HARTENERGY

Hydraulic Fracturing Techbook

2018

A supplement to E&P

SPONSORED CONTENT

Economics of Frac Pump Fluid Ends

Two reliability measures that can help reduce TCO and NPT. *(Potentially $1,000,000 annual savings on a 20 Pump Frac Fleet)*

"How many hours do your fluid ends get?" It's a common question in the "frac patch" – and one of the most difficult to legitimately answer. Hours alone do not kill fluid ends on positive-displacement frac pumps. Two primary "killers" lead to the seven widely accepted failure modes:

1. **High pumping pressures** – pushes metallurgy tensile strength beyond endurance limit
2. **Inadequate maintenance** – an age-old problem for mechanical equipment

The "fluid-end hours" question is a holdover from a pre-stainless steel era before ~2013. Until five or six years ago, 4330 carbon steel was industry standard metallurgy for fluid ends. For decades, frac crews rarely ever pumped at pressures over 5,000 to 6,000 psi. Lower pumping pressures typically kept intersecting bore stresses below carbon steel's limits. The highly corrosive nature of proppants chemically and mathematically cut carbon steel's endurance limit in half.

As frac treating pressures climbed toward 10,000 psi and higher, it was only a question of "when" carbon-steel fluid ends would crack. Internal stresses at intersecting bores increase exponentially as pumping pressures increase beyond 8,500 psi, so carbon-steel fluid end operating life became shorter and shorter. Before widespread migration to stainless steel, fluid-end life expectancy had dropped to 150-250 high-pressure pumping hours.

Accurately answering the *hours* question requires defining "hours." Percentage of engine hours? Or transmission hours? Or accurately recorded high-pressure pumping hours? Many pressure pumpers once believed fluid ends pumped upwards of 80% of engine hours. Yet, closer analysis does not correlate unrealistic pumping hour estimates to nominal pump use. High-pressure pumping hours by realistic estimations fall in the ~20% vicinity of engine hours.

Frac 1 CONNECT™

Frac fluid ends are still considered expendable – albeit the most costly expendables on a frac spread. When a fluid end must be swung from the pump for repair or maintenance, it is easy to lose track of pumping time to-date on a unit, then "best guess" hours when it returns to service. Maintaining frac pumps is challenging; keeping accurate service records adds to the challenge.

The number of high-pressure hours a fluid end can withstand is highly debated. A fluid end may fail in two hours if a packing-bore greaser malfunctions. A fluid end may last 200 pumping hours and experience a valve seat-deck washout. Or it may accumulate 2,000+ pumping hours before it is decommissioned and retired to the boneyard. Its ultimate failure mode is determined by random operating conditions and thoroughness of routine maintenance.

Five fluid-end failure modes were identified in a 2016 *Upstream Pumping* article "The Five Failures of Fluid Ends." Kerr Pumps addressed these failure modes with its Super Stainless™ metallurgy, design-specific intersecting bore geometries, and patented Super Seal™ technology in the packing, suction and discharge seal bores. With longer operating life, two more failure modes occur at a growing rate: Thread cracking/face peeling at the suction retaining nut, and opposing stress-cracking at the connecting flange.

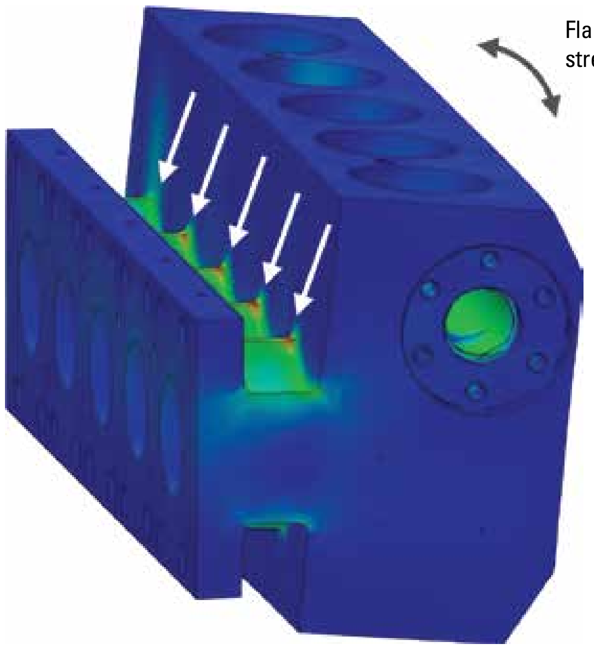
Kerr Pumps responded to the 6th and 7th failure modes with the January 2018 rollout of its patent-pending Frac 1 CONNECT™ fluid end. The F1C™ incorporates a bolt-on cover cap to disperse cyclic stress (more than 287,000 pounds) on suction caps across eight, gall-free studs and nuts.

