLATURE

- $t_R$: recycle liquid temperature, °F
- $t_s$: separator water supply temperature, °F
- $t_o$: combined separator water supply and recycle temperature, °F
- $t_f$: liquid feed temperature, °F
- $t_1$: expander inlet temperature, °F
- $Q_1$: expander inlet quality, %
- $P_1$: expander inlet pressure, psia
- $P_f$: liquid feed pressure, psia
- $T_{sup}$: amount of superheat of the steam, °F
- $P_v$: steam feed pressure, psia
- $P_s$: separator pressure, psia
- $P_w$: waste liquid pressure to flow control valve
- $\dot{m}_w$: waste liquid flowrate, 1000 #/hr
- $\dot{m}_r$: recycle liquid flowrate, 1000 #/hr
- $\dot{m}_s$: liquid flowrate from separator, 1000 #/hr ($= m_f - m_r$)
- $\dot{m}_f$: liquid flowrate to inlet mixing manifold, #/hr or 1000#/hr
- $\dot{m}_v$: steam flowrate to inlet mixing manifold, #/hr or 1000 #/hr
- $L_s$: liquid level in separator, in.
- $L_w$: liquid level in waste tank, in.
- \%/h: rate of change of liquid level in waste tanks, in/hr
- Trt %: linear throttle position as percent of fully open
- kW: electrical output of alternator
- freq: frequency of electrical output
- eff %: engine efficiency of helical screw expander, actual shaft power/theoretical shaft power
- Brg t: temperature of high speed rotor thrust bearing, °F
P₂  expander outlet pressure, psia

\( t₂ \)  expander outlet temperature, °F

Q₂  expander outlet quality (steam fraction), %

\( t_v \)  steam feed temperature, °F
<table>
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<th>DATE</th>
<th>TIME</th>
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</tbody>
</table>

| 1     | K.W. |
| 2     | E.   |
| 3     | P.S.G. |
| 4     | APROX SEAL |
| 5     | AP'S |
| 6     | MALE H P SEAL |
| 7     | P. |
| 8     | FEMALE H P SEAL |
| 9     | P. |
| 10    | MALE L P SEAL |
| 11    | P. |
| 12    | FEMALE L P SEAL |
| 13    | P. |
| 14    | MAIN OIL PUMP |
| 15    | P. |
| 16    | OIL SUPPLY |
| 17    | P. |
| 18    | OIL SUPPLY |
| 19    | T. |
| 20    | GREASE |
| 21    | T. |
| 22    | GEAR N°1 |
| 23    | T. |
| 24    | GEAR N°2 |
| 25    | T. |
| 26    | GEAR N°3 |
| 27    | T. |
| 28    | GEAR N°4 |
| 29    | T. |
| 30    | SAFETY N.2 |
| 31    | P. |
| 32    | SAFETY OIL |
| 33    | P. |
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| 38    | OIL RESEVOIR LEVEL |
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| 40    | MAIN FILTER N°1 |
| 41    | 10 |
| 42    | MAIN FILTER N°2 |
| 43    | 10 |
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| 45    | P. |
| 46    | WATER FILTER |
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| 52    | FLUSH WATER FLOW N°3 |
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| 55    | 10 |
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