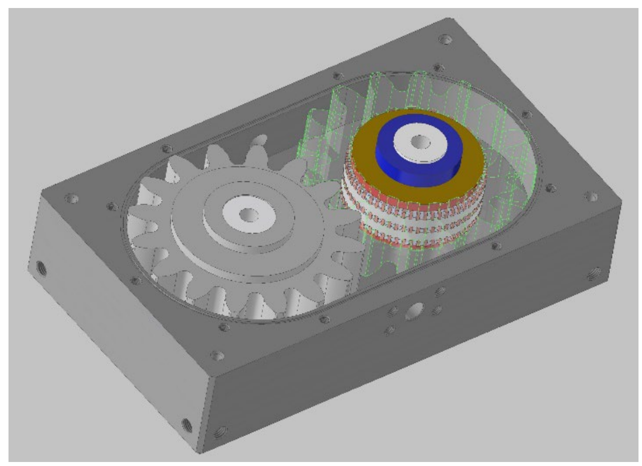
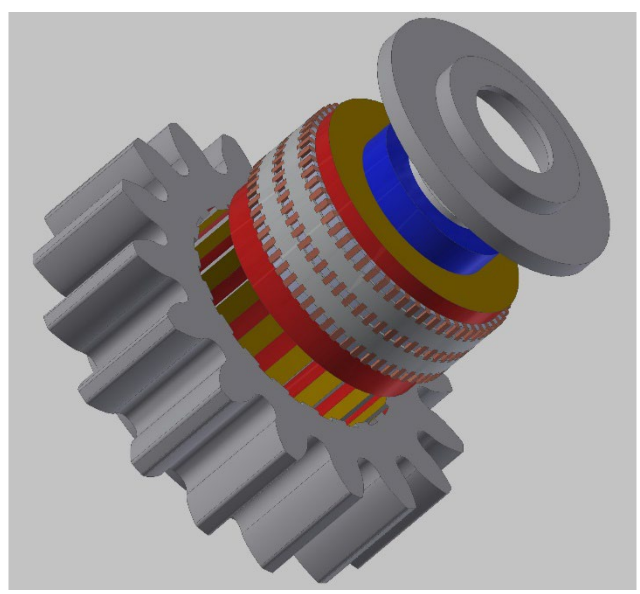
IES Technology Background and Benefits

IES pump is a positive-displacement external gear pump. It is a drive-drive system powered by two high-torque, low-speed servo motors and two high-torque spur gears. The spur gears are wrapped around the servo motors and are inside the hydraulic pump casing. The servo motor-gear system is independently driven and synchronized.





In summary, IES is an intelligent electrohydraulic system that is enabled by fly-by-wire technology. It includes one e-pump, two e-valves, one e-accumulator, a motion control package, a power supply, and at least one Energy Regeneration and Storage Unit (ERS). These components can be duplicated to provide redundancy for mission critical operations.

e-Pump Drive-Drive Synchronized Gear Technology and Contamination Control

In traditional drive-*driven* gear pumps, the gears are manufactured so that they transmit energy from one gear to another. The forced contact between the gears transmits input energy from the drive gear (shaft gear) to the driven gear. Contaminants that are too large to pass through the tight spaces inside the pump cause wear on the gears. This introduces larger contaminants into the pump, which causes scoring of the pump housing. This results in leaks and loss of performance. Additional contaminants perpetuate the overall problem.