Additionally, Kerr Pumps engineers began seeing minute flexing cycles at the connecting flange in FEA simulations. This led to a two-piece flangeless design that attaches a highly rigid CONNECT™ plate to the power-end's stay rods. With a Frac One™ fluid end attached to a CONNECT™ plate, flexing movement was reduced by 420% –likely contributing to longer packing and stay-rod life observed in field trials.

Reliability is Like Buying Uptime

Fracs are more efficient when pumps have less down time –longer operating life at lower total cost. Two widely accepted Key Performance Indicators (KPIs) for frac equipment are:

- Total Cost of Ownership (TCO) – accumulated costs over equipment's operating life
- Non-Productive Time (NPT) – time on site when planned work cannot be performed



Frac fluid-end TCO can be significantly higher when full operating life is shortened by premature failure. Total costs accumulate rapidly when routine maintenance occurs at compressed intervals. Arguably the most menacing demon on frac jobs is NPT – missing schedules when a pump is offline. Like any corporate asset, it is not Returning On the Investment (ROI) when it is not generating profitable revenue.

To improve these time-related KPIs, it pays to find ways to extend these *reliability* measures:

- MTBM – Mean Time Between Maintenance
- MTBF – Mean Time Before Failure

Make no mistake: High-pressure fracturing today is arguably the most intense it has been. With the capital required for hour-by-hour, stage-by-stage, job-to-job operations, reliability affects both time and cost. Yet many component suppliers grew to market-controlling proportions via simple "razor and blade" planned obsolescence replacement models. With lower commodity pricing, increased efficiency across the supply chain is required. Extending MTBM and MTBF can drive substantial time and cost savings.

Extending Mean Time Between Maintenance (MTBM)

Most frac service providers accept some basic assumptions about maintenance cost and intervals on valves and valve seats. To keep it simple, assume a fluid end pumps 10 hours/day for 20 days/month. In six months, this accumulates 1,200 pumping

TABLE 1: PURCHASE PRICE AND VALVE SEAT MAINTENANCE COST COMPARISON

Fluid End plus Valve Seat Maintenance Costs	6 Month Total		
	Legacy	F1C	Savings
Fluid End Cost	$62,000	$49,995	19%
Valve Seats	$20,800	$6,540	69%
6 Month Total	**$82,800**	**$56,535**	**32%**
12 Months	**$165,600**	**$113,070**	**$52,530**
20 Pump Fleet	**$3,312,000**	**$2,261,400**	**$1,050,600**

hours, respectable fluid-end operating life assuming no irreparable failures.

This translates to two fluid ends per pump each year. An hour of a maintenance technician's time is estimated (fully burdened) at $100 per hour, not including truck and tools sunk costs or travel time. The fluid end model for this analysis is a 10-inch between center-bore quintuplex running #4 valves and valve seats. The Legacy flanged-style fluid end costs $62,000 and the Frac 1 CONNECT™ costs $49,995 (table 1). Opportunity cost for a Legacy-style fluid end idled for repairs will be the expense of purchasing a new fluid end as a temporary replacement.

