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HIGH-SPEED ELECTRICAL MOTOR EVALUATION

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1.0 INTRODUCTION

This report describes the results of subtask 2.1, "High-Speed Electrical Motor Evaluation," of DOE Contract DE-FCC7-88ID2788, "Assessment and Development of an Advanced Heat Pump for Recovery of Volatile Organic Compounds." Under this task, MTI conducted a general review of state-of-the-art high-speed motors. The purpose of this review was to assess the operating parameters, limitations and performance of existing motor designs, and to establish commercial sources for a motor compatible with the requirements of the Brayton-cycle system. Assisting MTI in the motor evaluation were Dr. Patrick McCleer, PE, McCleer Power, Inc., Jackson, Missouri; and Dr. Ewald Fuchs, Professor in the Department of Electrical and Computer Engineering, University of Colorado, Boulder.

Figure 1 shows the task structure. After the motor requirements were established, a list of motor types, manufacturers and designs capable of achieving the requisite performance was compiled. This list was based on an in-house evaluation of designs and assistance from Dr. McCleer.

Following the establishment of these options, a technical evaluation of the designs selected was conducted by Dr. McCleer and Dr. Fuchs. In parallel with their evaluations, MTI focused on the establishment of commercial sources.

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Figure 1. Task 2.1 Flow

2.0 SUMMARY

Following consultation with Dr. Patrick McCleer and Dr. Ewald F. Fuchs, as well as MTI experts, MTI has determined that three different types of high-speed motors are viable candidates for the Brayton cycle heat pump machinery module. They are:

- A commercially available squirrel cage induction motor manufactured in quantity by Reuland Electric Company
- A solid-rotor induction machine designed and built by MTI in limited quantity.
- A homopolar motor, known as the Hi-Drive, manufactured by REM Technologies, Inc.

REM's motor, because of its homopolar design, has potential for excellent high-speed performance and could cover the entire application range anticipated for the heat pump; however, this motor has only been built in 5-hp sizes. A 25-hp motor is currently being developed, and larger sizes are planned. Near term, the squirrel cage induction motor designs are the preferred options.

The second option is the MTI solid-rotor squirrel cage motor. Two of these motors have been built and operated at 180 hp, 23,000 rpm. Dr. McCleer's analysis presented in Appendix A indicates that this motor design is capable of 400 hp or more at efficiencies of 85% or better. The cost of this motor in production is much more uncertain than the Reuland motor.

The Reuland motor most nearly satisfies all the desired characteristics for the heat pump machinery. It is off-the-shelf hardware available at a very reasonable price. Reuland's current catalog lists motors that will cover approximately 80% of the heat pump's expected application range. The use of this motor takes advantage of Reuland's position in the machine tool spindle drive market, which assures the heat pump of volume production pricing with small-quantity orders. This would not be currently possible with the other two options. Finally, MTI concludes that the high-speed motor is neither a technical nor an economic barrier to the development of the integrated motor turbocompressor concept and recommends the use of the Reuland motor for the prototype system.

3.0 HIGH-SPEED MOTOR REQUIREMENTS

3.1 Performance Requirements

A key feature of the MTI/Air Products and Chemicals, Inc. (AP) advanced heat pump for volatile organic compound (VOC) solvent recovery is an innovative turbomachine that includes an integral electric motor mounted on the same shaft with the compressor and turbine wheels.

As shown in the simplified system schematic, Figure 2, the air solvent mixture from the process is precooled to reduce compressor work. After exiting the compressor, the air/solvent mixture is sequentially cooled as it passes through a cooler, regenerator, and condenser such that the temperature drops to the dew point required to condense the solvent. The gases, which are still at elevated pressure, are then expanded through the turbine. This generates power to drive the compressor impeller which is mounted on the same shaft. The expansion process lowers the temperature further, causing further condensation of the solvent. The additional condensed solvents are separated from the gas stream after exiting the turbine. The clean air is returned to the process through the regenerator, where a portion of its original heat content is restored. The motor, located between the turbine and compressor and on the same shaft, provides the balance of the power required to drive the compressor.

The performance requirements of the integrated motor can be specified in terms of shaft horsepower and speed. The primary factors that affect horsepower are air volume, the solvent condensing temperature, and the balance-of-plant design. It is known that (1) horsepower requirements increase in direct proportion to air flow, (2) that for a given system, lower temperatures require higher pressure ratios and increased horsepower, and (3) that the efficiency of system components can significantly influence horsepower requirements, e.g., turbine and compressor efficiencies and regenerator effectiveness.

The affect of speed on motor performance can be described in terms of system flow and pressure ratio. For any combination of system flow and pressure ratio, there is an optimum speed for best compressor efficiency, turbine efficiency and overall system efficiency. Generally, the speed for the optimum system efficiency (lowest system horsepower) favors the speed for optimum turbine performance.

VOC = Volatile Organic Compounds

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Figure 2. MTI/AP System Schematic (Baseline System)

The specific characteristics of the application will determine the required motor performance. Later in the Phase I effort, an application site will be selected and a preliminary turbomachine design will be developed. Until then, the MTI/AP objective is to establish maximum flexibility with regard to process applications.

Figure 3 shows the application envelope that is being considered during Phase I and the relationship between application variables and motor performance requirements. As shown in this figure, there is an optimum speed and minimum motor horsepower requirement for each application, as defined in terms of cfm and pressure ratio.

Using the required motor performance characteristics shown in Figure 3, the objective of the task 2.1 motor performance evaluation was:

1. The establishment of a motor type for which current designs allow maximum application coverage.
2. The establishment of relationships or thresholds between performance, commercial availability, and cost for use in the optimization of a commercial system design.

Although the evaluation covered the complete envelope (50 - 500 hp) shown in Figure 3, the effort was focused on motors between 75 and 150 hp. This range was chosen because it is compatible both with the base system concept and with alternative system configurations, such as inert gas carbon bed dissorption. Also, systems designed in this range offer the best potential for application flexibility from a single frame size via flow adjustment for small application sizes, and parallel unit operation for larger system sizes.

3.2 Mechanical Interface Requirements

Packaging the motor on a common shaft relieves the motor manufacturer of the responsibility for supplying the high-speed rotor bearings and stator frame. The supply of motors for this product is therefore analogous to the supply of rotor/stator sets for hermetic refrigeration equipment, canned motor pumps, and submersible pumps. In the U.S., large numbers of motors are supplied as partial motors for a wide variety of products. Usually, in addition to the responsibility for bearings and rotordynamics, the packager also takes responsibility for motor cooling per the manufacturer's recommendations.

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Figure 3. Turbocompressor Operational Envelope; Horsepower and Speed

In the task 2.1 motor evaluation, the survey was primarily concerned with performance; therefore, wide latitude was given to potential motor suppliers in areas unrelated to performance.

Table 1 presents a summary of the motor design requirements that were presented to suppliers in the task 2.1 motor survey.

Table 1. Motor Design Requirements

Desired horsepower/speed envelope

Torque/Speed:	Driven load is a centrifugal compressor. Torque required (from motor) is proportional to N^2
Duty Cycle:	Normally continuous operation at rated load (7000 hr /yr) Maximum 3 starts per hour
Speed Control:	To be determined
Motor Voltage & Drive Requirements:	To be determined by motor supplier
Motor Shaft-Coupling:	The compressor impeller will be directly attached to (and balanced) with the rotor. Shaft may be supplied by motor manufacturer or Buyer (to be determined)
Bearing & Rotor Support:	Buyer will design and supply rotor support system to meet requirements
Cooling:	Motor may be liquid or air cooled. Air at -60°F available from driven load for coolant, if desired.

4.0 CONSULTANTS' EVALUATIONS

In the task 2.1 evaluation, consulting services were sought to extend the scope of the review beyond those areas of MTI design experience (i.e., homopolar and squirrel cage induction motors) to ensure that technical and commercial options were not overlooked. Both consultants had previously provided input to DOE, Idaho Falls on the general state of the art of high-speed motors. The subtasks defined by MTI requested a continuation of this assessment, in conjunction with the commercial goals and required motor performance criteria described in Section 3.0 of this report.

Following a review of the technical merits and commercial options for motor types capable of meeting the required performance, a technical evaluation of selected options was conducted for the purpose of validating performance and design compatibility.

One of the motor types included in this evaluation was a solid rotor, squirrel cage induction motor design owned by MTI. The design and initial prototype of this motor were purchased from the General Electric Company. MTI built, tested, and delivered two gas bearing helium circulators using this basic motor design.

Following the initial selection of the best options and motor types, it became apparent that this solid-rotor design had the potential to meet the requirements of the advanced Brayton heat pump product in applications above 150 hp as well as below 150 hp. Both consultants were given performance test data and manufacturing detail drawings of this motor. MTI's evaluation of the manufactured cost of this motor is provided in Section 5.0. The remainder of this section discusses the consultants' evaluations.

4.1 Evaluation of Motors Below 150 hp

The work statement directed to Dr. McCleer requested that he extend his evaluation of the five motor types presented in his report to DOE, Idaho Falls to the selection of one or two specific motors or options that, in the opinion of the consultant, were most likely to meet the dual performance and commercial availability criteria required of the Brayton heat pump motor. Commercial design criteria were to meet the required proforma considerations (i.e., development), manufacturability (i.e., relative cost) and commercialization and manufacturing options (i.e., are the owners of the designs in the commercial business?). Table 2 presents an annotated summary of the options.

Table 2. Existing High-Speed Machines or Machine Designs

Machine	Description and/or Specifications	Vendor	Recommended Approach for Implementation of Design	Commercialization or Manufacturing Options	Comments
Squirrel Cage Induction	200 hp, 24,000 rpm (High-Temp. Machine)	MTI	Redesign for Lower Temperature Operation	MTI Owns Design; MTI Build	Least-Cost Option
	350 hp, 20,000 rpm 15 hp/lb	Sundstrand	Recalculate Performance at Lower Output and Higher Speeds	License Design; MTI or Vendor Build	Same Technology as MTI Machine
Wound Rotor Synchronous	60 hp, 24,000 rpm Salient Pole (for F18 Fighter)	Allied-Bendix	Power Limit for Salient Pole Design Approx. 100 hp at 20,000 rpm; May Need 2 Machines	Mature But Difficult Technology; Vendor Build	Expensive
	1300 hp, 35,000 rpm Wound Rotor (Preliminary Design)	Allied-Bendix	Scale Design for Lower hp	Difficult Technology; Vendor Build	Expensive
Homopolar Inductor	15 hp, 25,000 rpm High Windage Loss Rotor	REM	Scale Design for 200 hp Redesign Rotor	Vendor Build	Less Expensive than Active Rotor Machines
	125 hp, 41,000 rpm High Windage Loss Rotor, Poor Cooling System	U.S. Army Fort Belvoir	Redesign Rotor and Cooling System	MTI or REM Build	Less Expensive than Active Rotor Machines
Permanent Magnet Synchronous	33 hp, 26,000 rpm Samarium Cobalt	Garrett	Scale Design for Higher Output	Vendor Build	Less Expensive than Wound Rotor Machines
	60 hp, 50,000 rpm Samarium Cobalt	Sundstrand	Scale Design for Higher Output and Lower Speeds	Vendor Build	Less Expensive than Wound Rotor Machines
	30 hp, 15,000 rpm Neodymium Iron Axial Gap Machine	DOE Oak Ridge	Scale Design for Higher Output	License Design from Oak Ridge; MTI Build	Less Expensive than Radial Gap Machines

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Professor McCleer's evaluation concluded that squirrel cage induction machines were the best option for the turbomachine, followed by homopolar inductors. These conclusions were based on an overview of machines suitable for the turbocompressor drive and a somewhat detailed evaluation of an existing design for a 24,000 rpm motor. The complete evaluation is presented in Appendix A. The following paragraphs summarize key elements and conclusions of the evaluation.

4.1.1 Present Status of High-Speed Brushless Electrical Machines

The only current, large-scale producers of high-speed electrical machinery are in the military and aerospace industries. The major corporate players in these fields and the types of machines that they manufacture (to Dr. McCleer's knowledge) are:

- Allied Bendix Aerospace, Eatontown, New Jersey; wound rotor synchronous
- Sundstrand, Rockford, Illinois; permanent magnet and wound rotor synchronous and squirrel cage induction.
- Garrett AiResearch, Torrance, California; permanent magnet and wound rotor synchronous and squirrel cage induction.
- Westinghouse, Lima, Ohio; permanent magnet and wound rotor synchronous.

Each of these manufacturers is capable of producing machines in the 15,000 to 50,000 rpm range at power levels up to the megawatt level.

By far the most mature technology is the wound rotor, salient pole synchronous machine. However, most machine designers think that at the 100-kVA level and above these machines cannot be built for shaft speeds in excess of approximately 30,000 rpm. At higher speeds, the trend is to cylindrical rotor (turboalternator type), wound rotor synchronous machines and to permanent magnet synchronous machines.