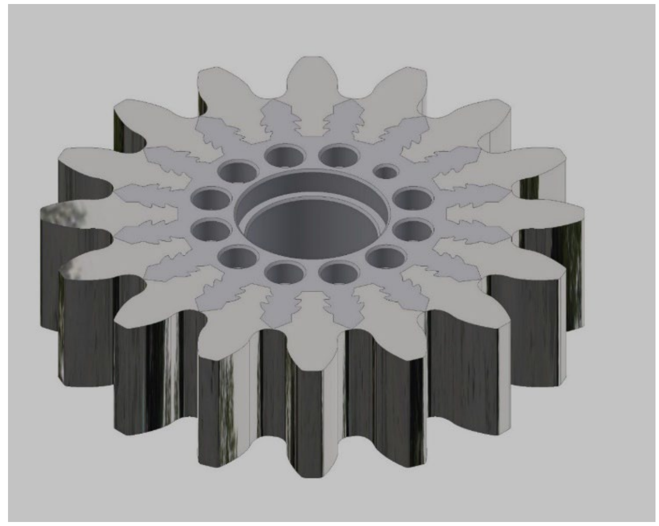
Our e-pump, on the other hand, is a drive-*driv*e synchronized system. This means that we have eliminated forced contact between the gear teeth. The gears enter and exit the meshing area without grinding against each other. The gears touch only to create a sufficient seal between the teeth. That seal places about 5Nm of direct torque on the sealed gears, but it is not a push-to-move force.

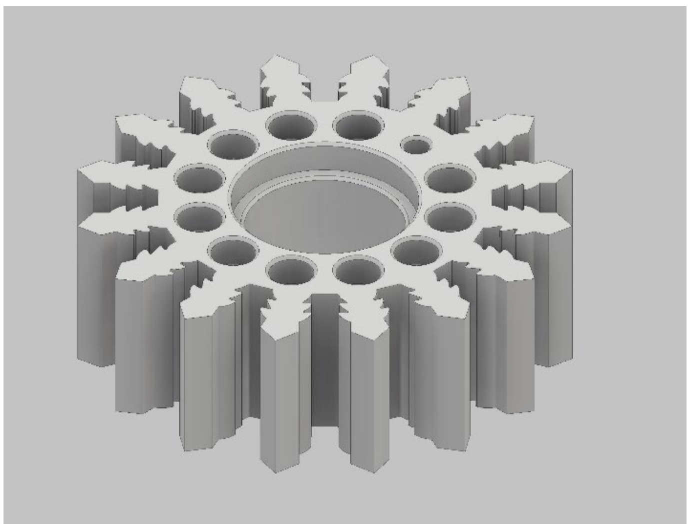
e-Pump is Bi-Directional

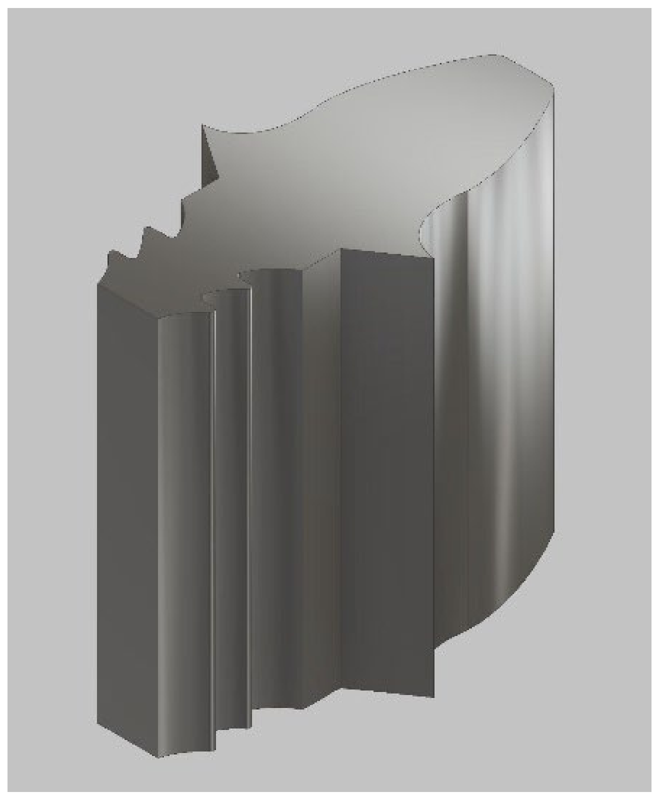
e-Pump has an Internal Motor Break

e-Pump Replaceable Gear Teeth Technology

In traditional gear pumps, when a gear tooth is damaged by contamination, cavitation, excessive heat, or abnormal wear, the entire gear needs to be replaced. In our IES, we designed replaceable gear teeth. In other words, our gear system has two components: gear teeth and a gear hub. Only the gear hub is attached to the motor's housing. (In the future, the gear hub may become the motor housing.) Each individual gear tooth is pressed to fit inside the gear hub by shrink fitment. If one tooth is damaged, we only need to replace that particular tooth.