Traditional Valves and Valve Seats

Valves are the first internal consumables routinely replaced. Industry standard valves on average cost $50 each. Ten valves per quintuplex fluid end are typically swapped out after 25-35 hours of harsh environment pumping and depending on proppant pumped. It is commonly accepted the second valves on a set of valve seats lasts 75-80% as long (because preceding valves slightly deformed each seats' strike-face). Kerr Pumps is field testing a valve design engineered to extend the maintenance interval at a commensurate price point that does not affect the valve seat strike-face. On average, traditional valve seats cost $60 each and are swapped on 30-60 hour increments.

Super Seat™

Super Seats™

Fluid-end technicians dread valve seat replacement. Kerr Pumps' patent-pending Super Seat™ reliably extends maintenance intervals over five times (v. traditional valve seats) in the worst pumping environments – and measurably longer in more favorable conditions.

The patent-pending "shoulderless" seat with tungsten carbide ring at the strike-face has consistently performed up to 5X (and sometimes 10X) longer for less than 2X cost ($89 for a #4 valve seat). Kerr Pumps' Super Seats™ consistently ran up to 200 pumping hours in the Haynesville Shale before routine replacement as a precaution.

Extending Mean Time Before Failure (MTBF)

Fluid-end failures are an unfortunate reality with intense duty cycles in harsh environments. Yet seeking incremental increases in operating life within the economic limits of today's frac patch can be a challenge.

Anyone reading this who has ever tackled economic time and cost analysis understands the many unexpected frac job variables that can make a well-thought, controlled analytical study look absolutely out of control. Anything that *can* happen, *might* happen. Should one factor for each "what if" potential failure mode to build a "contingency bank" of time and money?

In 2014 Kerr Pumps entered the market with replacement fluid ends for standard frac pumps and began experiencing varied failures at frequencies similar to other suppliers. Intersecting bore cracks are the kiss of death; that fluid end is destined for the boneyard. Shifting to stainless steel pushed intersecting bore cracking out to a high-hour, end-of-life failure mode – if it happens at all anymore.

Packing-bore Washout

Packing-bore washout is today's most prominent failure mode (roughly 40% of all fluid ends). It isn't a widow-maker, but it can sideline Legacy-style fluid ends for a $5,000 per-bore weld repair (including transportation) for up to two months. A $62,000 backup fluid end must be purchased as a replacement (table 2). Maintenance usually requires a couple of hours for each fluid end swing with two service technicians. Plus, it is widely acknowledged that most weld repairs may only return a fluid end to operating service for another ~150 pumping hours before end-of-life cracking failure. Total cost includes two months' downtime –*lost opportunity cost* – plus premature cost of a replacement fluid end.

Kerr Pumps' *Transfer the Wear*™ design philosophy inspired its patented Super Seal technology with removable stuffing box sleeve in the packing bore. If packing-bore washout occurs with a Frac 1 CONNECT™ fluid end, washout transfers to an $800 sacrificial sleeve that can be changed in the field if necessary. No material downtime alleviates need for a redundant fluid end.

Seat-deck Washout

The next most common and often life-ending failure mode is valve "seat-deck washout" at the lower suction valve seat deck. This begins with valves' constant high force hammering onto seats at the strike-face. The OD of the metal-to-metal strike-face is near directly aligned above the landing deck circumference for the seat (on the fluid end), so a radial shear point can start. Under the right random conditions, this shear point weakens and allows high-pressure fluid to jet through the seat to create seat-deck washout failure. As in packing-bore washout, this area can sometimes be weld-repaired for similar $5,000 cost. This requires two service technicians for two, 2 hour fluid end swings, and a replacement fluid end for two months out-of-service downtime.

Kerr Pumps' answer to seat-deck washout is its patent pending Super Seat™ design. It eliminates the shoulder and almost any possibility of seat-deck washout. A tungsten carbide ring at the metal-to-metal strike-face withstands the valve's high force pounding. Through seven months field testing, the Super Seat™ design eliminated seat-deck washout. There were no weld repair costs or out-of-service downtime, nor need for replacement fluid ends.