The wound rotor machines presently in production are all intended for application in the aircraft industry or the military. Both of these groups are non-price sensitive, as compared to industrial user groups. Thus, even though the machine designs exist, and there is manufacturing experience for the machines, they will be expensive.

4.1.2 The Homopolar Inductor Machine

The homopolar inductor machine is synchronous with dc field windings on the stator rather than on the rotor as in a standard synchronous machine. The rotor can be a simple tooth-slot, salient pole-like structure which can be machined from a single piece of ferromagnetic steel. At first glance, this rugged construction seems to indicate an ideal candidate for very high-speed applications. However, the machine does not make full (bipolar) use of its field flux, which results in a larger machine design as compared to more standard synchronous machine designs having an equal power-speed rating basis. The homopolar machine will always be significantly larger at an equivalent design point. Therefore, windage losses, which increase as a function of N^3 (speed) and D^4 (diameter), became very large at high speeds and horsepower. This windage loss for the open salient structure would greatly reduce the machine's efficiency. To mitigate the windage loss, nonmagnetic filler material would have to be attached to the inter-pole area of the rotor. This type of construction would add considerable cost to the rotor, thus negating one of the principal arguments for the machine's usage.

4.1.3 The Squirrel Cage Induction Machine

From the standpoints of both cost and experience, the squirrel cage induction machine is unexcelled. The efficiency and power density of the squirrel cage machine will always be less than a well-designed permanent magnet synchronous machine, but the ruggedness and low cost of the squirrel cage rotor outweigh these advantages in most applications. Since the "package cost" is deemed paramount in the present application, the squirrel cage motor is the recommended machine. Also, as a practical bonus, MTI owns the design for, and has experience with, a nominal 180 hp, 24,000 rpm motor that was designed to drive a high-temperature helium compressor.

The existing MTI squirrel cage machine has a rotor constructed of solid iron, unlike the laminated rotor found in standard low-frequency induction machines. The use of an unlaminated rotor body eases rotor construction and increases rotor strength, but it also introduces additional rotor loss due to enhanced rotor eddy currents. These rotor eddy currents are reaction currents induced by the radial flow of magnetic flux due to stator winding currents. They flow in an axial direction in the rotor body (as do currents in the rotor bar conductors) and contribute to the development of mechanical torque. But since these eddy currents flow through the rotor iron, which has a higher resistivity than the

copper of the rotor bars, their I^2R heating increases the rotor loss above that attainable in a laminated structure. At very low slips, however, the major portion of the induced rotor currents flow through the copper cage conductors, and the total rotor I^2R loss is only slightly above that of an equivalent laminated structure.

The performance of the machine was evaluated by circuit analysis using measurements and test data supplied to the consultant. By establishing the element values of the equivalent circuit, the machine's performance at any frequency of excitation can be accurately predicted. This analysis, given in Appendix A, shows that at 400 Hz (24,000 rpm synchronous speed) and a stator voltage of 460 V rms, the machine operates at a slip speed of 175 rpm, develops 169 hp at an electrical efficiency of 90%, and an input power factor of 80%. The analysis concludes that the machine or a slight variation of it is capable, electromagnetically, of substantially greater output, depending on the thermal rating of the cooling system.

4.2 Evaluation of Motors Above 150 hp

The work statement directed to Professor Fuchs requested an evaluation of the potential for increasing the horsepower of the solid-rotor machine. Two specific design points were suggested as targets: 200 hp at 20,000 rpm and 280 hp at 17,000 rpm. Because the induction machine produces essentially constant torque (at constant slip and rotor flux), the horsepower capability goes up directly with speed. The target performance points offer an extension to the application coverage of the solid-rotor motor; however, they would require a significant increase in torque. Professor Fuchs' initial draft evaluation suggested several methods of improving the performance of the design, and he requested that MTI evaluate the mechanical impact of these options prior to the completion of his report. MTI's subsequent mechanical analysis indicates that the suggested modifications are easily achieved within the allowable stress limits of the rotor material. Key elements of his draft analysis are presented below.

- The conservative approach to the achievement of the increased torque is to increase the active length of the machine from 5.5 in. to 8.72 in. With this increase, the 280 hp at 17,000 rpm performance can be achieved.
- Redesign of the rotor for increased flux penetration depth offers the potential for a significant increase in efficiency and power. Professor Fuchs offered several specific rotor design configurations for this purpose. (These designs were the subject of the mechanical stress evaluation by MTI). The design modifications could provide increased power, increased efficiency at design speed, a minimum loss in starting torque, and superior rotor cooling. In the

recommended design, a double squirrel cage is employed using 44 rather than 24 rotor conductors.

- Further improvement in efficiency, and therefore, power, can be achieved through modification of the motor stator. The design improvements include redesign of the end regions to reduce stray losses and to reduce the iron stator losses by increasing the cross section of the teeth and yoke.

5.0 COMMERCIAL OPTIONS

During the task 2.1 evaluation, two options for the commercial supply of motors meeting the performance requirements of the Brayton heat pump turbomachine were established in addition to the Hi-Drive motor described in the MTI/AP proposal. The first option to be established was the manufacture of the solid-rotor design owned by MTI. The second option was established through a search of manufacturers.

5.1 REM Technologies

At the time of the MTI/AP proposal for advanced Brayton heat pump development, MTI identified a new motor as a probable component of the turbomachine. This product was a homopolar motor called the Hi-Drive manufactured by REM Technologies. REM's business plan for the recently introduced motor called for the near-term scale-up of their existing small, high-speed motor to include a full commercial product line of motors which easily met the requirements of the advanced heat pump application envelope.

The established frame sizes and performance envelope of the Hi-Drive product line is shown in Figure 4. For comparison, a proposal was requested from REM for a motor rated at a performance point comparable with other alternatives. The potential performance of the Hi-Drive motor far exceeds the requirements of the heat pump turbomachine. Unfortunately, REM's business plan to develop and demonstrate the larger motor sizes required is not on schedule. A summary of REM's offering* is listed below:

Design point:	115 hp @ 24,000 rpm
Scope:	Design, manufacture, assemble, test, deliver Hi-Drive motor and inverter/controller
Delivery:	Estimate 15 months
Pricing:	Fixed price • 1 prototype unit @ \$363,500 • 20 units @ \$79,500 each

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Figure 4. REM Motor Frame Sizes

5.2 MTI Solid-Rotor Machine

Following the establishment of the electromagnetic capabilities of the solid-rotor induction machine described in Section 4.0, an internal MTI technical review was made of the design. The original service duty of the motor was for direct coupling to a 650°F circulator impeller. The review indicated that the nominal rotor design speed of 24,000 rpm was extremely conservative, thereby leaving significant margin for an increase in speed and performance, or, alternatively, a relaxation in manufacturing tolerances and materials allowing a significant reduction in manufactured cost.

In the event that the solid-rotor design is selected for the advanced heat pump turbomachinery, the manufacturing procedure will be to individually subcontract the motor and stator from a source external to MTI; then, as with all motor options, assemble the components as part of the turbomachine.

Because the manufacture of the rotor is a machine shop procurement, it is likely that this component would be manufactured by or for Air Products as part of the turbomachine shaft. For the purpose of this report, the manufactured price of the rotor assembly has been established through manufacturing cost estimates and solicitation of quotations based on the existing manufacturing drawings. The design has not been adjusted for high-volume manufacturing.

For comparative purposes, the cost of a high-frequency inverter drive must be added to the price of the solid-rotor option. The cost estimate for the MTI solid-rotor motor is presented below.

Design Point:	125 - 150 hp, 24,000 rpm
Delivery:	Estimate 6 months
Pricing:	Type/Fixed
Rotor assembly:	quantity, one; \$12,000
Stator assembly:	quantity, one; \$3,500
Inverter: (150 kVA)	\$12,600
Total:	\$28,100
20-unit pricing (estimate)	
Rotor assembly:	\$9,000, each
Stator assembly:	\$2,700, each
Inverter:	\$11,700, each
Total:	\$23,400

5.3 Manufacturer Search

Following the establishment of the motor performance envelope identified in Section 3.0, a considerable effort was made to locate manufacturers having existing product lines capable of meeting the required performance.

Manufacturers of state-of-the-art, high-speed electric machines, such as aircraft-type, synchronous wound electric generators, were contacted. Allied Bendix was the only manufacturer of these machines who expressed some interest in converting an aircraft generator design to that of an electrical motor. Aircraft generators in excess of 20 kW are a low-volume manufacturing item. Engineering and development would be required and the eventual manufacturer cost would be expected to be very high. Other manufacturers, such as Sundstrand and General Electric, indicated that the technical motor requirements were achievable but they currently had no offering. Development would be required and, due to current engineering loading, could not be undertaken for periods ranging from nine months to one year.

The primary industrial market for high-speed electrical motors is for spindle drives -- boring, drilling, cutting, grinding, and milling. These drives are machine tool building blocks for the metal working and woodworking industries. Generally speeds are under 20,000 rpm and motor horsepower below 75. This is not a large-volume business and motors are frequently supplied to the spindle drive manufacturer as partial motors for manufacture into the spindle drive. Sources of these partial motors have in the past included Louis Allis and Westinghouse. Recently Louis Allis closed his manufacturing facility and suspended, indefinitely, production of this product line. Westinghouse sold its manufacturing facility and product line in Lima, Ohio to Reliance Electric.

Currently the leading supplier of high-speed partial motors for spindle drives is Reuland Electric. Reuland Electric's product line in both inverter-duty NEMA framed motors and partial motors is impressive and far exceeds the normal performance requirements of industrial spindle drives. Custom inverter drive motors in standard NEMA frame sizes are available rated at speeds from 30,000 rpm, 25 hp to 12,000 rpm, 200 hp. Reuland's product line of partial motors consisting of wound stators and shaftless rotors is considerably more extensive, and it is this product line that provides an extremely good fit with the requirements of the advanced Brayton heat pump turbomachine.

Reuland Electric is a manufacturer of a wide variety of electric motors, including gear motors, brake motors, wound rotor motors, fluid shaft motors, as well as the inverter-duty and partial motor product line. The company has annual sales of \$20 to \$30 million, and it employs 285 people in three manufacturing facilities in Industry, California, Howell, Michigan, and Cincinnati, Ohio. The company has been in business for over forty years, and 100% of the capital stock is owned by the Reuland family. According to Richard Flowers (Technical Sales, Cincinnati, Ohio) the inverter-duty and high-speed partial motor products represent \$5 to 6 million annually in business. Partial motors for this project would be built in Cincinnati.

The rating of a partial motor is a shared responsibility between the motor supplier and the equipment manufacturer, primarily because rating is impacted by motor cooling. Maximum shaft speeds are established by Reuland. Provided that cooling is adequate and motors are driven at a constant potential-to-frequency ratio (V/Hz), load may be increased in direct proportion from the base 3,600 rpm rating. It is expected that the horsepower ratings required by the advanced heat pump product line motors will be liquid cooled and auxiliary blower force ventilated. Reuland has provided several preliminary frame size selections and costs for motors meeting the requirements of selected turbo-machine performance points. Appendix B contains data on the complete, partial motor product line. For comparison to the REM and MTI motors, a summary of the Reuland motor, rated at 24,000 rpm and 125 hp, is provided below.

Motor design point:	24,000 rpm, 125 hp
Reuland frame size:	800 - 1240
Maximum horsepower:	133 hp (20 x 24,000/3600)
Scope:	Motor with cold rolled-steel shell, special bore, key way, square rotor ends, high-frequency low-loss laminations, 460 V, 3-phase, 400 Hz
Delivery:	14-16 weeks
Price:	quantity, one; \$2,337
Inverter:	\$12,600
Total:	\$14,937
20-unit pricing:	
Motor:	\$1,986, each
Inverter:	\$11,700, each
Total:	\$13,686

6.0 MOTOR COMPARISON AND RECOMMENDATIONS

6.1 Comparison

Three commercially available motor types have been evaluated as being capable of integration into the advanced Brayton heat pump turbomachine and providing the requisite performance for compatibility with a significant percentage of applications. These motor types are:

- Hi-Drive - a homopolar motor from REM Technology
- Solid-rotor induction - motor to be built by MTI/Air Products
- Reuland Electric - a full family of inverter-duty, high-speed motors

There are significant differences in the application flexibility, commercial status and cost of these options. Figure 5 shows the overall performance capabilities of these options relative to the system application envelope.

6.2 Recommendations

6.2.1 Third-Ranked Option

The REM Hi-Drive motor has the superior speed and performance potential; unfortunately, this potential has only been demonstrated in small sizes. Also, this additional performance is not required to meet the currently established application envelope.

Because alternative options more adequately meet the performance requirements and immediate commercial goals of the program, the Phase I preliminary design will not be based on the Hi-Drive motor. An effort will be made, however, not to preclude the future utilization of this motor, should applications require the higher speeds and horsepower available from this design.