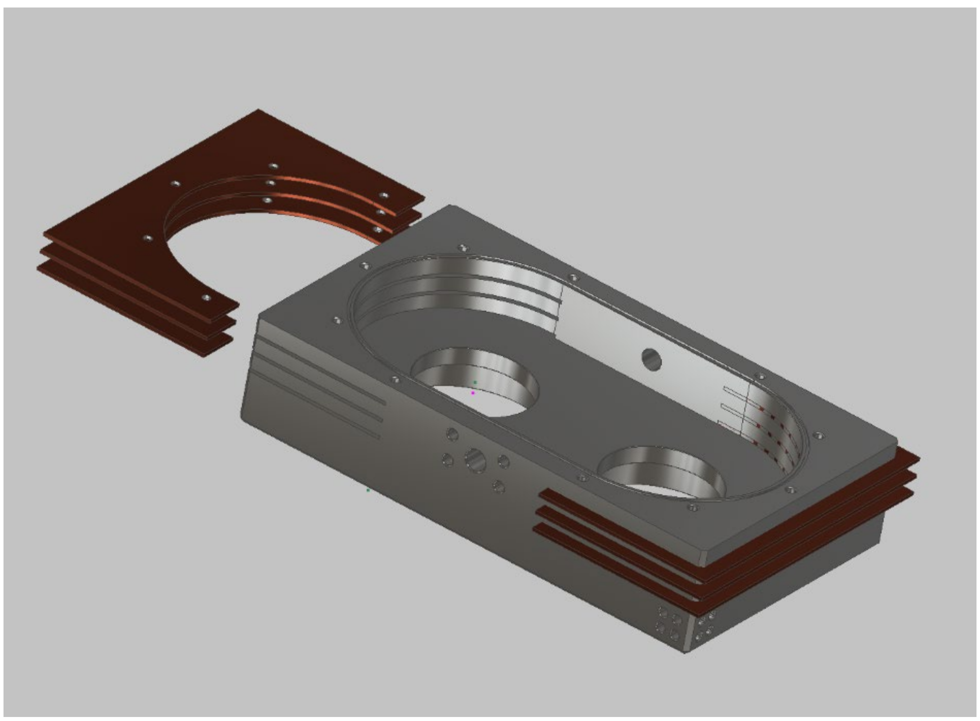


e-Pump Elimination of Cavitation Due to Lower Speed of Operation Without Sacrificing Flow
The high-torque, low-speed servo motors in our IES generate a large amount of torque. To take advantage of this, our gear teeth have a longer face width than traditional gear teeth. If the currently high-torque, low speed servo motors in our IES become faster, we will be able to reduce the face width of our gear teeth and increase the e-pump's speed. If the e-pump is faster, we can make it smaller.

e-Pump Built-in Redundancy
Our IES utilizes two high-torque, low-speed servo motors that are synchronized. If one of motor fails, our IES will enter "limp" mode and will continue to operate until the critical safety algorithms are executed. Then it will shut down.

e-pump Active Cooling System
Our e-pump has machined channels inside the e-pump casing. Our IES circulates coolant through these channels to keep the core temperature of the motor and the hydraulic fluid between 90F and 140F (and no greater than 185F).

Our IES is also capable of cooling the e-pump with forced air when coolant is not available. This may require the addition of copper layers to the e-pump casing that extend to the outside of the e-pump for efficient heat radiation.



e-Pump Built-in Intelligence Self-Diagnostic Algorithm (ISDA)
One of the most significant advantages of using drive-drive servo motors in our IES application is that it permits us to precisely position the motor-gear combo at a specific angle for perfect synchronization. Because both motor-gear systems are equipped with absolute encoders, these positions are recorded and repeated as many times as our motion controller requires.