Suction-Cap Thread Cracking, Face Peeling and Seizing

Transition to stainless steel fluid ends slowly extended operating life and revealed the next weakest link in the chain: thread cracking / face peeling on the front suction side. Thread cracking results as suction retaining nuts back-out ever so slightly and begin pulsating with plunger pumping. Threads are inherently machined stress risers. Tiny fractures can form along the second or third thread from the front on the cap and inside the front suction bore.

Face peeling is when that superficial crack occurs inside a suction bore, then propagates outward to the fluid end's front surface, producing a visible circular fissure around the weakened bore. This failure mode usually does not occur until 500-600 pumping hours, but it is a catastrophic fatigue failure. It immediately removes a fluid end from service and requires a new replacement.

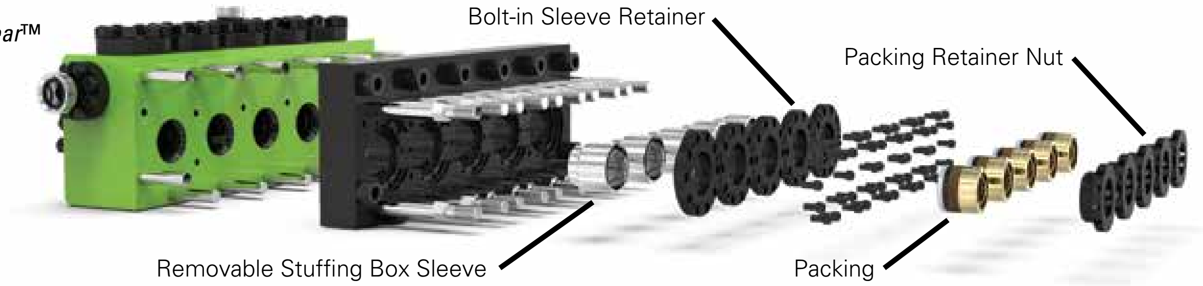
TABLE 2: EXTENDED OPERATING LIFE COST COMPARISON

Packing Bore Washout at 600 hours	Legacy	F1C	
Fluid End Washout Weld Repair Cost	$5,000		
Replacement Fluid End Cost (while original out for weld repair)	$62,000		
Replacement Sleeve		$800	
Service Technician Cost	$800	$400	
Total Legacy Replacement FE or F1C Repair	**$67,800**	**$1,200**	
6 Month Total (*table 1*)	**$82,800**	**$56,535**	
6 Month Maintenance, Repair and Replacement FE Total	**$150,600**	**$57,735**	**Savings 62%**

One cannot exaggerate how punishing duty-cycles affect frac-pump systems. As frustrating as thread cracking and face peeling can be, imagine another extreme situation when a front side cover cap is completely seized in the bore! This can happen when cracked threads cross paths or foreign debris becomes impregnated on opposing thread faces from the load created with each plunger stroke.

Kerr Pumps engineers conducted a root cause failure analysis of this increasingly problematic scenario. Their findings proved over 287,000 pounds of cyclic load can be forced upon a retainer nut with a 4.50" plunger when pumping at 12,000 psi. Such a pressure load would require 19,404 lb-ft of torque on the cap to overcome that cyclic stress. Add galling plus wear and tear on fluid-end and retainer-nut threads. Result? Regular thread cracking.