6.2.2 Second-Ranked Option

The MTI solid-rotor squirrel cage motor currently exists in only one fully developed and demonstrated frame size. The documented performance capabilities of this frame size are, however, very well matched to the center of the targeted application envelope. Analysis has shown that the design is conservative, and with little or no modification the

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Figure 5. Application Coverage of Motor Options

performance can be extended. The solid-rotor design allows for a hollow shaft (minimum weight) which can be an advantage in a machine incorporating gas bearings.

There are pros and cons to the commercial status of the solid-rotor motor. Because the manufacturing design is owned by MTI and components can be competitively bid and manufactured by dozens of sources, commercial availability is assured. The negative aspect is that neither MTI's or Air Products' near-term business plans include entering the motor manufacturing business. Therefore, this motor will not achieve the manufacturing volume and low cost of a motor in an established product line.

The solid squirrel cage motor option will be maintained during the turbomachinery optimization task of Phase I. This option is currently in a backup position to the fully commercial Reuland Electric partial motor product line.

6.2.3 Recommended Option

The standard partial motor product line from Reuland Electric offers performance that covers approximately 80% of the estimated Brayton heat pump application envelope. Additionally, based on discussions with Reuland, there appears to be potential to extend the performance (speed capabilities) through the use of precision fabricated rotors. If required, this option may add up to \$5,000 to the standard rotor price.

The application screening and system optimization task of Phase I will therefore emphasize the establishment of a turbomachinery design capable of achieving the desired system performance utilizing motors available from this product line.

Evaluation of High Speed Electrical Machinery for Turbocompressor Drives

Patrick J. McCleer PE, McCleer Power, Inc. Jackson, Michigan

December 29, 1988

1 Introduction

This report contains:

- a short review of existing technology in high speed electrical machines suitable for turbocompressor drives
- a somewhat detailed evaluation of an existing design for a 24,000 RPM squirrel cage induction motor
- a short discussion of solid-state inverter drives for use as power sources for high speed AC machines.

2 High Speed Electrical Machines

This section is a short summary of the present status of medium power, high speed electrical machines. We will define medium power, high speed electrical machines as motors or generators with ratings of 10 to 500 HP and shaft speeds of 15,000 RPM or more.

In short, aside from high speed alternators produced for the military or the aerospace industry, there are very few medium power, high speed machines produced worldwide. Those that are manufactured commercially are specialty motors for high speed machine tools such as grinders. The principal reasons for the lack of these machines have been cost and a very limited need. A high speed AC motor requires a high frequency power supply, usually a solid-state inverter which, in the past, has been a very costly item. However, recent advances in power semiconductor devices and microcomputer control

have driven down the system costs of variable speed drives and peak motor speeds have been creeping upward, past their previous synchronous, 60 Hz limit. But still, even with drives with higher available drive frequencies, there are few loads which require shaft speeds in excess of 10,000 RPM. A turbocompressor, however, works best and requires minimum volume when operated at high speeds. As such it is an ideal direct drive, mechanical load for a high speed motor. The high speed motors considered in this section are all suitable candidates for turbocompressor drives.

2.1 Review of the Different Types of High Speed Electrical Machines

Figure 1 is a "family tree" of large electrical machines. In general, the foremost distinction between AC and DC machines, excluding the AC Homopolar machine, is the fact that the full machine line current must be "wired" through brushes to the rotating element of a DC machine while the full machine line current connects to the stationary member (stator) of an AC machine. This fact alone leads us to dismiss all DC machines, the AC homopolar machine, and all slip ring AC machines from consideration for very high speed applications. The brush loss and wear at high speeds could not be tolerated. All high speed machines must be "brushless." A short description of candidate high speed AC brushless machines follows:

AC Synchronous: Wound Rotor Wound rotor synchronous machines can be further subdivided into smooth (cylindrical) and non-smooth (salient pole) rotor machines. Smooth rotor machines are in general of higher speed and lower in pole order when compared to salient pole machines. Both versions can be made brushless through the use of a small, auxiliary, co-rotating, inside-out (stationary DC field, rotating multi-phase power windings), rectified output AC alternator which feeds the rotor DC field winding of the larger machine. The rotor in a synchronous machine follows or leads in synchronism the rotating magnetic field produced by multiphase stator winding currents. Therefore to use the machine as a variable speed drive the rotor position must always be known such that the drive frequency can remain in "sync."

AC Synchronous: PM (Permanent Magnet) This machine, sometimes referred to as a "brushless DC machine," is identical in operation to a wound rotor synchronous machine with a fixed level of rotor excitation current. Rotor DC flux is produced by rotating permanent magnets which are either mounted on the rotor's outer surface or embedded within the rotor structure

(along with suitable magnetic flux barriers) such that the PM flux paths are in a radial direction through the stator windings. With the commercial introduction of high strength permanent magnets such as samarium-cobalt and neodymium-iron-boron these machines have quickly become prime contenders in all areas of variable speed drive applications. This machine has the capability of highest efficiency operation all electrical machines. This is due to the lack of a loss mechanism in the production of magnetic excitation.

AC Synchronous: Reluctance If the DC field winding in a salient pole synchronous machine is open circuited the machine will continue to produce torque in the motoring mode or electrical power in the generating mode if magnetizing currents can be drawn from the load or the drive connected to the stator terminals. A torque will be produced to maintain a constant flux - minimum energy system (minimum stored magnetic energy within the rotor - rotating stator magnetic field system) and the rotor will tend to remain in synchronism with the rotating magnetic field produced by the multiphase currents within the stator windings. A reluctance machine is similar in construction to a wound rotor salient pole machine except for its complete lack of rotor windings. The rotor is a simple, ferromagnetic salient structure. In steady-state operation there are no rotor losses but the available power from the same frame size machine is somewhat lower than a machine which supplies DC rotor flux, such as the wound rotor machine or the PM machine.

AC Synchronous: Homopolar Inductor This machine has a rotating DC flux that is produced by a DC field winding which is mounted on the stator of the machine. Field flux passes both radially and axially through both the stator and the rotor structures. The rotor poles essentially "pull" the radial components of the field flux around the inner surface of the stator, inducing voltage within the distributed stator windings. From the stator terminals the machine appears as a standard synchronous machine, however the flux variation within the stator windings is unipolar, not bipolar, varying only from a maximum to a minimum value of the same algebraic sign. Therefore a homopolar inductor machine must be larger than (approximately twice as large as) a similarly rated, power and speed, standard synchronous machine. There are variations of this machine, the heteropolar inductor machine and the flux-switch machine, but the principle of excitation flux supplied by stator side windings is the same in all versions. There is further discussion on this class of machine in the next section of this report.

AC Induction: Squirrel Cage Induction machines produce rotor winding currents through transformer like action between the rotor and the stator

windings. Under motor operation the rotor speed is slightly less than that of the synchronously rotating magnetic field produced by the stator winding currents. The difference in these two rotational speeds is referred to as the "slip" speed. The rotor windings then "cut" through, at the slip frequency, a moving magnetic field, inducing rotor currents at the slip frequency as in a transformer operating at the slip frequency. The rotor currents react with a component of the stator magnetic field to produce a motoring torque. In generator operation the rotor speed is slightly greater than the synchronous speed and the slip is negative, but the transformer like action is the same as in motor operation. As in the reluctance machine magnetizing currents must be supplied from the load or source connected to the stator terminals. Squirrel cage rotors are composed of circumferentially symmetric bar conductors placed within slots on the rotor surface or near the rotor surface within the rotor iron. These bar conductors are shorted together at the rotor (axial) ends. This is an extremely rugged and inexpensive construction and in the main accounts for the fact that squirrel cage machines make up approximately 90 machines manufactured throughout the world.

2.2 Present Status of High Speed Brushless Electrical Machines

As stated earlier the only current, large scale producers of high speed electrical machinery are in the military and aerospace industries. The major corporate players in these fields and the types of machines that they manufacture (to the author's knowledge) are:

- Allied Bendix Aerospace, Eatontown NJ, wound rotor sync
- Sundstrand, Rockford IL, PM and wound rotor sync and squirrel cage induction
- Garrett Airesearch, Torrance CA, PM and wound rotor sync and squirrel cage induction
- Westinghouse, Lima OH, PM and wound rotor sync

Each of these manufacturers is capable of producing machines in the 15,000 to 50,000 RPM range at power levels up to the megawatt level.

By far the most mature technology is the wound rotor, salient pole synchronous machine. However, most machine designers think that at the 100

KVA level and above these machines cannot be built for shaft speeds in excess of approximately 30,000 RPM. At higher speeds the trend is to round rotor (turbo alternator type) wound rotor synchronous machines and to PM synchronous machines.

Most wound rotor synchronous machines use spray oil cooling to remove the heat developed by the DC rotor current needed to provide the magnetic excitation. This method of cooling may be incompatible with an integral compressor configured for solvent recovery. Alternate cooling methods would increase the price and therefore defeat the advantage of using an existing machine design. Also (we state again, for emphasis), the wound rotor machines presently in production are all intended for application in the aircraft industry or the military, both non price sensitive (as compared to industrial) user groups. Thus even though the machine designs exist, and there is manufacturing experience for the machines, they will still be expensive, particularly when compared to similarly rated (though slower) 60 Hz industrial machines.

We show in Table 1 an annotated summary of existing machine designs that may be suitable for turbocompressor drives.

3 Evaluation of Best Candidate Machines

Of all the machines listed in Table 1 the two simplest and therefore the two least cost candidates are the homopolar inductor machine and the squirrel cage induction machine. Of these two, for the reasons detailed below, we recommend the squirrel cage induction machine.

3.1 The Homopolar Inductor Machine

The homopolar inductor machine is a synchronous machine with DC field windings on the stator rather than on the rotor as in a standard synchronous machine. The rotor can be a simple tooth-slot, salient pole like structure which can be machined from a single piece of ferromagnetic steel. This type of construction leads to a very rugged machine design and therefore the machine, at first glance, seems to be an ideal candidate for very high speed applications. However, the machine does not make full (bipolar) use of its field flux and this results in a larger machine design, in comparison to more standard synchronous machine designs, on an equal power-speed rating basis.

Field flux in a stator phase winding in a homopolar inductor machine (or in its multi-pole version, the hetropolar inductor machine) pulsates from a maximum to a minimum value as a rotor tooth passes across the face of the stator winding. This pulsation effect is shown for an idealized 4-pole rotor, 12-slot 3-phase concentrated winding stator structure in Figure 2. In Figure 2(a) the rotor pole tooth is in such a position that the maximum field flux passes through the phase "a" windings. In Figure 2(b) the rotor has advanced 90 mechanical degrees and is in such a position that a minimum value of field flux passes through the "a" phase windings. The total variation of the flux passing through the "a" phase windings is shown in Figure 2(c). The voltage or back-emf induced in the "a" phase stator windings is then proportional to the derivative of this flux function with respect to time (or the rotor angle for constant speed operation). Note that the maximum rate of change of the flux through any one stator coil is proportional to the difference between the maximum and minimum values of flux through that particular coil. In the inductor machine this change is only between a maximum value, set by the magnetic saturation level of the machine iron, and a minimum value, determined by the difference between the rotor tooth and rotor slot air gaps.

An idealized 4-pole rotor, 12-slot 3-phase concentrated winding stator structure for the standard salient pole synchronous machine is shown in Figure 3. Similar to the inductor machine cases of Figures 2(a) and 2(b), the rotor flux is a maximum in the phase "a" winding at the rotor position shown in Figure 3(a) and minimum at the rotor position shown in Figure 3(b). But note that this minimum is a negative value of equal magnitude the peak positive value. The total variation of the "a" phase winding flux is shown in Figure 3(c) as a function of rotor angle. In this case the rate of change of the field flux through the stator coil is proportional to two times the peak flux value in any one direction, which is at least two times the value of the case for the inductor machine (assuming equal stator coil axial lengths and rotor pole face areas).

Thus for an inductor machine to have the same power rating at the same shaft speed as a standard synchronous machine, for similar stator structure and windings, the inductor machine must have a stator axial length of at least two times that of the standard machine. And this does not account, in the homopolar version, for the needed space for the circumferentially wound field coil which must also be placed within the stator structure. However, for equal power ratings and similar stator structure, an inductor machine operating at twice the shaft speed (and therefore twice the drive frequency),

of a standard machine should be of roughly equal size to the standard machine. Of course at even high speeds, the inductor machine will become even smaller. Since the standard machine could also be run at higher speeds the inductor machine will only have an advantage at very high speeds if its rotor construction (because of its seeming simplicity) leads to a more rugged, lower cost design. But at very high speeds the rotor cannot be the single material, simple salient structure, such as that shown in Figure 2. The windage loss for the open salient structure would greatly reduce the machine's efficiency. To mitigate the windage loss, non-magnetic filler material would have to be placed and attached to the inter-pole area of the rotor. This type of construction would add considerable cost to the rotor, thus negating one of the principal arguments for the machine's usage.