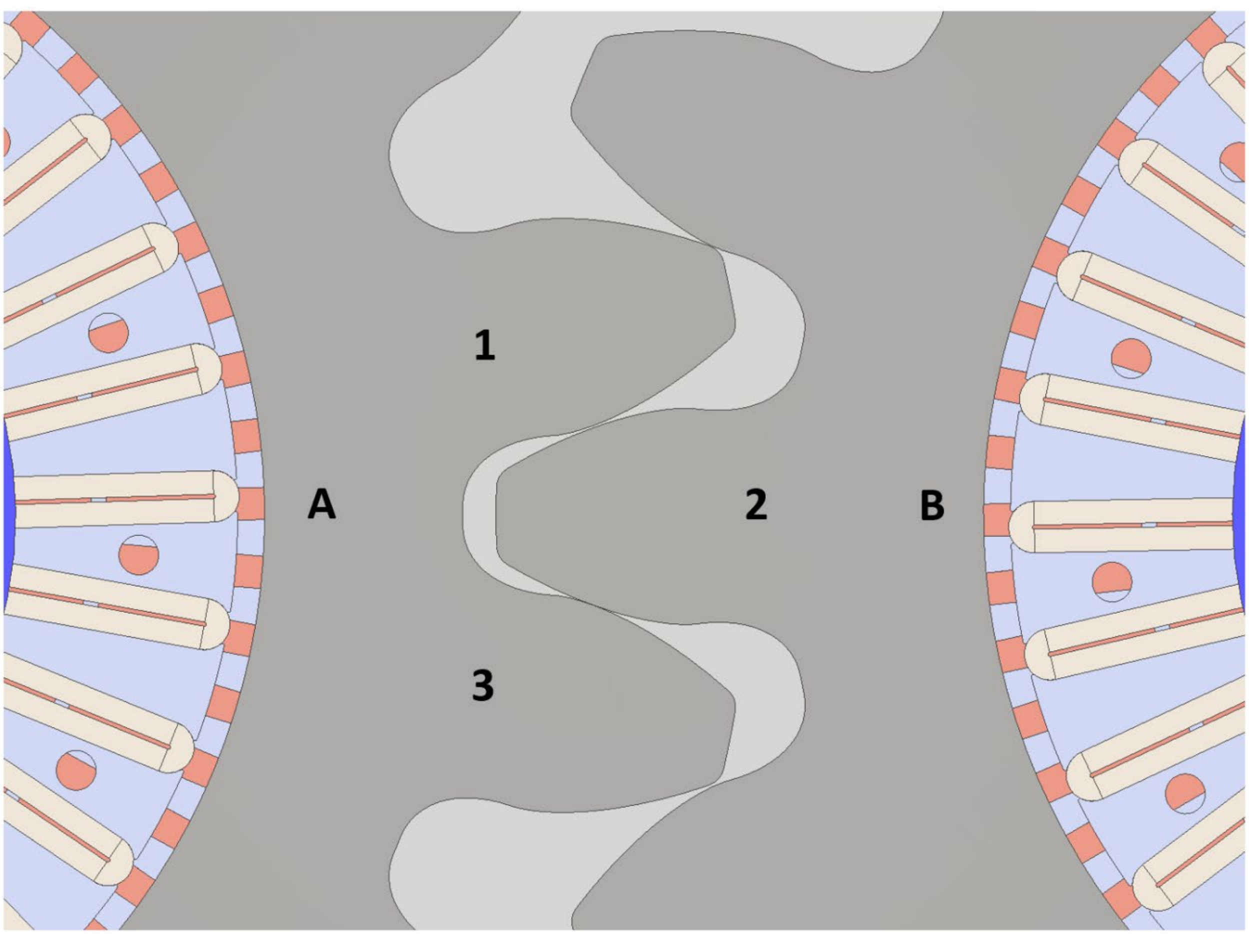
At the time of assembly, the motor-gear combos are synchronized and the position of all the teeth are electronically recorded. We currently use a few methods to synchronize our gear system at the time of manufacturing. Here are some examples:

Degree Positioning System**:** Our current e-pump prototype has 16 teeth. The center of the top land of each tooth is therefore 22.5 degrees from the next tooth. The “Setup Position” of our gear system is set during assembly at 22.5 degrees minus the clearance amount. During operation, any deviation from the Setup Position indicates wear, and will eventually result in loss of sealing torque. Our IES automatically repositions the teeth to accommodate for this wear and to maintain seal. The original Setup Position set during assembly is used to calculate the life expectancy of the e-pump based on the historical wear.

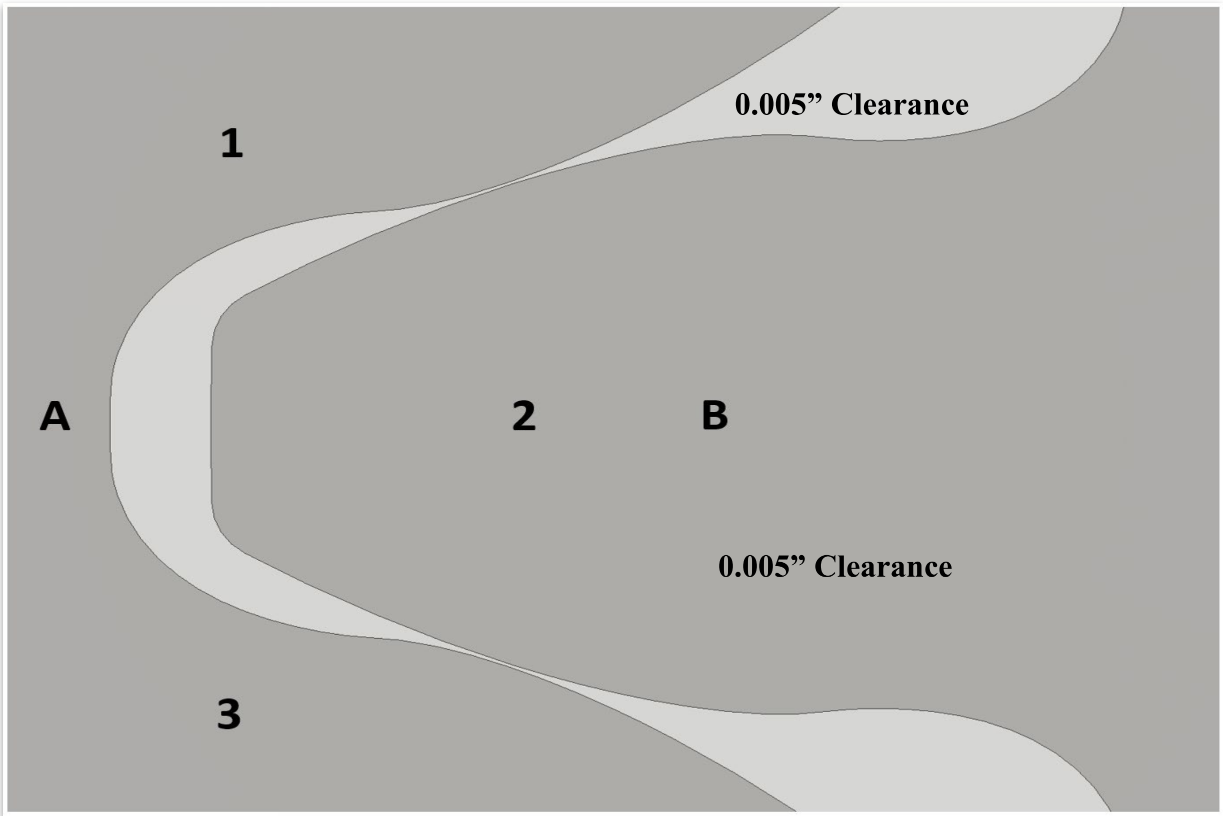
Touch Probe Positioning System**:** We can synchronize the gears and record their position by probing them against each other. By design, our gear system has close tolerances. The clearance between each tooth face is no greater than 0.005 inch on each side.