Thread cracking/ Face peeling

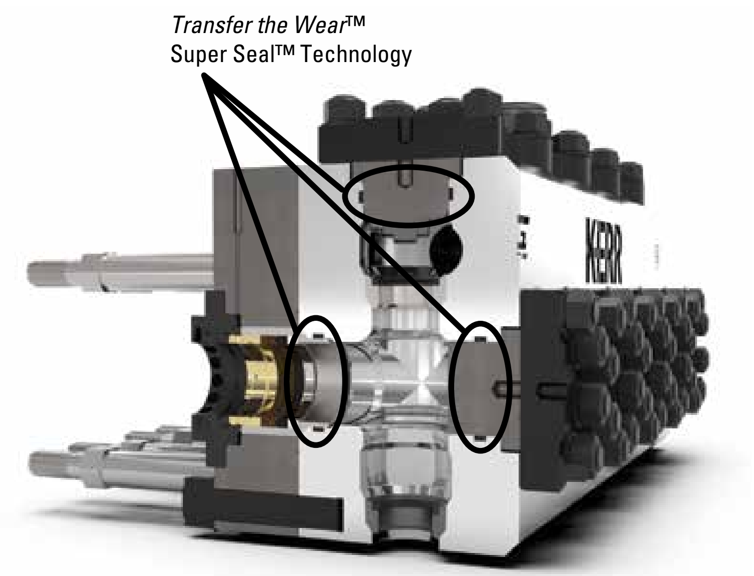


In 2017 Kerr Pumps created its patent-pending Frac One™ bolt-on cover cap design to combat this problem. By spreading load to 8 studs per front bore, load for each stud was reduced to only 35,934 pounds. Now each nut needs only 700 lb-ft of torque to dissipate cyclic stress.

Packing Retainer Nut Damage

Whether related to maintenance or intense pulsation, a threaded packing retainer nut on the plunger side of a fluid end will gradually back-out from pulsation. Once a packing retainer nut enters the stroke of a plunger clamp, the clamp begins smashing into the backed-out nut.

In a Legacy fluid-end this hammering effect likely will damage threads cut into the fluid end to hold it –even to irreparable failure. To remove all threaded bore connections, Kerr Pumps utilized a bolt-in sleeve retainer that is ID threaded for the packing retainer nut. If a packing nut backs out and gets hammered in by the plunger clamp, it is a simple fix to replace the sacrificial bolt-in sleeve retainer.



Washboarding

The next three failure modes are less common, but happen nonetheless. They are: pulsation wear or "washboarding" in the fluid end at the packing on the packing bore, and at the D-rings around the suction and discharge plugs. Leakage through a wear ring (or series of rings in the case of packing washboarding) may occur in the suction or discharge bores. The remedy (again) is costly weld repair and up to two months downtime. Experience shows these welds are further away from the intersecting bore and usually last the remaining expected life of the fluid end.

Kerr Pumps' answer to this failure is to *Transfer the Wear*™ to a sacrificial suction or discharge cap (or removable stuffing box sleeve), away from the expensive fluid end. Transferring wear is the primary way a Frac 1 CONNECT™ fluid end extends its useful operating life and reduces Total Cost of Ownership.

The Economic Differences

Solving the first five failure modes incrementally extended fluid ends' useful operating life. These plus the next weakest links (sixth and seventh failure modes) collectively inspired Kerr Pumps to develop, design and deploy the Frac 1 CONNECT™ fluid end.

The frac industry is still recovering from its worst recorded downturn. Pressure pumpers and their customers demand more efficient fracs driven by new technologies at a lower price. Kerr Pumps accepted that challenge and delivered its Frac 1 CONNECT™ with greater reliability (longer MTBM and MTBF) to reduce TCO and NPT. ■

