DFE

Dynamic Filter Efficiency

HY-PRO

hyprofiltration.com/

What is DFE?

DFE matches filter testing with real-life conditions

All hydraulic and lube systems have a critical contamination tolerance level that is often defined by, but not limited to, the most sensitive system component such as servo valves or high speed journal bearings. Defining the ISO fluid cleanliness code upper limit is a function of component sensitivity, safety, system criticality and ultimately getting the most out of hydraulic and lube assets.

Filters remove the particulate contamination that enters a system or is generated by the system as it operates. All filters are subjected to some form of system dynamics: hydraulic filters encounter frequent and rapid changes in flow rate when valves shift, cylinders unload and pump output changes; lube filters experience dynamic conditions during start up and shut down. Filters validated only to current ISO testing standards don't perform as expected when subjected to the demands of real world dynamic operating systems.

A filter is not a black hole. Two key characteristics of filter performance are capture efficiency and retention efficiency. Capture efficiency can be thought of simply as how effectively a filter captures particles while retention efficiency is a measure of how effectively that filter retains the particles it has captured. A filter is not a black hole, and its performance must not be based solely on how efficiently it captures particles. If not properly designed and applied, a filter can become one of the most damaging sources of contamination in a system if it releases previously captured particles when challenged with dynamic conditions.

The Dynamic Filter Efficiency Test (DFE) is the evolution of standard hydraulic and lube filter performance testing. DFE goes further than current industry standards to quantify capture and retention efficiency in real time by inducing dynamic duty cycles, measuring real- time performance during dynamic changes and the filters ability to retain particles. DFE testing is the method for predicting worst case fluid cleanliness along with average fluid cleanliness. The DFE test method was pioneered in 1998 during a joint effort between Scientific Services Inc (SSI) and Hy-Pro Filtration.

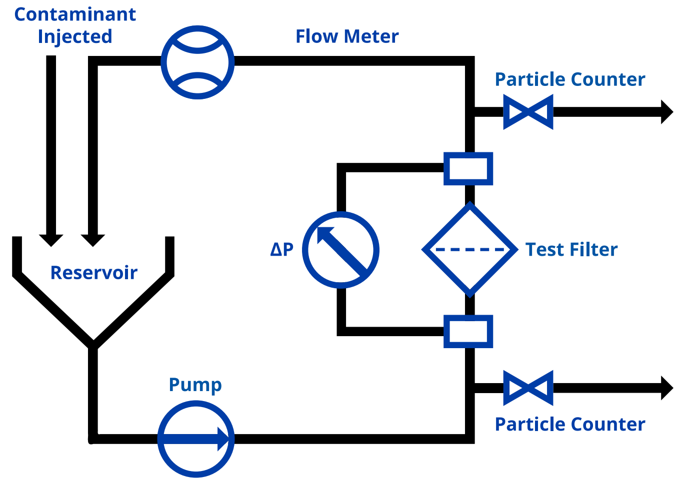
Dynamic Filter Efficiency

Current Filter Performance Testing Methods

To understand the need for DFE it is important to understand how filters are currently tested and validated. Manufacturers use the industry standard ISO16889 multi-pass test to rate filter efficiency and dirt holding capacity of filter elements under ideal lab conditions.

Figure 1 depicts the test circuit where hydraulic fluid is circulated at a constant flow rate in a closed loop system with on-line particle counters before and after the test filter. Contaminated fluid is added to the system at a constant rate. Small amounts of fluid are removed before and after the filter for particle counting to calculate the filter efficiency (capture). The capture efficiency is expressed as the Filtration Ratio (Beta) which is the relationship between the number of particles greater than and equal to a specified size ($X\mu_{[c]}$) counted before and after the filter. In real world terms this test is the equivalent of testing a filter in an off-line kidney loop rather than replicating an actual hydraulic or lube system. It's basically a filter cart test.

Figure 1: ISO16889 Multi-Pass Test



Filtration Ratio (Beta) per ISO16889:

$$\beta x_{[c]} = \frac{\text{quantity particles} \geq X\mu_{[c]} \text{ upstream of filter}}{\text{quantity particles} \geq X\mu_{[c]} \text{ downstream of filter}}$$

Example: $\beta 7_{[c]} = 600/4 = 150$

Filtration Ratio (Beta): $\beta 7_{[c]} = 150$

In the example, 600 particles greater than or equal to $7\mu_{[c]}$ were counted upstream of the filter and 4 were counted downstream. This Filtration Ratio is expressed as "Beta $7_{[c]}$ = 150". The $_{[c]}$ is referred to as "sub c". The sub c is used to differentiate between multi-pass tests run per the current ISO16889 multi-pass test with new particle counter calibration per ISO11171 from ISO4572. Filtration Ratio expressed or written without the "sub c" refers to the antiquated ISO4572 multi-pass test superseded by ISO16889. The efficiency may also be expressed as a percentage by converting the Filtration Ratio:

$$\text{Efficiency of } \beta X_{[C]} = \frac{(\beta - 1)}{\beta} \times 100$$

Example: Efficiency % of $\beta 7_{[c]}$=150 = (150-1)/150 x 100

Efficiency %: 99.33%

Using our Beta Ratio found in the first example, we can calculate that the test filter is 99.33% efficient at capturing particles $7\mu_{[c]}$ and larger.

