Rotary Motion vs Linear Motion vs Magnetic Fluids for Power

Technical comparison of electric motors, hydraulic motors/cylinders, and ferrofluid & magnetorheological (MR) fluid devices · Infinity Turbine LLC · November 2026

1. Executive summary

Bottom line: Electric and hydraulic machines are *power-conversion* technologies that move kilowatts to megawatts continuously. Ferrofluids and the related "semi-magnetic" fluids (MR fluids) are *power-control and interface* materials: they excel at sealing, damping, clutching and braking, but they are not a practical primary source or carrier of bulk mechanical power. Use electric drives for efficiency and control, hydraulics for force density and shock tolerance, and magnetic fluids as enablers inside both.

ELECTRIC

Highest efficiency (90–97%), precise control, low maintenance. Rotary is mature and cheap; linear motors give direct-drive precision at modest force.

HYDRAULIC

Highest force and torque density, stall-tolerant, shock-tolerant. Cylinders dominate heavy linear work. System efficiency is typically 40–70%.

MAGNETIC FLUIDS

Ferrofluids: seals, cooling, damping, µW–mW energy harvesting. MR fluids: controllable clutches, brakes and dampers. Not a bulk power source.

2. Definitions and scope

Category	What it is	Representative devices
Rotary motion	Output is shaft torque × speed (P = T·ω).	AC induction, PMSM/BLDC, switched-reluctance motors; hydraulic gear, vane, gerotor/orbital, axial- and radial-piston motors.
Linear motion	Output is force × velocity (P = F·v).	Linear PM/induction motors, voice coils, ball/roller-screw actuators; hydraulic cylinders, hydraulic linear actuators.

Category	What it is	Representative devices
Ferrofluid	Colloidal suspension of ~10 nm magnetic nanoparticles (magnetite) with surfactant in a carrier oil or water. Stays liquid in a field; does not develop yield stress.	Rotary shaft seals, loudspeaker cooling/damping, inertial dampers, thermomagnetic pumps, lab-scale energy harvesters.
MR fluid ("semi-magnetic")	Suspension of larger 1–10 µm iron particles. In a field it turns semi-solid within milliseconds, with yield stress up to ~50–100 kPa.	MR clutches, brakes, vehicle/seismic dampers, haptic devices, prosthetic knees.

3. Rotary motion: electric motor vs hydraulic motor

Parameter	Electric motor	Hydraulic motor
Operating principle	Lorentz/reluctance force between stator field and rotor.	Pressurized fluid (typically 200–420 bar) acts on gears, vanes or pistons.
Power range	Watts to more than 100 MW	~1 kW to several MW (large radial-piston units)
Power density (machine only)	Industrial ~0.2–1 kW/kg; high-performance PM ~3–10+ kW/kg	Axial-piston ~5–10+ kW/kg (excluding pump, tank and HPU)
Torque at low speed	Needs a gearbox or large-diameter torque motor for high torque at low rpm.	Excellent. Radial-piston motors deliver very high torque at 0–100 rpm without a gearbox.
Stall / overload	Stall causes overheating; current limiting is needed.	Can stall indefinitely at full torque because the relief valve protects it.
Efficiency (machine)	90–97% (IE3–IE5, PMSM)	80–92% (piston); 60–85% (gear/vane)
Efficiency (wire/shaft → output)	~85–95% with VFD	~40–70% overall (motor + pump + valves + lines + cooling)
Control	Excellent: VFD/servo, precise speed and position, regenerative braking.	Good with proportional/servo valves; displacement control improves efficiency.
Environment	Sensitive to water and heat unless sealed; explosion-proof versions are costly.	Tolerant of dirt, shock, vibration and wet conditions; intrinsically spark-free.
Maintenance	Low (bearings only)	Moderate to high (fluid, filters, seals, hoses, leaks)
Noise	Low	Moderate to high (pump noise, pressure ripple)

Parameter	Electric motor	Hydraulic motor
Typical uses	Pumps, fans, compressors, EVs, generators, robotics, conveyors.	Winches, excavator swing/track drives, mining, marine deck machinery, drilling.