3.2 The Squirrel Cage Induction Machine

From the standpoints of both cost and experience the squirrel cage induction machine is unexcelled. The efficiency and power density of the squirrel cage machine will always be less than a well designed PM synchronous machine but the ruggedness and low cost of the squirrel cage rotor will outweigh these advantages in most applications. Since the "package cost" is deemed paramount in the present application the squirrel cage motor is the recommended machine. Also, as a practical bonus, MTI owns the design for, and has experience with, a nominal 180 hp, 24,000 RPM machine that was intended to drive a high temperature helium compressor. In the remainder of this section we evaluate the MTI machine by equivalent circuit analysis.

The existing MTI squirrel cage machine has a rotor constructed of solid iron (not laminated as in standard low frequency induction machines) with round beryllium-copper rotor bars placed in partially open slots near the rotor surface. the rotor bars are shorted at the rotor ends by beryllium-copper rings brazed to the bars and held in place by nonmagnetic alloy steel retaining rings. Beryllium-copper is used for the cage conductors because of the high temperature environment. For the present low temperature solvent recovery application standard, high conductivity, copper conductors can be used for the rotor bars, which will enhance the rotor efficiency correspondingly.

The use of an unlaminated rotor body eases rotor construction and increases rotor strength. But it also introduces additional rotor loss due to enhanced rotor eddy currents. These rotor eddy currents are reaction currents induced by the radial flow of magnetic flux due to stator winding

currents. They flow in an axial direction in the rotor body (as do currents in the rotor bar conductors) and contribute to the development of mechanical torque. But since these eddy currents flow through the rotor iron, which has a higher resistivity than the copper of the rotor bars, their I^2R heating increases the rotor loss above that attainable in a laminated structure. At very low slips however the major portion of the induced rotor currents flow through the copper cage conductors and the total rotor I^2R loss is only slightly above that of an equivalent laminated structure.

The approximate per phase equivalent electrical circuit for the MTI machine is shown in Figure 4. The rotor has two circuits, an eddy current branch with equivalent leakage reactance X_{eo}/s and equivalent resistance R_{eo}/s , where s is the rotor slip, X_{eo} is the eddy current rotor leakage reactance at unity slip, and R_{eo} is the eddy current rotor resistance at unity slip. The fact that the eddy current leakage reactance varies inversely with slip (contrary to the standard, non deep-bar, wound or cage rotor leakage reactance, which is not a function of slip) is due to the almost fully magnetically saturated regions of eddy current flow. See references [1] and [2] for explanations of this saturation effect. Note that these saturation regions are due to "large signal" effects and are not due to the "skin effect" which is a "small signal" effect wherein the iron permeability is assumed constant and large.

The second rotor branch in the equivalent circuit of Figure 4 represents the copper rotor bars. In this branch the leakage reactance X_r is not a function of slip but the resistance term R_r/s still varies inversely with slip.

The magnetizing reactance X_m is a nonlinear but weak function of the magnitude of the airgap flux ϕ_m . The magnetizing loss resistance R_{mo} is also a nonlinear but weak function of the magnitude of ϕ_m . We have included a frequency dependent factor which multiplies R_{mo} by the square root of the ratio of the stator frequency f to a reference frequency f_o (which in our case is 60 Hz). This multiplication factor accounts for the total variation of magnetization loss with excitation frequency. The choice of the exponent of the ratio f/f_o is a compromise, as the eddy current loss in the stator varies as the square of the excitation frequency and the hysteresis loss varies directly with frequency. Since the stator terminal voltage V_s , at full excitation, will vary directly with frequency, that is

$$V_s = V_{s0} \frac{f}{f_o}$$

where V_{s0} is the full excitation stator terminal voltage at 60 Hz, the power

consumed in the magnetizing loss resistor is approximately given by

$$\frac{V_{so}^2(f/f_o)^2}{R_{mo}\sqrt{f/f_o}} = \frac{V_{so}^2}{R_{mo}}(f/f_o)^{1.5}$$

which represents the compromise between eddy current and hysteresis loss.

The stator elements of the equivalent circuit are the stator resistance R_s and the stator leakage reactance X_s . These elements are not functions of the excitation level.

We can determine the element values of the equivalent circuit of Figure 4 by performing tests on the actual machine. This determination is made more difficult by the presence of the eddy current rotor elements. But as stated previously, at low values of slip very little current flows through the eddy current branch, so as a first order approximation we can neglect this branch altogether. The remaining elements are then determined from DC and low or zero slip measurements as follows:

1. The stator resistance is measured directly at DC at the stator terminals.
2. The magnetization elements R_{mo} and X_m are obtained from zero slip (synchronous speed), 60 Hz measurements by neglecting X_s . An iterative correction for X_s can be made after it has been determined in step 3.
3. The breakdown or pullout torque is not a function of R_r . Therefore by assuming $X_s = X_r$ a measurement of the breakdown torque will determine X_s and X_r . Note that this step is not valid if the breakdown torque does not occur at a sufficiently low value of slip, such that the eddy current elements can still be neglected.
4. Finally, the slip at which the breakdown torque occurs is directly proportional to, and therefore determines, R_r . An alternative method of determining R_r is to iteratively find a value which will give the correct slip at which a given amount of torque (rated torque, for example) is attained.

We have used the above procedure and MTI reduced voltage 60 Hz measurements¹ to determine the following element values for the MTI machine:

¹Reported in Appendix IV of "Motor Test Report for Helium Circulators for CFTL," supplied by MTI

$$\begin{aligned}
R_s &= 0.020 \, \Omega \\
X_s &= 0.046 \, \Omega \\
R_{mo} &= 5.990 \, \Omega \\
X_m &= 0.944 \, \Omega \\
R_r &= 0.008 \, \Omega \\
X_r &= 0.046 \, \Omega
\end{aligned}$$

The low slip calculated results using these element values are compared with experimental results (taken from Table I, page IV-21 of the previously mentioned MTI report) in Figure 5 for a 60 Hz stator voltage of 100 VRMS (line to line). The agreement with experiment is quite good. Comparison at higher values of slip for the same stator excitation is shown in Figure 6. As can be seen at slip speeds above approximately 300 RPM the agreement between the simple one rotor circuit rotor model and experiment begins to falter. At even higher values of slip speed the torque developed due to the rotor eddy currents would dominate and the simple one rotor circuit model would no longer be adequate.

We can use the approximate equivalent circuit model to accurately predict the machine performance at any frequency of stator excitation as long as we restrict our predictions to slip speeds of approximately 300 RPM and below. We show one such prediction in Figure 7. In this case we assume a 400 Hz stator voltage of 460 VRMS and the machine WYE connected, as in the 60 Hz experiments. Note that this excitation is not at the airgap flux level of the 100 VRMS, 60 Hz experiment. That is

$$\frac{100 \, V}{60 \, Hz} = 1.67 \, V/Hz$$

while

$$\frac{460 \, V}{400 \, Hz} = 1.15 \, V/Hz.$$

Even so, at a slip speed of approximately 175 RPM the machine is predicted to develop 169 hp (neglecting windage and friction loss) at an electrical efficiency of approximately 90% and an input power factor of 80%.

To show the potential of higher levels of excitation we have calculated the machine performance for a DELTA connection of the windings at the same 400 Hz stator voltage as the previous case, 460 VRMS (line to line). The results of these calculations are shown in Figure 8. Since we are using

a linear model the output will scale as the square of the magnitude of the stator terminal voltage. This factor of three in output can be seen in the results given in Figure 8. The equivalent V/Hz excitation using the DELTA connection is then

$$\frac{\sqrt{3} 460 V}{400 Hz} = 1.99 V/Hz$$

which is at the upper end of the excitation levels used in the 60 Hz experimental evaluation of the machine (see the saturation results given in Figure 2 on page IV-15 of the previously mentioned MTI report). Whether or not the machine can be driven in the steady-state at this level is dependent upon the thermal rating of the cooling system, the strength of the winding insulation, and the mechanical rating of the shaft and stator housing. But magnetically and electrically the machine as it stands, or even a slight variation of it, is fully capable of outputs of greater than 400 hp, at efficiencies of 85% or better, at shaft speeds near 24,000 RPM.

4 Inverter Drives for High Speed Motors

There are two main classifications of inverter circuits suitable for multiphase excitation of high speed AC machines: voltage source inverter (VSI) drives and current source inverter (CSI) drives. Both systems utilize a DC link input which is usually powered by AC line rectification.

A CSI drive requires a series reactor (inductor) in the DC bus to maintain an approximately constant DC line current. This current is then switched in a square wave fashion sequentially to the phases of the driven motor. A typical three phase CSI bridge circuit is shown in Figure 9. The solid-state switching devices need only be able to turn-on upon command and thus standard thyristors can be used. Current through the devices self commutates (turns-off) as it tries to reverse direction within the unidirectional conducting solid-state device structure. A major requirement of CSI circuits is the need for this reverse current which is referred to as commutation current. It can only be supplied by loads with a leading power factor such as an overexcited synchronous machine. Since an induction motor operates at a lagging power factor reactive compensation (capacitors) must be used to supply the needed commutation current. This requirement is commonly achieved by a slight modification of the standard CSI circuit by the addition of six capacitors and six power diodes. This modified circuit, also shown in Figure 9, is called a auto sequentially commutated CSI drive. However problems with this circuit arise (see reference [3]) when operation at frequencies

greater than 60 Hz is attempted. For this reason the thyristor CSI drive is not recommended for the present application.

In the VSI drive a capacitor, placed across the DC bus, maintains an approximately constant DC bus voltage. This DC voltage is then sequentially switched across the phase conductors of the driven motor. A typical three phase VSI circuit is shown in Figure 10. The solid-state devices are shown as bipolar transistors though, as indicated below, there are several suitable devices for this circuit. The diodes placed across each switching device in the reverse conducting direction carry circulating reactive currents and do not contribute to or participate in the real power transfer from the DC source.

The solid-state switching devices in the VSI circuit must be able to both close and open their switching path upon command. Suitable devices are:

- power bipolar junction transistor (BJT) and its cascade connection of two devices, referred to as the Darlington transistor
- power metal-oxide-semiconductor field effect transistor (MOSFET)
- insulated gate bipolar transistor (IGBT)
- gate turn off thyristor (GTO)
- normal thyristor (SCR) with auxiliary commutation circuitry
- MOS controlled thyristor (MCT), the newest power device.

The power and the voltage levels of the proposed drive (100 hp or greater and 460 VRMS) restrict the actual choice of devices to only a handful of device types and versions. Only the GTO and the normal thyristor can operate in drives for hundreds of hp but the Darlington and the IGBT could work at levels near 100 hp. The best device for the application will be the MCT, but its commercial introduction at these power levels is still approximately one to two years away. It is recommended that experience be developed with an IGBT drive at the 100 hp level. The IGBT has similar gate drive requirements to the MCT and the power circuit will also be similar. As the higher rated MCT devices are introduced the existing drive can be upgraded to higher power levels. If near term drives are required to function at the several hundred hp level then the GTO device must be utilized. For an excellent summary of present day power solid-state devices capabilities see reference [4].

5 References

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Table 1. Existing High-Speed Machines or Machine Designs

Machine	Description and/or Specifications	Vendor	Recommended Approach for Implementation of Design	Commercialization or Manufacturing Options	Comments
Squirrel Cage Induction	200 hp, 24,000 rpm (High-Temp. Machine)	MTI	Redesign for Lower Temperature Operation	MTI Owns Design; MTI Build	Least-Cost Option
	350 hp, 20,000 rpm 15 hp/lb	Sundstrand	Recalculate Performance at Lower Output and Higher Speeds	License Design; MTI or Vendor Build	Same Technology as MTI Machine
Wound Rotor Synchronous	60 hp, 24,000 rpm Salient Pole (for F18 Fighter)	Allied-Bendix	Power Limit for Salient Pole Design Approx. 100 hp at 20,000 rpm; May Need 2 Machines	Mature But Difficult Technology; Vendor Build	Expensive
	1300 hp, 35,000 rpm Wound Rotor (Preliminary Design)	Allied-Bendix	Scale Design for Lower hp	Difficult Technology; Vendor Build	Expensive
Homopolar Inductor	15 hp, 25,000 rpm High Windage Loss Rotor	REM	Scale Design for 200 hp Redesign Rotor	Vendor Build	Less Expensive than Active Rotor Machines
	125 hp, 41,000 rpm High Windage Loss Rotor, Poor Cooling System	U.S. Army Fort Belvoir	Redesign Rotor and Cooling System	MTI or REM Build	Less Expensive than Active Rotor Machines
Permanent Magnet Synchronous	33 hp, 26,000 rpm Samarium Cobalt	Garrett	Scale Design for Higher Output	Vendor Build	Less Expensive than Wound Rotor Machines
	60 hp, 50,000 rpm Samarium Cobalt	Sundstrand	Scale Design for Higher Output and Lower Speeds	Vendor Build	Less Expensive than Wound Rotor Machines
	30 hp, 15,000 rpm Neodymium Iron Axial Gap Machine	DOE Oak Ridge	Scale Design for Higher Output	License Design from Oak Ridge; MTI Build	Less Expensive than Radial Gap Machines

FAMILY TREE OF LARGE ELECTRICAL MACHINES

Figure 1.