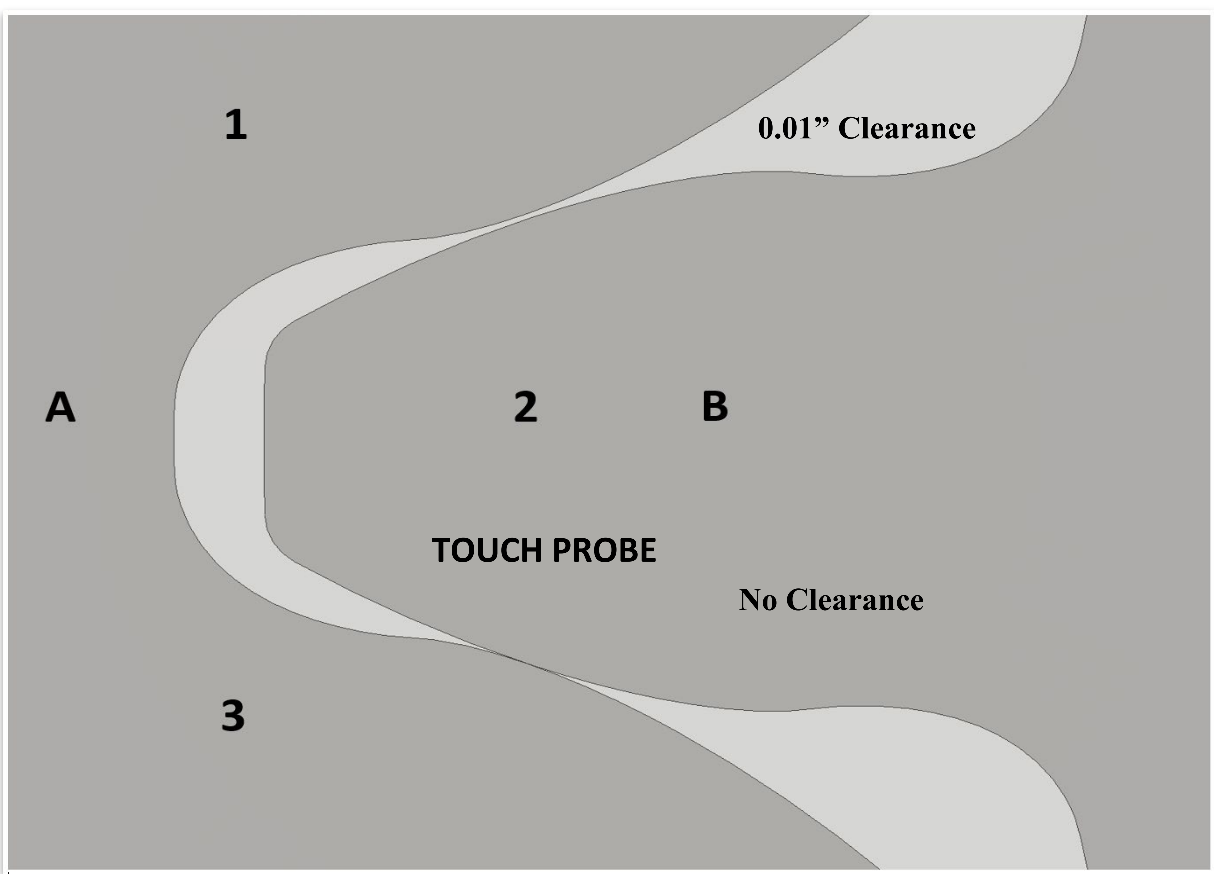
As demonstrated below, the clearance between teeth 1A and 2B and teeth 2B and 3A is 0.005 inch. This would be the base of our e-pump’s gears placement.