4. Linear motion: electric linear vs hydraulic cylinder

Parameter	Electric linear (direct-drive motor / screw actuator)	Hydraulic cylinder
Force capability	Direct-drive linear motor: ~0.1–20 kN continuous. Roller-screw actuator: up to ~500 kN+.	Very high: kN to several MN. F = P·A, so a 100 mm bore at 300 bar gives ~235 kN.
Force density	Linear motors are limited by magnetic shear stress (~20–100 kPa air-gap).	Pressure 20–42 MPa, roughly 200–1000× the magnetic shear stress per unit area.
Speed / acceleration	Linear motors: up to 5–10 m/s and more than 10 g, with sub-µm precision.	Typically 0.05–1 m/s. Faster speeds need large flow.
Precision	Excellent (nm–µm with encoders)	Good with servo valves (~10–100 µm); compliance from oil compressibility.
Holding a load	Linear motor needs continuous current. Screws can be self-locking or braked.	Holds with pilot-operated check or counterbalance valves at near-zero power.
Efficiency	Linear motor ~70–90%. Ball screw ~85–95% mechanical.	Cylinder ~90–95%. Throttled valve system ~30–60% overall.
Shock loads	Screws and bearings can be damaged by impact.	Excellent. Oil plus relief valves absorb impact.
Typical uses	Semiconductor stages, CNC, packaging, maglev, pick-and-place.	Presses, excavator booms, lifts, steering, injection molding, heavy fixtures.

> **Trend:** Electro-hydraulic actuators (EHAs) combine a servo motor, a small pump and a cylinder in one sealed unit. They keep hydraulic force density while delivering power only on demand, which raises system efficiency to roughly 60–80% and removes the central HPU and hose runs.

5. Ferrofluids and MR fluids for power

5.1 Ferrofluid: what it can and cannot do

Application	Mechanism	Power scale	Maturity
Rotary vacuum and pressure seals	Ferrofluid O-rings held in the gap by permanent magnets. Zero leakage and near-zero friction.	Enabler for shafts transmitting kW–MW	Commercial (semiconductor, vacuum, lasers)

Application	Mechanism	Power scale	Maturity
Thermal management	Fills the voice-coil gap to conduct heat and damp resonance; thermomagnetic convection.	W-scale heat transfer	Commercial (loudspeakers)
Thermomagnetic pump / engine	Magnetization falls with temperature near the Curie point, so a field plus a temperature gradient drives flow with no moving parts.	mW–W lab scale; very low efficiency (<1–2% of Carnot)	Research
Energy harvesting	Sloshing ferrofluid changes flux in a pickup coil (vibration, waves, motion).	µW–mW (some prototypes reach tens of mW)	Research / niche sensors
Damping and bearings	Inertial dampers, levitation of non-magnetic bodies, ferrofluid bearings.	Passive	Commercial niche

5.2 MR fluid: controllable power transmission

MR fluids do transmit real torque. In a shear-mode clutch, torque ≈ $\tau_y(B)$ × area × radius. At τ_y ≈ 50–100 kPa, a compact multi-disc MR clutch can transmit hundreds of N·m with electrical control in ~5–20 ms and no wear-contact friction. They control power that comes from somewhere else. They do not generate it.

- **Strengths:** fast, continuously variable torque/damping, simple mechanics, fail-safe options with permanent magnets, quiet.
- **Limits:** slip losses become heat, particle settling and in-use thickening over time, off-state viscous drag, heavy fluid (~3–4 g/cm³), coil power needed.
- **Uses:** vehicle adaptive suspension, seismic building dampers, robot clutches and torque limiters, exercise and haptic brakes, prosthetics.

> **Why ferrofluid is not a bulk power medium:** Its saturation magnetization (~20–90 kA/m) is far below solid iron (~1700 kA/m), and its magnetic pressure is only kPa-scale. Hydraulic oil carries 20–40 MPa, about 10,000× more. Ferrofluid power devices therefore stay at milliwatt to watt levels, except for seals and dampers that serve conventional machines.