(a)

(b)

(c)

Figure 2. Four-Pole Homopolar Machine

Figure 3. Four-Pole Standard Sync Machine

Figure 4. Per Phase Equivalent Circuit of MTI Machine

100 V RMS (L-L)
WYE CONNECTION

ROTOR SPEED (RPM)

60 Hz

Figure 5.

Figure 6.

460 V RMS (L-L)
WYE CONNECTION

ROTOR SPEED (RPM)

400 Hz

$P_{me} = P_{in} (B/P)^{1/2}$

Figure 7.

460 V RMS (L-L)
DELTA CONNECTION

ROTOR SPEED (RPM) 400 Hz

Figure 8.

CSI DRIVE CIRCUIT

Figure 9.

Figure 10. VSI Drive Circuit

Reuland Special A.C. Motors For Aerospace Applications

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drive

.3 hp, 24,000 rpm,
200V/400HZ
power train drive

50 hp,
25,000 rpm
184T, liquid
cooled, oil
mist
lubrication,
4 pole,
208V/
833HZ test
stand drive

.1 hp, 4/8 pole,
200V/400HZ wind
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motor

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SHAFTLESS PARTIAL MOTORS

For over 40 years, Reuland Electric has been an industry leader in the design and manufacture of custom motors, gear reducers and disc brakes; well known for our wide product scope, quality and capabilities. Partial motors consisting of precision manufactured rotors and stators are yet another indication of Reuland's flexibility and commitment to fulfilling marketplace needs. Maximum performance designs combined with time proven high quality materials and workmanship result in outstanding reliability and value.

The partial motor comprises two essential electrical components of an electric motor — the rotor and stator. Mechanical components such as the housing, end brackets, shaft, bearings and cooling apparatus are furnished by the equipment manufacturer. These components are ideal for built in power drives on equipment with limited space. The rotor is installed on the common shaft with the work piece resulting in compactness, lower inertia, elimination of couplings, transmissions, sheaves and belts. With no parts to couple together, alignment and guards are eliminated.

Performance is essentially the same as an induction motor but versatility is improved. Partial motors lend themselves readily to any practical diameter and length configuration since the rotor/stator set is not bound by conventional NEMA frame size limits. Typical applications include machine tools, spindles, drilling and boring machines, routers, arbors, grinders, lathes, pumps, hoists, compressors or any other machine where a space saving, built in drive is desirable.

The Reuland partial motor offers the broadest product scope in the industry including the eight (8) popular competitive shell type motor diameters.

All of the standard and special electrical characteristics of the squirrel cage induction motor are available including over 20,000 ratings from 0.1 hp to 300 hp with 60 hz speeds from 3600 to 200 RPM as well as multispeeds. With a variety of fully processed, high silicon lamination steels, frequencies to 1500 hz are available resulting in speeds to 90,000 RPM. Optimum lamination and slot geometry combined with the highest grades of insulation materials result in maximum performance designs.

Partial motors may be cooled by various techniques. The most often used are non-ventilated, open internally cooled, enclosed fan cooled, liquid cooled and auxiliary blower forced ventilated. In that Reuland Electric is *not* furnishing components essential to the proper operation of the motor, a shared responsibility exists between Reuland Electric and the equipment manufacturer. The electrical operating characteristics, i.e., flux density, current density, losses, etc., are consistent with complete motors of similar size and cooling technique. Reuland Electric will assist in the design of an adequate ventilation scheme although the equipment manufacturer is ultimately responsible for the operating temperature rise.

WOUND STATOR AND SHAFTLESS ROTOR RATINGS

230/460 VOLTS 3 PHASE 60 HERTZ
OPEN ENCLOSURE, 40°C AMBIENT

DIAMETER		REULAND FRAME		REFERENCE FRAMES		2 POLE — 3600 RPM			4 POLE — 1800 RPM		6 POLE — 1200 RPM	
WITH SHELL	WITHOUT SHELL	WITH SHELL	W/O SHELL	(3)	(4)	MAX HP 60 HZ	NOM HP 60 HZ	MAX SPEED	MAX HP 60 HZ	NOM HP 60 HZ	MAX HP 60 HZ	NOM HP 60 HZ
		(1)	(2)			(5)		(6)	(7)		(8)	
3.500	3.150	350-333	315-333	—	430-250	.10	—	66,000	.07	—	.07	—
3.500	3.150	350-375	315-375	—	430-375	.20	—	66,000	.13	—	.10	—
3.500	3.150	350-450	315-450	—	430-450	.25	—	66,000	.20	—	.13	—
3.500	3.150	350-550	315-550	—	430-550	.38	—	66,000	.25	—	—	—
4.000	3.540	400-315	354-315	—	480-315	.20	—	59,000	.14	—	.14	—
4.000	3.540	400-430	354-430	—	480-430	.33	—	59,000	.33	—	.20	—
4.000	3.540	400-500	354-500	—	480-500	.50	—	59,000	.38	—	.25	—
4.000	3.540	400-600	354-600	—	480-600	.63	—	59,000	.50	—	.33	—
4.500	4.190	450-400	419-400	—	550-400	.50	—	48,000	.33	—	.25	—
4.500	4.190	450-490	419-490	—	550-490	.75	—	48,000	.50	—	.38	—
4.500	4.190	450-590	419-590	—	550-590	1.13	—	48,000	.75	—	.50	—
4.500	4.190	450-710	419-710	—	550-710	1.50	—	48,000	1.00	—	.63	—
4.703	4.724	470-375	472-375	407	615-375	.55	.33	43,000	.38	—	.25	.10
4.703	4.724	470-460	472-460	410	615-460	1.50	.50	43,000	1.00	.25	.65	.20
4.703	4.724	470-540	472-540	413	615-540	1.75	.75	43,000	1.20	.33	.75	.25
4.703	4.724	470-618	472-618	416	615-618	2.25	1.00	43,000	1.50	.50	1.00	.30
4.703	4.724	470-718	472-718	420	615-718	2.50	1.25	43,000	1.75	.60	1.20	.33
4.703	4.724	470-818	472-818	424	615-818	3.30	1.50	43,000	2.25	.75	—	—
4.703	4.724	470-918	472-918	428	615-918	3.75	1.75	43,000	2.50	.80	—	—
4.703	4.724	470-980	472-980	432	615-980	4.00	2.00	43,000	2.75	1.00	—	—
5.703	5.320	570-400	532-400	507	700-400	1.50	.50	38,000	1.00	.25	.75	.20
5.703	5.320	570-450	532-450	509	700-450	1.75	.75	38,000	1.38	.50	.88	.25
5.703	5.320	570-530	532-530	512	700-530	2.50	1.00	38,000	1.75	.75	1.25	.50
5.703	5.320	570-680	532-680	518	700-680	3.75	1.50	38,000	2.25	1.00	1.75	.75
5.703	5.320	570-830	532-830	524	700-830	5.50	2.00	38,000	3.50	1.50	2.50	1.00
5.703	5.320	570-980	532-980	530	700-980	7.00	2.50	38,000	—	—	—	—
6.468	5.905	647-570	591-570	609	145-570	3.00	1.00	33,000	2.00	.75	1.25	.50
6.468	5.905	647-650	591-650	612	145-650	3.50	1.50	33,000	3.00	1.00	1.50	.75
6.468	5.905	647-710	591-710	616	145-710	5.00	2.00	33,000	4.00	1.30	2.00	.80
6.468	5.905	647-800	591-800	618	145-800	5.30	3.00	33,000	4.80	1.50	2.75	1.00
6.468	5.905	647-950	591-950	624	145-950	8.00	5.00	33,000	6.00	2.00	3.00	1.50
6.468	5.905	647-1100	591-1100	630	145-1100	10.00	6.00	33,000	7.50	3.00	—	—
6.468	5.905	647-1140	591-1140	—	145-1140	—	—	33,000	8.50	5.00	—	—
8.000	7.874	800-630	787-630	811	184-630	5.00	1.50	24,000	3.50	1.00	—	—
8.000	7.874	800-690	787-690	814	184-690	6.50	2.00	24,000	4.50	1.50	—	—
8.000	7.874	800-730	787-730	816	184-730	7.50	3.00	24,000	5.00	2.00	2.80	1.50
8.000	7.874	800-850	787-850	820	184-850	10.00	5.00	24,000	7.50	3.00	4.00	2.00
8.000	7.874	800-1000	787-1000	826	184-1000	12.00	7.50	24,000	8.50	5.00	5.50	3.00
8.000	7.874	800-1140	787-1140	832	184-1140	17.50	10.00	24,000	12.50	6.00	7.00	—
8.000	7.874	800-1240	787-1240	836	184-1240	20.00	13.00	24,000	15.50	7.50	7.50	5.00
8.000	7.874	800-1300	787-1300	840	184-1300	—	—	24,000	16.50	—	8.50	6.00
8.000	7.874	800-1420	787-1420	844	184-1420	—	—	24,000	17.50	10.00	9.50	7.00
10.000	9.449	1000-800	945-800	1016	215-800	11.00	5.00	19,000	8.80	3.00	5.00	2.00
10.000	9.449	1000-880	945-880	1018	215-880	13.00	7.50	19,000	10.50	5.00	7.00	3.00
10.000	9.449	1000-1000	945-1000	1023	215-1000	17.00	10.00	19,000	14.00	7.50	9.00	5.00
10.000	9.449	1000-1120	945-1120	1028	215-1120	21.00	15.00	19,000	17.50	10.00	12.00	7.50
10.000	9.449	1000-1300	945-1300	1036	215-1300	25.00	20.00	19,000	20.00	15.00	14.50	10.00
10.000	9.449	1000-1500	945-1500	1044	215-1500	34.00	25.00	19,000	27.00	20.00	18.00	13.00
11.000	10.630	1100-800	1063-800	—	256-800	9.50	6.00	17,000	7.50	4.00	5.80	3.00
11.000	10.630	1100-1060	1063-1060	—	256-1060	13.50	8.00	17,000	11.00	6.00	7.50	4.00
11.000	10.630	1100-1140	1063-1140	—	256-1140	20.00	16.00	17,000	18.50	11.00	11.00	6.00
11.000	10.630	1100-1300	1063-1300	—	256-1300	25.00	18.00	17,000	21.00	12.00	14.00	8.00
11.000	10.630	1100-1530	1063-1530	—	256-1530	33.00	21.00	17,000	22.50	14.00	17.50	10.00
11.000	10.630	1100-1820	1063-1820	—	256-1820	43.00	29.00	17,000	36.00	22.00	22.00	13.00
12.375	11.811	1238-1200	1181-1200	1226	286-1200	35.00	20.00	15,500	30.00	15.00	20.00	10.00
12.375	11.811	1238-1350	1181-1350	1232	286-1350	45.00	25.00	15,500	35.00	20.00	23.00	15.00
12.375	11.811	1238-1420	1181-1420	1240	286-1420	48.00	30.00	15,500	40.00	22.00	25.00	16.00
12.375	11.811	1238-1600	1181-1600	1244	286-1600	65.00	35.00	15,500	50.00	25.00	30.00	20.00
12.375	11.811	1238-1680	1181-1680	1248	286-1680	70.00	40.00	15,500	52.00	30.00	35.00	22.00
15.000	14.764	1500-1150	1476-1150	1518	365-1150	37.50	30.00	12,200	35.00	25.00	25.00	15.00
15.000	14.764	1500-1340	1476-1340	1522	365-1340	55.00	40.00	12,200	45.00	30.00	30.00	20.00
15.000	14.764	1500-1450	1476-1450	1528	365-1450	66.00	50.00	12,200	60.00	40.00	35.00	25.00
15.000	14.764	1500-1700	1476-1700	1536	365-1700	90.00	60.00	12,200	75.00	50.00	55.00	30.00
15.000	14.764	1500-1900	1476-1900	1544	365-1900	110.00	75.00	12,200	90.00	60.00	60.00	40.00
15.000	14.764	1500-2040	1476-2040	1552	365-2040	135.00	100.00	12,200	100.00	75.00	65.00	50.00
17.000	16.535	1700-1800	1654-1800	1736	405-1800	120.00	100.00	11,000	95.00	75.00	65.00	50.00
17.000	16.535	1700-2000	1654-2000	1748	405-2000	145.00	125.00	11,000	125.00	100.00	90.00	60.00
17.000	16.535	1700-2250	1654-2250	1760	405-2250	170.00	150.00	11,000	160.00	125.00	105.00	75.00
17.000	16.535	1700-2480	1654-2480	—	405-2480	—	—	11,000	170.00	132.00	110.00	85.00
20.000	19.685	2000-2000	1969-2000	—	445-2000	160.00	96.00	9,000	150.00	125.00	105.00	66.00
20.000	19.685	2000-2200	1969-2200	—	445-2200	200.00	120.00	9,000	190.00	140.00	115.00	70.00
20.000	19.685	2000-2500	1969-2500	—	445-2500	250.00	150.00	9,000	250.00	150.00	130.00	78.00
20.000	19.685	2000-3000	1969-3000	—	445-3000	300.00	180.00	9,000	—	—	175.00	105.00

See next page for notes

WOUND STATOR AND SHAFTLESS ROTOR OUTLINE DIMENSION DESIGNATIONS

DIMENSION TOLERANCE

WITH SHELL

(+.250, -.250)
 (+.000, -.002)
 (+.00, -.03)
 (+.060, -.060)
 (+.200, -.200)
 (+.000, -.002)
 (+.025, -.025)
 (+.200, -.200)

BJ
 BH
 BM
 BO
 BL
 CA
 BR
 BP

WITHOUT SHELL

(+.250, -.250)
 (+.005, -.000)*
 (+.060, -.060)
 (+.060, -.060)
 (+.200, -.200)
 (+.005, -.010)*
 (+.025, -.025)
 (+.200, -.200)

*Not machined as standard

NOTES

- Shell-less motors provide best heat transfer at minimum cost.
- NEMA B design is standard.
- Straight bore without keyway is standard.
- Maximum bore shown is for die cast rotor without keyway.
- Maximum bore with keyway may be smaller.
- Standard lead length is 3 feet.
- Solid magnetic shaft material is generally required for large rotor bores and maximum horsepower designs.
- Customer to finish turn rotor to specified diameter at $\pm .001$, $-.001$ and then balance. Rotor may be finish turned by Reuland upon request.