FRAC ONE CONNECT

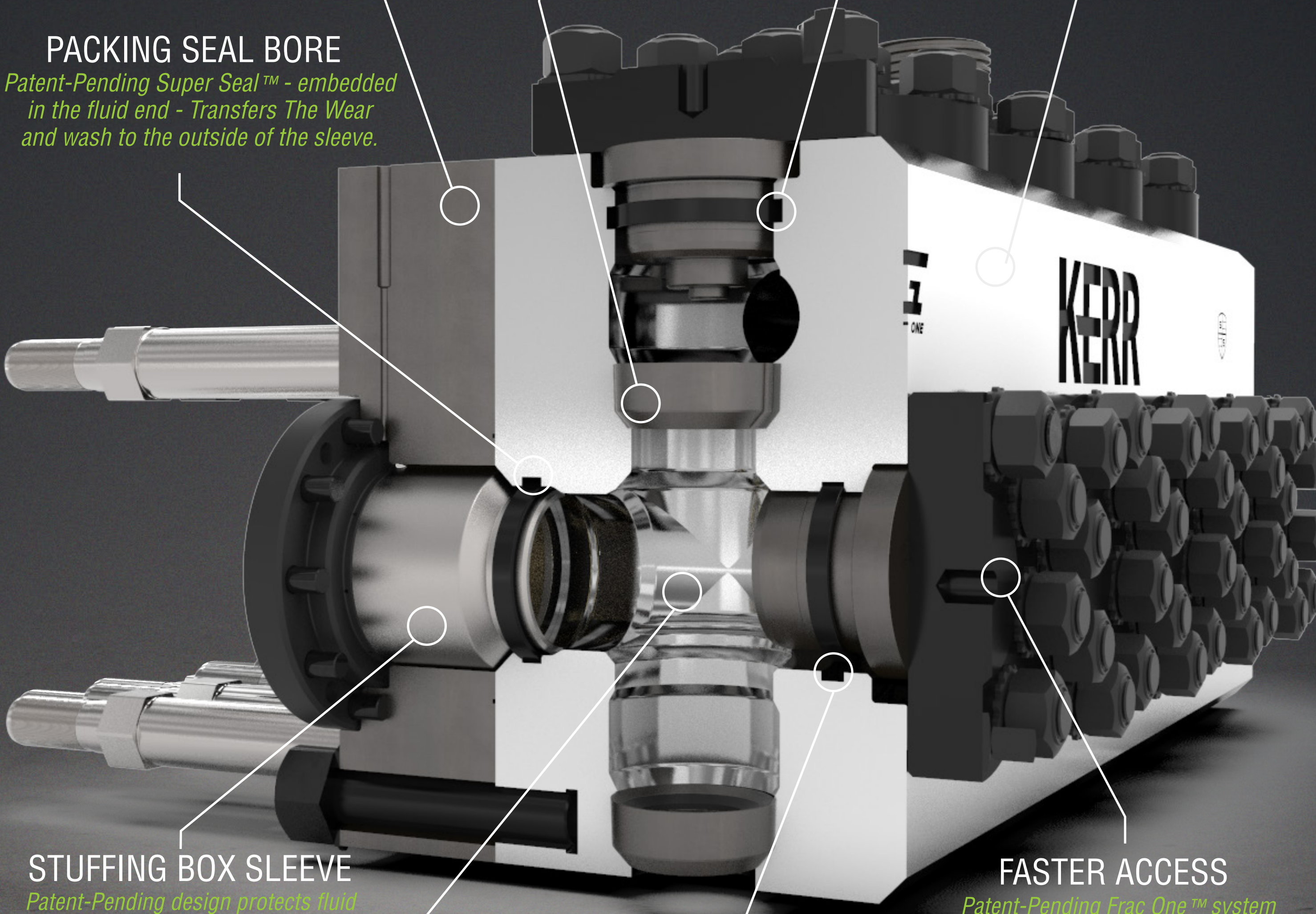
SUPER STAINLESS II™
The strongest and toughest stainless steel ever used in a frac fluid end.

CONNECT™ PLATE
Connects right up to your existing stay rods with a stronger connection. Removing the flange reduces flexing of the fluid end by 420%.

DISCHARGE SEAL BORE
Patent-Pending Super Seal™ - embedded in the fluid end - Transfers the Wear to the discharge plug.

SUPER SEATS™
Patent-Pending tungsten carbide valve seats last up to 10X the life.

PACKING SEAL BORE
Patent-Pending Super Seal™ - embedded in the fluid end - Transfers The Wear and wash to the outside of the sleeve.



STUFFING BOX SLEEVE
Patent-Pending design protects fluid end from washouts and washboarding.

FASTER ACCESS
Patent-Pending Frac One™ system torques each cylinder out of cyclic stress. Eliminates thread cracking of the fluid end. Safer to operate by eliminating the need for sledge hammers or hammer wrenches.

SUCTION SEAL BORE
Patent-Pending Super Seal™ embedded in the fluid end - Transfers The Wear to the suction plugs.

IMPROVED GEOMETRY
Precision Machined, Repeatable Geometries for Optimized Performance

Kerr Pumps | +1 (580) 622-4207 | KerrPumps.com
2214 W 14th Street, Sulphur, Oklahoma, USA

KERR PUMPS