6. Head-to-head comparison matrix

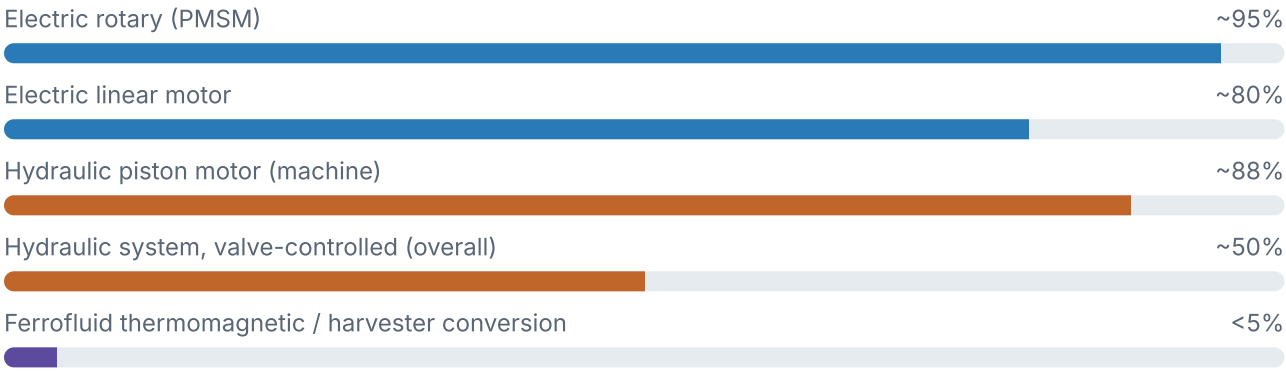
Criterion	Electric rotary	Electric linear	Hydraulic motor	Hydraulic cylinder	Ferrofluid	MR fluid
Role	Power conversion	Power conversion	Power conversion	Power conversion	Seal / thermal / harvest	Power control
Practical power	W – 100+ MW	W – 100s kW	kW – MW	kW – MW	µW – W	Controls W – 10s kW
Characteristic stress	Air-gap shear 20–100 kPa	Air-gap shear 20–100 kPa	20–42 MPa	20–42 MPa	~1–10 kPa magnetic pressure	Yield 50–100 kPa
Efficiency	90–97%	70–90%	80–92% (machine)	90–95% (cylinder)	<5% (conversion)	N/A (slip = loss)
Force / torque density	Medium	Low–medium	Very high	Very high	Very low	Medium
Precision	Excellent	Best	Good	Good	N/A	Good (torque)
Response time	ms	sub-ms	10–50 ms	10–50 ms	Slow (thermal)	5–20 ms
Maintenance	Low	Low	Med–high	Med–high	Low	Medium (fluid life)
Relative cost / kW	Low	High	Medium	Low–medium	High (per W)	Medium
Maturity	Very mature	Mature	Very mature	Very mature	Niche / research	Commercial niche

Relative scores (1 = poor, 5 = best)

Criterion	Electric rotary	Electric linear	Hydraulic motor	Hydraulic cylinder	Ferrofluid	MR fluid
Energy efficiency	●●●●●	●●●●○	●●●○○	●●●○○	●○○○○	●●○○○
Force / torque density	●●●○○	●●○○○	●●●●●	●●●●●	●○○○○	●●●○○
Controllability	●●●●●	●●●●●	●●●○○	●●●○○	●●○○○	●●●●○
Robustness / shock	●●●○○	●●○○○	●●●●●	●●●●●	●●●○○	●●●●○

Criterion	Electric rotary	Electric linear	Hydraulic motor	Hydraulic cylinder	Ferrofluid	MR fluid
Maintenance burden (5 = least)	●●●●●	●●●●○	●●○○○	●●○○○	●●●●○	●●●○○
Scalability to MW	●●●●●	●●○○○	●●●●○	●●●●○	●○○○○	●●○○○

Efficiency at a glance (typical device efficiency)



7. Selection guide

If you need...	Choose	Why
Continuous rotation, best efficiency, grid or battery supply	Electric rotary	90–97% efficient, low maintenance, mature VFD control.
High torque at very low rpm, harsh environment	Hydraulic motor	No gearbox, stall-proof, shock-tolerant, spark-free.
Very high linear force (presses, booms, lifts)	Hydraulic cylinder or EHA	MPa-level pressure gives unmatched force per volume.
Fast, ultra-precise linear positioning	Linear motor	No backlash, high acceleration, nm-level resolution.
Hermetic rotating shaft seal (vacuum, sCO_2, gas)	Ferrofluid seal	Zero-leak, low-friction dynamic seal. Check pressure-per-stage limits (~0.2–0.3 bar per stage, multi-stage to a few bar).

If you need...	Choose	Why
Variable torque coupling, braking or damping	MR clutch / damper	Millisecond electronic control of torque transfer without wear contact.
Self-powered sensor from vibration or waste heat	Ferrofluid harvester	No moving solid parts. Suitable for µW–mW loads only.

> **Note for high-pressure turbomachinery (e.g., sCO_2):** Ferrofluid seals cannot hold supercritical CO_2 pressures (75–250 bar) on their own. CO_2 can also degrade some carrier oils. Use them, if at all, only as a low-pressure buffer or vent-side seal behind dry-gas or labyrinth seals, and verify carrier-fluid compatibility.

8. Conclusions

- **Electric drives** win on efficiency, control and lifecycle cost for most rotary applications and for precision linear motion.
- **Hydraulics** win on force and torque density, low-speed torque and ruggedness. EHAs and displacement-controlled systems are closing the efficiency gap.
- **Ferrofluids** are valuable as seals, thermal media and micro-harvesters. Their magnetic pressure is about four orders of magnitude below hydraulic pressure, so they are not viable for bulk power.
- **MR fluids** are the "semi-solid" bridge: they transmit and modulate real torque and force electronically, but they are a control element, not a power source.

Figures are typical engineering ranges compiled from manufacturer data and technical literature. Specific products vary, so verify against vendor datasheets for design work.

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