LEGEND FOR COLUMNS

- 1 & 2 REULAND FRAME SIZE. First digits are the respective stator diameters (BH) by putting a decimal two places to the left. The last digits are the coil extension overall length (BJ) by placing a decimal two places to the left. This is the maximum coil extension.
- 3 & 4 REFERENCE FRAMES. Reuland's frames are designed to replace these competitive frames.
- 6 MAXIMUM SPEED. This is the maximum allowable RPM for standard bores. Consult factory for maximum speeds with larger than standard bores or speeds that exceed these values.
- 5, 7 & 8 REULAND MAXIMUM HORSEPOWER. These horsepower values are the maximum horsepower capacity allowable at 60 hertz (at elevated temperature rise) with adequate cooling by customer, usually liquid cooling.

SHAFTLESS PARTIAL MOTORS SUMMARY DIMENSIONS WITH SHELL

DIE CAST ROTORS
WOUND STATORS

3 PHASE STANDARD VOLTAGE
AND FREQUENCY

REULAND FRAME W/SHELL	2 POLE							4 POLE							6 POLE							MAX BJ	BM	BH	BL	MHP NV*
	H.P.		BO	BP	DB	#CA	BR	H.P.		BO	BP	DB	#CA	BR	H.P.		BO	BP	DB	#CA	BR					
	NOM	MAX						NOM	MAX						NOM	MAX										
350-333	—	.10	.980	2.24				—	.067	.980	2.24				—	.067	1.77	2.05				3.33	2.00			
350-375	—	.20	2.17	3.42				—	.125	2.17	3.42				—	.10	2.17	2.44				3.75	2.50			
350-450	—	.25	3.15	4.41	1.559	.591/ .687	.89	—	.20	3.15	4.41	1.756	.591/ .750	1.00	—	.125	2.76	3.04	1.953	.591/ 1.00	1.10	4.50	3.50	3.50	2.9	2
350-550	—	.375	3.94	5.20				—	.25	3.94	5.20				—	—	—	—				5.50	4.25			
400-315	—	.25	1.77	3.03				—	.15	1.77	3.11				—	.15	1.77	3.35				3.15	2.00			
400-430	—	.33	2.36	3.62				—	.33	2.36	3.70				—	.20	2.36	3.93				4.30	2.50			
400-500	—	.5	3.15	4.41	1.756	.709/ .750	1.00	—	.375	3.15	4.49	1.952	.708/ .875	1.12	—	.25	3.15	4.72	2.149	.709/ 1.000	1.20	5.00	3.50	4.00	3.3	33
400-600	—	.625	3.94	5.20				—	.5	3.94	5.28				—	.33	3.94	5.51				6.00	4.25			
450-400	—	.5	1.77	3.34				—	.33	1.77	3.35				—	.25	1.77	3.31				4.00	2.00			
450-490	—	.75	2.56	4.13				—	.5	2.56	4.13				—	.375	2.56	4.09				4.90	2.75			
450-590	—	1.12	3.15	4.72	2.145	.787/ 1.000	1.20	—	.75	3.15	4.72	2.421	.787/ 1.125	1.20	—	.5	3.15	4.69	2.739	.787/ 1.375	1.65	5.90	3.50	4.50	3.8	5
450-710	—	1.5	4.72	6.30				—	1	4.72	6.3				—	.625	3.94	5.47				7.10	5.00			
470-375	.33	.55	1.77	3.35				—	.375	1.77	3.31				—	.25	1.77	3.15				3.75	1.96			
470-460	.5	1.5	2.56	4.13				25	1	2.56	4.10				—	.65	2.56	3.94				4.60	2.72			
470-540	.75	1.75	3.15	4.72				33	1.2	3.15	4.69				25	.75	3.15	4.53				5.40	3.46			
470-618	1	2.25	3.94	5.51				5	1.5	3.94	5.48				—	1	3.94	5.31				6.18	4.22			
470-718	1.25	2.5	4.92	6.50	2.417	.984/ 1.375	1.40	—	1.75	4.92	6.46	2.736	.984/ 1.375	1.65	33	1.2	4.72	6.10	3.134	.984/ 1.750	2.13	7.18	5.22	4.703	4.3	1
470-818	1.5	3.3	5.91	7.48				.75	2.25	5.91	7.44				—	—	—	—				8.18	6.22			
470-918	1.75	3.75	6.89	8.46				—	2.5	6.89	8.43				—	—	—	—				9.18	7.22			
470-980	2	4	7.09	8.66				1	2.75	7.09	8.62				—	—	—	—				9.80	8.22			
570-400	.50	1.5	1.77	3.66				25	1	1.77	3.66				—	.75	1.77	3.62				4.00	1.97			
570-450	.75	1.75	2.17	4.06				50	1.38	2.17	4.06				25	.875	2.17	4.02				4.50	2.47			
570-530	1	2.5	2.95	4.84				.75	1.75	2.95	4.84				50	1.25	2.95	4.80				5.30	3.22			
570-680	1.5	3.75	4.53	6.42	2.732	1.181/ 1.500	1.57	1	2.25	4.53	6.42	3.126	1.181/ 1.500	1.81	.75	1.75	4.53	6.38	3.527	1.181/ 2.000	2.28	6.80	4.72			
570-830	2	5.5	5.91	7.80				1.5	3.5	5.91	7.80				1	2.5	5.91	7.56				8.30	6.22	5.703	4.9	1.5
570-980	2.5	7	7.87	9.76				—	—	—	—				—	—	—	—				9.80	—			
647-570	1	3	2.17	4.30				.75	2	2.17	4.33				—	1.25	2.36	4.13				5.70	2.59			
647-650	1.5	3.5	2.95	5.08				1	3	2.95	5.12				.75	1.5	2.95	4.72				6.50	3.34			
647-710	2	5	4.13	6.30				—	4	4.13	6.30				—	2	4.13	5.90				7.10	4.34			
647-800	3	5.25	4.53	6.65	3.125	1.417/ 1.500	1.89	1.5	4.75	4.53	6.69	3.523	1.417/ 1.750	2.05	1	2.75	4.53	6.30	4.035	1.417/ 2.375	2.72	8.00	4.72	6.468	5.5	2
647-950	5	8	5.91	8.04				2	6	5.91	8.07				1.5	3	5.71	7.48				9.50	6.22			
647-1100	—	10	7.28	9.41				3	7.5	7.28	9.45				—	—	—	—				11.0	7.72			
647-1140	—	—	—	—				—	8.5	8.27	10.4				—	—	—	—				11.4	9.22			
800-630	1.5	5	1.97	4.49				1	3.5	1.97	4.53				—	—	—	—				6.30	2.88			
800-690	2	6.5	2.76	5.28				1.5	4.5	2.56	5.12				—	—	—	—				6.90	3.62			
800-730	3	7.5	3.15	5.67				2	5	3.15	5.71				1.5	2.75	2.95	5.19				7.30	4.12			
800-850	5	10	4.13	6.65				3	7.5	4.13	6.69				2	4	4.13	6.32				8.50	5.12			
800-1000	7.5	12	5.71	8.23	4.300	1.968/ 2.125	2.54	5	8.5	5.71	8.27	4.891	1.968/ 2.750	3.15	3	5.5	5.71	7.95	5.295	1.968/ 3.500	3.62	10.0	6.62			
800-1140	10	17.5	7.09	9.61				—	12.5	7.09	9.65				—	7	7.09	9.33				11.4	8.12	8.00	7.5	5
800-1240	—	20	7.87	10.3				7.5	14	7.87	10.4				5	7.5	7.87	10.1				12.4	9.12			
800-1300	—	—	—	—				—	15.5	8.66	11.2				—	8.5	8.66	10.9				13.0	10.12			
800-1420	—	—	—	—				10	17.5	9.84	12.4				—	9.5	9.84	12.1				14.2	11.17			
1000-800	5	11	3.15	5.94				3	8.75	3.15	5.87				—	5	3.35	6.11				8.00	4.12			
1000-880	7.5	13	3.74	6.54				5	10.5	3.74	6.46				3	7	3.74	6.50				8.80	4.62			
1000-1000	10	17	4.92	7.72				7.5	14	4.92	7.64				5	9	4.92	7.68				10.0	5.87			
1000-1120	15	21	6.10	8.90	5.275	2.165/ 2.500	3.07	10	17.5	6.10	8.82	5.865	2.165/ 3.375	3.62	7.5	12	6.10	8.86	6.466	2.165/ 4.375	4.72	11.2	7.12	10.00	9	10
1000-1300	20	25	8.07	10.8				15	22	8.07	10.8				10	14.5	8.07	10.8				13.0	9.12			
1000-1500	25	34	10.24	13.0				20	27	10.24	13.0				—	18	10.24	13.0				15.0	11.12			
1100-800	—	9.5	2.76	6.54				—	7.5	2.76	6.81				—	5.75	3.15	6.14				8.00	3.75			
1100-1060	—	13.5	3.94	7.72				—	11	3.94	7.80				—	7.5	3.94	6.93				10.6	4.25			
1100-1140	—	20	5.91	9.69				—	18.5	5.91	9.76				—	11	5.91	8.90				11.4	6.00			
1100-1300	—	25	7.48	11.2				—	21	7.48	11.3	6.853	2.559/ 4.000	4.06	—	14	7.48	10.4	7.057	2.559/ 4.750	4.25	13.0	7.75	11.00	10.2	15
1100-1530	—	33	9.84	13.6				—	22.5	9.84	13.7				—	17.5	9.84	12.8				15.3	10.00			
1100-1820	—	43	12.60	16.3				—	36	12.6																

MECHANICAL FEATURES

- Vast selection of diameters and stacking lengths are available as standard. Special lengths upon request.
- High pressure die cast aluminum rotors for NEMA B designs include cooling fins and balancing lugs. Fabricated rotors with captivated bars are available for special performance characteristics.
- Large straight rotor bores are standard with oversize diameters or tapered bore upon request.
- Maximum bore shown is for die cast rotor without keyway. Fabricated rotors generally allow for larger bores.
- Shell type motors may be furnished with standard length or extended length shells made from carbon or stainless steel. Shells are also available with heavy wall thickness and grooved for customer liquid cooling.
- High temperature, oil resistant, 3 foot lead length is standard.
- For uniform air gap and optimum balance, rotor diameters are furnished rough for customer to finish turn and balance after the rotor is installed on the shaft.
- Maximum speeds shown are limited by the centrifugal forces acting on the rotor and are based upon the standard rotor bore. An oversize bore or deep keyway may reduce these values. High speed rotor/shaft combinations should have balancing rings in order to allow for the delicate trim balance required.

ELECTRICAL FEATURES

- 0.1 to 300 hp maximum performance designs.
- 2 through 16 poles available as standard, higher upon request. Multi-speeds upon request.
- Squirrel cage induction, NEMA design B is standard.
- To 600 volts as standard, 2300 volts upon request.
- High silicon electrical steel, fully insulated, to reduce core losses allow standard designs to operate to 120 hertz. Special low loss laminations with minimum core loss are available for high frequency applications to 1500 hertz.
- Premium class H insulation system with high temperature polyester varnish is standard.
- Customer is responsible for cooling partial motors. The *nominal horsepower* ratings shown will have NEMA class A temperature rise when used in an open enclosure with adequate air flow, in a 40 degree C ambient at up to 3300 foot elevation. *Inverter driven* motors generate higher losses and will therefore have a higher temperature rise. The *maximum horsepower* ratings will also have higher temperature rise.