After initial rough installation using a minus filler gauge, we apply full break on motor B and command motor A to rotate until tooth 3A touches tooth 2B. This rotation continues until motor A and B measure 5Nm and -5Nm, respectively. At this exact moment, the position of the contact between teeth 3A and 2B is recorded. This process is repeated for teeth 1A and 2B until the entire gear system (360 degrees) is probed. At the end of this process, we can precisely recall the position of each tooth at any moment.



We repeat this process at the beginning and the end of each operating day. As the e-pump suffers wear through operation, the positions of the teeth will change relative to the Setup Position. This change in position is indicative of the e-pump's health. Our IES has a reporting system that tracks the wear and suggests appropriate maintenance protocols.





It is critical for any gear pump to maintain a reliable seal between the teeth face and to maintain a reliable seal between the teeth top land and the pump's casing. It is well known and documented that when gear pumps (in general) lose internal seals, the pump will start to fail. Some of the major indicators of pump failure are contamination created internally by the pump's moving components, as well as pressure drops, heat, and noise. For example, contamination trapped between teeth faces will tend to cause an immediate increase in contact torque. The prolonged wear caused by this contamination and other normal wear and tear will then tend to decrease contact torque.

Our e-pump fully solves this problem by constantly monitoring the contact torque between the gear face and measuring that against the original center-to-center of each tooth's top land position. If the contact torque increases or decreases, the program will offset the original position to maintain the seal.

More specifically, after we gather all the positioning information from ISDA's touch probe positioning system, the e-pump will maintain 0.1 to 5Nm (motor torque) contact between the teeth face. This number is driven by the size of our gear system, mainly based on the face width. (This contact torque is constrained to a specific position within 360 degrees of our gear system.)

e-pump Hybrid Sleep Mode

The e-pump hybrid sleep is designed exclusively for our IES. The hybrid sleep mode is a combination of sleep and hibernation. This permits the operator to quickly resume working when ready.

e-pump Built-in Energy Regeneration and Storage Unit (ERSU)

In every configuration of our e-pump, we have the option of recovering some of the lost energy in the system by combining the hydraulic platform's weight and Earth's gravity. By adding this option to our IES, we are able to operate the e-pump's internal electric motors as generators and store energy. The stored energy may be used to assist the next operation cycle.

Hypothetical example: Missile launcher. In a missile launcher, the hydraulic lift platform weighs approximately 4 tons, the missiles weigh 2 tons and we need to lift the combination of the lift platform and the missiles to 10 feet or 60 degrees. After the missiles are launched or the launch is aborted, the lift platform must retract to its original position. By controlling our e-valves to restrict the retracting fluid back to the e-pump, we can control the retraction speed and allow the motors inside the e-pump to generate electricity. Generated electricity will be stored and may be used to assist the next launch cycle.

e-pump on Demand Variable Flow and Variable Pressure Capability

In light of the versatility of electric motors to supply variable power (torque and speed), our IES is able to control the electric motors to output a specific speed and torque for a specific cycle. The control unit is programmed with the motors upper and lower performance chart to avoid any potential damage to the motors inside the e-pump. The control unit will manipulate the motor torque for a specific hydraulic pressure and motor speed for a specific hydraulic flow.

Patents

<u>DriveDrive Power E-Pump with External Motors</u>

The DriveDrive Power e-pump with external motors is a positive-displacement external gear pump that includes two spur gears. The spur gears are independently driven by two servo motors mounted external to the pump casing.

<u>Covered by:</u>
U.S. Patent No. 9,228,586

<u>DriveDrive Power E-Pump with Internal Motors</u>

The DriveDrive Power e-pump with internal motors is a positive-displacement external gear pump that includes two spur gears. The spur gears are independently driven by two servo motors mounted in the spur gears internal to the pump casing.

<u>Covered by:</u>
U.S. Patent No. 9,228,586
U.S. Patent No. 9,920,755
U.S. Patent No. 11,118,581
Patent Pending: U.S. Patent Application No. 17/411,326