MISCELLANEOUS

- Stator and rotor sets are identified with their model or serial number, along with a stamped loose nameplate.
- A certified dimension drawing is available for each order. Always review these dimensions or call our factory before releasing the housing to production on new designs.

Wound rotor motor

Reuland wound rotor motors provide adjustable starting current, starting torque and speed. So they're ideal for applications like hoisting mills, conveyors, printing presses, pulp and paper mills, plunger and centrifugal pumps, reciprocating compressors, crushers, and fans, blower and transfer drives on cranes.

Typical speed-torque curve.

The series of speed-torque curves show the typical performance characteristics of a wound rotor motor with the proper resistance in the rotor circuit. Using arm resistance as a starting point, the addition of resistance produces a maximum torque and slow speed. Further increasing resistance, as in "B" and "A" progressively reduces torque from maximum. Note that maximum resistance produces minimum torque.

Standard Configuration:
Frame: 100-1500
Voltage: 480-600V
Power: 10-1000 HP
Speed: 1800-3600 RPM
Inertia: 0.01-1.0
Weight: 100-1000 lbs
Dimensions: 100-1500
Lead time: 12-16 weeks

Squirrel cage motors

This rugged, economical squirrel cage motor is used in many industries such as metal forming, material handling, hydraulics, textile, machine tool, and food processing. As dependable as it is sturdy, the Reuland motor runs quietly. Over 16,000 ratings available—low starting torque, high starting torque, high breakdown torque. Nema design A, B, C and D, (both 5-8% and 8-13% slip).

Standard Configuration:
Frame: 100-1500
Voltage: 480-600V
Power: 10-1000 HP
Speed: 1800-3600 RPM
Inertia: 0.01-1.0
Weight: 100-1000 lbs
Dimensions: 100-1500
Lead time: 12-16 weeks

Gearmotors

We've combined Reuland motor (and brakemotor) technology with our reducers to offer you the Reuland gearmotor.

Numerous reducer configurations are available.

Right angle single worm. It's available with (large or small) mounts, each with solid (single or double) or hollow shaft. Torque arm mounts are available with the hollow shaft.

Rated: 1/2-30HP

Rated: 1/2-60HP

Output torque: up to 10,000 in. lb.

Combination helical/right angle worm. It's available with (large or small) mounts, each with solid (single or double) or hollow shaft. Torque arm mounts are available with the hollow shaft.

Rated: 1/2-10HP

Rated: 1/2-17.5HP

Output torque: up to 18,000 in. lb.

Helical bevel. It's available with (large or small) mounts, each offered with solid (single or double) or hollow shaft.

Rated: 1/2-15HP

Rated: 1/2-16HP

Output torque: up to 350,000 in. lb.

Helical parallel and concentric shaft. These Reuland gearmotors are available with (large or small) mounts, each offered with solid (single or double) or hollow shaft.

Rated: 1/2-15HP

Rated: 1/2-17.5HP

Output torque: up to 18,000 in. lb.

Helical parallel shaft "Versa-Drive". It's available in solid (single and double) hollow shaft with torque arm mount. Three integral sets of mounting feet allow versatility in mounting, without adapters.
Rated: 1/2-10HP
Rated: 1/2-19HP
Output torque: up to 9,075 in. lb.

REULAND HYDRAULIC PUMP MOTORS

Brakemotors

We've combined all the features and modifications of Reuland motors with the time-proven Reuland heavy-duty Direct Acting disc brakes and MagnaStop brakes to offer you the Reuland brakemotor, available from 1/2 to 150 HP.

It's engineered to be virtually trouble free. Every brakemotor is assembled from all heavy-duty components.

Our heavy-duty Direct Acting disc brake has just seven major parts. And only one moves. The arrangement.

The spring set design provides a built-in safety feature. In case of a power failure, the drive automatically stops. Without power, the magnetic release is gone. And the spring loaded armature is drawn against the brake lining for a fast, positive stop. When the power resumes the magnet restricts the armature, releasing the brake.

In addition, a manual brake release is located outside the housing.

A cast metal housing protects the brake from external damage, so no shrouds are necessary.

The economical Reuland MagnaStop brake has a double action ball bearing cam and wedge linkage, so it puts less strain on the internal. Like our Direct Acting brake, the MagnaStop brake is also approved and magnetically released.

REULAND PARTIAL MOTORS 0.1 TO 300 HORSEPOWER

for applications with limited mounting areas

REULAND

ELECTRIC MOTORS

- machine tools
- textile machines
- cranes and hoists
- door openers
- tensioning devices
- special machinery

Standard modifications

Available on all Reuland motors.

- Auxiliary cooling.
- Balance, special.
- Brake, motor mounted.
- Bearing, special.
- overload.
- Brushless and drives.
- Cadmium plating.
- Chemical coating treatments.
- Conduit box, oversize.
- Export packaging.
- End bells: "C" face.
- "D" flange.
- "D" base.
- "DD" flange (metric).
- Helical inserts.
- High altitude.
- Insulation Class, Super B, F, Super F, H.
- Marine duty (IEEE-45, USCG, ABS).
- Metric flanges (DIM).
- Paint, special.

- Part winding starting.
- Resistor, fabricated bar.
- Rotors, ventilated.
- Safety wire.
- Screened openings.
- Shafts: Spline.
- Stainless steel.
- Squared.
- Tapered.
- Double extended.
- Scrap reduction.
- Various bore sizes.
- Shaft axis.
- Space heaters.
- Speed switches (anti-plugging).
- Star delta starting.
- Special ambient.
- Tachometers.
- Thermoprotection.
- Tests, special.
- Tropical protection.
- Zinc chromate primers.

REULAND ELECTRIC

17969 E. Railroad Street, P.O. Box 1464, Industry, California 91749
Tel: 818-964-6411, Telex: 964-6411

REULAND ELECTRIC
THE POWER DRIVE PEOPLE

17969 EAST RAILROAD STREET
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INDUSTRY, CALIFORNIA 91749
TELEPHONE: (818) 964-6411
TELEX 269360 FAX (818) 965-1283

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P.O. BOX 40385
CINCINNATI, OHIO 45280
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A.C. HIGH SPEED INVERTER MOTORS

The Demand/Need

Greater speed and performance range, higher cycle times, increased productivity, quality and reliability.

The conventional prime mover is being pushed beyond its mechanical and electrical limits.

A prime mover must be developed to handle these ever increasing needs.

The Solution

Reuland Electric has developed a line of Inverter Duty A.C. Motors that maximize horsepower to frame ratios. Reuland's A.C. Inverter Motors can be tailored to a variety of load/speed ranges. Speeds of 40,000 RPM and beyond can be achieved. Our Inverter Duty Motor design incorporates enough capacity to provide high torque at low speed, a wide constant horsepower range and higher speed capability, while retaining familiar NEMA "T" Frame dimensions.

Typical solutions designed into Reuland Electric's high speed prime movers are:

- Thinner, high silicon, low loss lamination steel. Allows for frequencies above the 1000 Hz level of conventional high frequency lamination steel.
- Fabricated rotor construction. To achieve speeds above the peripheral speed of conventional cast rotor construction.
- Oil mist lubrication. Allows greater bearing speeds and life.
- Auxiliary cooling. Liquid or forced air systems to reduce the thermal limits associated with extreme speed ranges, extended constant horsepower ranges, and low speed high torque ranges.
- High power density designs. Allows for compact packaging.

Reuland Electric's A.C. Inverter Duty Motor offers the O.E.M who is trying to compete in today's and tomorrow's competitive climate, state-of-the-art materials and design techniques.

Reuland's A.C. Inverter Drive system can provide the solution to the ever increasing demands placed upon your equipment by the requirements of the application.

We are setting the pace for 21st century designs.

Applications

Machine tool centers, milling machines, grinders, test stands, index drives, centrifuge drives, rapid accel/decel drives and many others require special considerations as follows:

1. When selecting an inverter drive system, duty cycle, load requirements and environmental considerations must be provided.
2. Horsepower and torque at a given speed for a given period of time.
3. Environmental and space limitations; acceleration and deceleration requirements, with a given reflected inertia.

CUSTOM INVERTER DRIVE MOTORS

(MAY DEVIATE FROM NEMA STANDARDS)

Conventional Mechanical Options

Enclosures	Open drip-proof, drip-proof force ventilated, totally-enclosed fan cooled, totally-enclosed force ventilated, totally-enclosed non-ventilated, liquid cooled, air purged provisions, partial motor (rotor/stator set).
Bearings	ABEC Class 1 through 9, and duplex angular contact.
Bearing Lubrication	Prelubricated sealed or shielded, open regreasable, jet oil, mist lubricated with reservoir, regulator, pressure gauge, and manifold.
Materials	Cast iron, cast aluminum, stainless liquid cooled shells, corrosion proof features.
Balance and Runout	Precision and/or NEMA standard.
Speeds	145T Frame to 40,000 RPM through 445T Frame to 9000 RPM (special designs for speeds beyond this range).
Auxiliaries	Gear and probe speed pickup.
Insulation	Class B, F, H and V.P.I.
Brakes	Standard and heavy duty, available for some speeds.
Shafts	Standard NEMA T, TS, taper, straight, solid or hollow, standard or stainless, specials.
Mounting	Foot or footless, precision bracket mounting, conventional C or D flange, metric DIN special flanges.
Gear Reduction	All types available.

Conventional Electrical Options

Voltage	Minimum to 600 volts A.C.
Phase	1, 2, and 3 Phase.
Frequency	Minimum to 2000 Hertz.
Volts/HZ Range	As required.
Lamination	Standard, fully processed standard, high silicon low loss, high frequency low loss.
Rotors	Die cast and fabricated.
Number of Poles	2 to 36 poles.
Windings	1, 2, and 3 separate windings for 1 to 6 speeds.
Designs	NEMA A, B, C, D, F, and 100% stall duty.
Variable Frequency Control	Available.

Design and Construction

Each inverter application presents unique environmental, electrical and/or mechanical problems that direct the selection of size and enclosure to best suit the need economically. The duty cycles, space limitations, environment, and maximum speeds generally determine the minimum size and cooling system best suited for long life and reliability.

CUSTOM HIGH SPEED INVERTER MOTORS

*Maximum HP at maximum speed requires liquid cooling
and mist or jet lubricated bearings.

3 PHASE Load HP may increase directly from base speed 50C DEGREES
UP TO 600 VOLTS with constant volts/HZ if cooling is adequate. AMBIENT

FRAME	SYN RPM 60 HZ BASE SPEED	60 HZ "MAXIMUM HP AND ENCLOSURE" STD. LAM.					"LOW LOSS HIGH FREQUENCY LAMINATION"			
		DPFV	DP	TEFV	TEFC	TENV	MAX. SPEED STD. ROTOR	CONT. DUTY MAX HP AT MAX SPEED	HERTZ AT MAX SPEED	INT. DUTY MAX HP AT MAX SPEED
145T	3600	5	5	4	4	2	30,000	25	500	33
	1800	5	5	5	4	2	25,000	25	950	55
	1200	4	3	3	2	1	20,000	25	1000	33
	900	3	2	2	1	1	15,000	16	1000	16
	600	2	1	1	0.5	0.5	10,000	8	1000	8
184T	3600	13	12	10	10	4	22,000	35	370	61
	1800	10	8	8	7	4	20,000	35	730	77
	1200	8	5	6	4	3	18,000	35	900	60
	900	7	5	6	4	2	15,000	30	1000	67
	600	3	2	3	2	1	10,000	30	1000	33
215T	3600	25	23	18	18	8	19,000	50	317	105
	1800	18	16	17	14	7	17,000	50	567	142
	1200	14	11	13	9	5	16,000	50	800	133
	900	12	8	9	6	3	15,000	45	1000	117
	600	7	3	4	4	2	10,000	45	1000	66
256T	3600	40	35	30	30	13	17,000	75	283	142
	1800	39	33	35	30	12	15,000	75	500	250
	1200	30	25	27	20	10	14,000	75	700	233
	900	20	17	19	15	7	13,500	70	900	225
	600	12	9	10	7	3	10,000	70	1000	116
286T	3600	65	60	55	50	18	14,500	100	242	201
	1800	55	50	52	40	17	13,500	100	450	300
	1200	40	35	37	30	12	13,000	100	650	325
	900	30	25	27	20	10	12,000	90	800	267
	600	18	14	15	12	7	10,000	90	1000	200
326T	3600	80	72	75	60	18	12,200	150	203	203
	1800	78	70	73	60	17	11,000	150	367	367
	1200	50	45	47	40	15	10,000	150	500	333
	900	40	35	37	30	10	10,000	140	667	333
	600	25	20	22	17	8	10,000	140	1000	283
365T	3600	100	90	95	75	21	12,000	200	200	250
	1800	95	87	92	75	20	11,000	200	367	458
	1200	67	60	65	50	17	10,000	200	500	417
	900	55	50	52	40	12	10,000	180	667	444
	600	35	27	30	25	10	10,000	180	1000	416

Next smaller NEMA frame mounting available by shifting back foot hole forward to NEMA 2F dimension.

Where drive requires more than 1000 hertz, special ultra high frequency lamination is available.

AC SQUIRREL CAGE MOTORS

STANDARD NEMA - HIGH SPEED INVERTER - STANDARD AND PRECISION CONSTRUCTION

TENV (TOTALLY ENCLOSED NON-VENTILATED)

DPFC (DRIIPROOF FAN COOLED)

DPAV (DRIIPROOF AUXILLARY VENTILATED)

TEFC (TOTALLY ENCLOSED FAN COOLED)

TEAV (TOTALLY ENCLOSED AUXILLARY VENTILATED)

DP (OPEN MOTOR NO FAN)

TELC (LIQUID COOLED, PRECISION)

FRAME		C				D	E	2F	H	O	P	U	N-W	AB	BA	SQ. KEY	AA
		TELC	OPEN TENV	DPFC TEFC	DPAV TEAV												
NEMA (INCHES)	56	11.25	11.25	13.63	16.88	3.50	2.44	3.00	34X75	7.50	8.00	.625	1.88	6.38	2.75	.188	.75
	56H	11.25	11.25	13.63	16.88	3.50	2.44	5.00	34X75	7.50	8.00	.625	1.88	6.38	2.75	.188	.75
	145T	11.63	11.63	14.00	17.50	3.50	2.75	5.00	34	7.50	8.00	.875	2.25	6.38	2.25	.188	.75
	184T	13.63	13.63	16.63	19.00	4.50	3.75	5.50	41	9.25	9.60	1.125	2.75	7.18	2.75	.250	.75
	215T	17.63	17.44	20.50	24.25	5.25	4.25	7.00	41	11.00	11.50	1.375	3.38	8.75	3.50	.312	1.00
	256T	22.63	22.63	25.75	29.75	6.25	5.00	10.00	.53	12.68	12.87	1.625	4.00	10.00	4.25	.375	1.25
	286T	25.00	25.00	26.88	33.63	7.00	5.50	11.00	.53	14.25	14.50	1.875	4.62	12.25	4.75	.500	1.50
	326T	27.00	27.00	30.63	36.38	8.00	6.25	12.00	.66	16.88	15.50	2.125	5.25	14.00	5.25	.500	2.00
	365T	29.75	29.75	32.14	38.39	9.00	7.00	12.25	.66	17.88	17.75	2.375	5.88	14.00	5.88	.625	3.00
	405T	34.00	34.00	39.75	46.75	10.00	8.00	13.75	.81	20.50	20.75	2.875	7.25	18.50	6.62	.750	3.00
	445T	39.75	39.75	45.81	52.81	11.00	9.00	16.50	.81	22.62	23.06	3.375	8.50	19.06	7.50	.875	3.00

NEMA "C" FLANGE

FRAME	AH	AJ	AK	BB	BD	BF (4)
NEMA (INCHES)	56C	2.06	5.875	4.500	.16	6.50 3/8-16
	145TC	2.12	5.875	4.500	.16	6.50 3/8-16
	184TC	2.62	7.250	8.500	.25	9.00 1/2-13
	215TC	3.12	7.250	8.500	.25	9.00 1/2-13
	256TC	3.75	7.250	8.500	.25	10.00 1/2-13
	286TC	4.38	9.000	10.500	.25	11.25 1/2-13
	326TC	5.00	11.000	12.500	.25	14.00 5/8-11
	365TC	5.62	11.000	12.500	.25	14.00 5/8-11
	405TC	7.00	14.000	12.500	.25	15.50 5/8-11
	445TC	8.25	14.000	16.000	.25	18.00 5/8-11

NEMA "D" FLANGE

FRAME	AH	AJ	AK	BB	BD	BF 4
NEMA (INCHES)	56	NOT AVAILABLE				
	145TD	2.25	10.00	9.00	.25	11.00 .53
	184TD	2.75	10.00	9.00	.25	11.00 .53
	215TD	3.38	10.00	9.00	.25	11.00 .53
	256TD	4.00	12.50	11.00	.25	14.00 .81
	286TD	4.62	12.50	11.00	.25	14.00 .81
	326TD	5.25	16.00	14.00	.25	18.00 .81
	365TD	5.88	16.00	14.00	.25	18.00 .81
	405TD	7.25	20.00	18.00	.25	22.00 .81
	445TD	8.50	20.00	18.00	.25	22.00 .81

CERTIFIED FOR _____ P.O. _____
 HP _____ RPM _____ FRAME _____

PH/HZ/VOLTS _____
 BY _____ DATE _____

NOTE: "C", "BA" AND "O" DIMENSIONS MAY VARY - CONSULT FACTORY DATA SUBJECT TO CHANGE WITHOUT NOTICE

**Our inventory isn't
in a warehouse,
it's in our capabilities.**

Reuland gives you made to order power drives. Fast delivery. At a fraction of what custom could cost.

You see, Reuland builds equipment from the ground up. And the bat, this gives us a competitive edge.

We develop the design. We produce the prototype. We have a pattern shop. And we're very particular about the inner workings of our equipment. Every stator is hand wound because that provides the flexibility in designing electrical characteristics.

Every critical winding area is carefully insulated. Then the stators are dipped into special moisture-resistant varnish. Baked. Redipped. Baked again. Just to make sure that everything is held securely in place.

Reuland numerically controlled machining assures accurate and absolute consistency.

And even after the final product is assembled, it's tested and tested again. And tested again.

Meanwhile, Reuland's Research and Development Team is working on new product designs to make your operations even more

Modular design. Reuland's secret to cutting time, cutting costs.

You see, we've reduced all our power drive designs into individual components.

Reuland has developed over 16,000 combinations, and they're all stored on microfilm. Then, it's just a matter of putting the pieces together to fit your specifications.

For you, this presents an attractive alternative: Made-to-order power drive equipment, that performs exactly like you want it to perform. Can be delivered in a surprisingly short time. At a price most companies would call impossible.

And modular means that all the power drive parts are readily available. So if your equipment ever needs servicing, the parts are available.

Our standard motors:

Reuland offers only precision constructed configurations in 60Hz or 50Hz.

Squirrel Cage: Standard 60Hz in 3,600, 1,800, 1,200, 900, 720, 600 and 450 rpm. Frame sizes 56-445.

Wound Rotor: Variable speed and step starting for standard adjustable motor output. Standard 60Hz in 1,800, 1,200, 900, 720, and 600 rpm. Frame sizes 56-445.

Crane-Hoist: High slip. High torque. Ideal where smooth starts of heavy loads are frequent. In 15, 30, and 60 minute ratings. Frame sizes 56-445.

Hydraulic Pump: The pump mounts directly to the motor to save time and parts. The perfect alignment reduces bearing, seal and pump wear. One motor with a double end shaft can operate two pumps. They are designed with high breakdown torque. High full load speed. Frame sizes 182-445.

Multispeed: Single and double winding. In two, three and four speed models. Constant torque at all speeds. Also available in variable torque and constant horsepower design. Frame sizes 56-445.

Waferthin: All the power. Half the length. And unsurpassed in efficiency and design. Fractional through 35hp.

Some of our modifications:

Auxiliary cooling	Part winding starting
Balance, special	Rotors, fabricated bar
Brake, motor mounted	Rotors, ventilated
Bearing: special	Safety wire
oversized	Screened openings
Breathers and drains	Shafts: Spline
Cadmium plating	Stainless steel
Chemical casting	Squared
treatments	Tapered
Conduit box, oversize	Double extended
Export packaging	Step reduction
End bells: "C" face	Various bore sizes
"D" flange	Shaft seals
"P" base	Space heaters
"DIN" flange	Speed Switches (anti-
(metric)	plugging)
Helicoil inserts	Star delta starting
High altitude	Special ambient
Insulation Class F, H	Tachometers
Super B, F, H	Taconite protection
Marine duty (IEEE-45,	Tests, special
USCG, ABS)	Tropical protection
Metric flanges (DIN)	Zinc chromate primer
Paint, special	

Torque: They can adjust their speed to load changes while maintaining constant torque. They can be installed or "locked" into a load with the current on. Frame sizes 56-445.

Vertical Pump Motors: Specifically designed for irrigation, water reclamation, waste water and sewage systems. Frame sizes 182-445.

The result: better quality, longer-lasting power drives.

In fact, we insist on it. And to make sure, every motor and motor-reducer is subjected to grueling examination. The surge test. The high potential test. The no-load test.

And as you would expect, every rotor is dynamically balanced to assure quiet operation and long-life.

Our standard motoreducers:

Right angle single worm: Converts the motor's high speed into slow speed, high torque output directly through the worm and worm gear train. Available with flange or foot mounts, each offered with solid or hollowshafts. Torque arm mounts available with hollowshaft.

Ratios: 5:1-60:1. Ratings: 1/4hp-30hp. Output torque: up to 10,000 in. lbs.

Combination helical/right angle worm: Gives maximum speed reduction by incorporating both helical gears and worm gear set. Available with flange, foot, and torque arm mounts. Ratios: 7.2:1-372:1. Ratings: 1/3hp-10hp. Output torque: up to 18,000 in. lbs.

Helical bevel: Converts the motor's high-speed into slow speed, high torque output directly through the worm and helical bevel

gear train. Available with flange or foot mounts, each offered with solid or hollowshafts. Torque arm mount available with hollowshaft.

Ratios: 10:1-160:1. Ratings: 3/4hp-150hp. Output torque: up to 350,000 in. lbs.

Helical parallel shaft: Precision ground helical gears in eleven gear box sizes. Available with single, double and triple reduction gear systems, and foot or flange mount.

Ratios: 1.5:1-1800:1. Ratings: 1/2hp-150hp. Output torque: up to 350,000 in. lbs.

Helical versa-drive: Double end output shaft designed to power two related but separate operations. Available with hollowshaft in various bore sizes. Three integral sets of mounting feet allow vertical or horizontal mounting, without adaptations.

Ratios: 4:1-190:1. Ratings: 1/2hp-10hp. Output torque: up to 9,075 in. lbs.

Reuland's unique approach to a better built brake. It's simple.

The brakemotors. Super simple, super efficient.

Reuland's heavy duty magnetic disc brakes are combined with our motors to form one complete, compact unit. And they're available in standard squirrel cage, torque motor, crane-hoist motor, multispeed and waferthin configurations.

It stands to reason, cut down the quantity of moving parts and you cut down the chances of a breakdown. So at Reuland, we design our brakes with fewer moving parts than most conventional brakes.

Our heavy duty, direct acting magnetic disc brake has seven major parts. And only one, the armature, moves. This eliminates cumbersome linkages, the maintenance problem of most brakes. It's an excellent replacement for worn out brakes.

Our MagnaStop brake puts less strain on the solenoid because of its double action ball bearing cam and simple linkage. It's our quality, low cost brake.

Reuland brakes are available from 1.5 to 75 lb/ft. They fit standard NEMA "C" face motors and can be delivered immediately.

With Reuland, you're in complete control. Electronically.

RTC Soft-Start Control: Takes the jolts out of production line startups. It controls the motor's acceleration until it reaches full speed. Reduces damage to equipment and keeps products online.

RTC reduces your inrush current. That puts less load on the motor and prolongs your motorlife. This can reduce your downtime. Dramatically.

You can order your Soft-Start with Controlled Stop (for gradual motor deceleration), and a variety of other options in one single complete unit. RTC Soft-Start Controls are available for three-phase motors fractional to 300hp.

Electronic Braking: Eliminates dangerous equipment coasting time for safer operation. Braking is controlled and gradual, which can increase your production time. You set torque and time adjustments to control motor deceleration. Available for single and three-phase motors through 125hp.

Reuland's special products fill specific needs.

If you have a power transmission problem that is not addressed in this brochure, let Reuland help. The combination of our total product capability and our modular approach to design means we're sure to find the solution. You'll have the equipment you need, and you'll have it fast. At a price that's sure to please. Just call a Reuland representative and tell him what you need.

Hydraulic Pump Adaptors: Bolts the pump to the motor for safer, quieter operation. The one-piece, cast aluminum adapter fits standard NEMA "C" face motors and almost any pump.

Cushion Drive Fluid Coupling: Provides stepless soft-start for high inertia loads. Mechanically.

Motors are able to deliver greater load starting torque. So you can choose your motor for its running load rather than its starting load requirements. That means you can use a smaller, less expensive motor.

Fluid Shaft Motors: Combines mechanical soft-start control and the motor in a single frame. Reducing the overall length of the design by almost a third.

And a big plus: Our exclusive honor system motor service policy. If your equipment should happen to break down (an unlikely occurrence to be sure) you may take it to your local repair shop. Ask your Reuland representative for details.

REULAND ELECTRIC

THE POWER DRIVE PEOPLE

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