Dynamic Filter Efficiency

The DFE Multi-Pass Testing Method

DFE multi-pass enhances the industry standard by inducing dynamic conditions (duty cycle) and measuring the effects of the duty cycle in real time instead of looking at normalized numbers over a time weighted average. DFE also quantifies retention efficiency in real time in order to identify a filter's ability to properly retain previously captured contaminant and the degree to which it unloads captured contaminant back into the system. For an easy comparison, think of it as a sneeze that releases a rush of contamination to levels that are well above the upper limit of fluid cleanliness then fades as the flow rate normalizes.

In the DFE test, flow rate is truly dynamic in that rapid changes can be made while maintaining full system flow through the test filter. The raw data is continuously collected and organized so filter efficiency can be reported for variable flow conditions including time weighted averages and isolated moments to reveal true filter performance during hydraulic stress conditions – exactly when you need the filter to perform at its best.

At the end of the initial test when the filter element is loaded with contaminant, it is subjected to a restart test in which the flow goes from zero to max flow in milliseconds, replicating a hydraulic or lube system restart. Through rapid particle counting with precise control, this dynamic flow change allows Hy-Pro to analyze the amount of particles released and understand both the capture and retention efficiencies of each and every filter tested.

The DFE Testing Method

Quantifying Contaminant Capture and Retention

Filters for critical hydraulic, lube and fuel systems are specifically designed for high efficiency particle capture. However, a filter is not a black hole, capturing and retaining particles in a real-world dynamic environment is far more challenging. Hy-Pro pioneered the DFE (Dynamic Filter Efficiency) multipass test to optimize performance under real-world conditions. This methodology drives the development of proprietary media layers, media support structure, and filter construction. The results are higher efficiency particle capture and retention and cleaner fluids when Hy-Pro upgrade elements are in service.

Hy-Pro uses DFE and the ISO/CD23369 Cyclic Flow Multi-Pass Test to benchmark performance between its filters and those of its competitors. The Cyclic Flow Multi-Pass protocol ISO/CD23369 moves the industry standard one step closer to real-world conditions by incorporating cyclic flow with rapid flow transitions (between 100-200 msec) as shown in Figure 2.

Figure 2: ISO23369 Flow Cycle

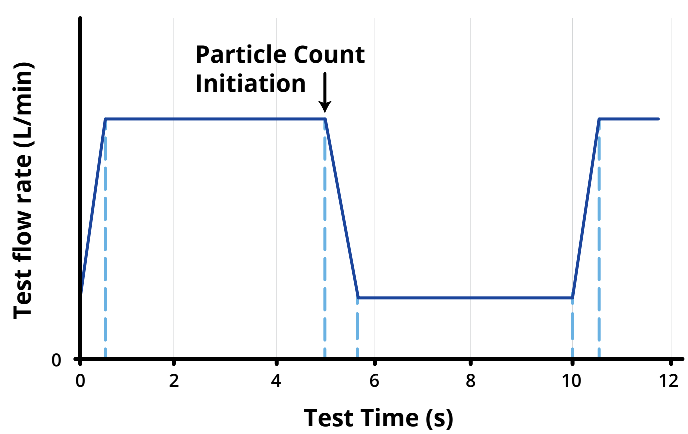


Table 1 illustrates this differentiation during dynamic conditions. Hy-Pro filters and a competitor's filters (Filter X) of similar rating were tested using ISO16889 and ISO23369. The average Beta ratios are listed and plotted vs particle size in Figure 3. Under static ISO16889 (dashed lines) both filters easily exceeded a Beta ratio of $B7_{[c]}$ > 2000 (Hy-Pro filter averaged β 6.2µm=2000, Filter X averaged a higher level of performance, β 6.0µm=2000). In beta ratios the lower the BX number the better the efficiency.

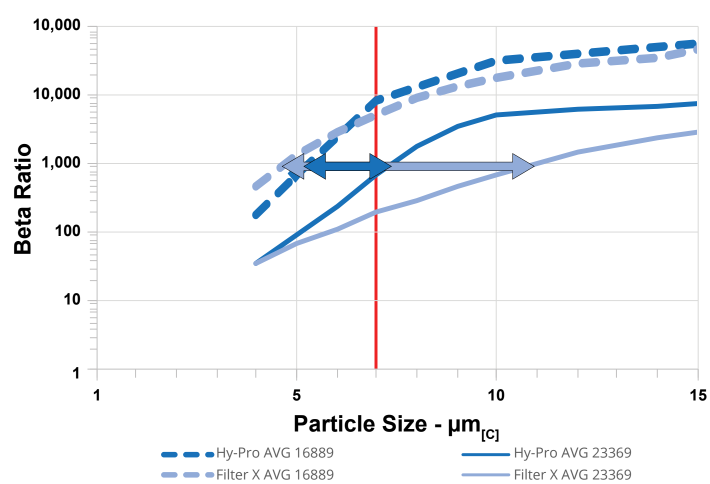
Table 1: Test Conditions and Results

ISO/CD23369 Test Conditions		
Flow Rates	114 lpm:28.5 lpm (30 gpm:7.5 gpm)	
ISO16889 Test Results		
	Hy-Pro	Filter X
β≥1000	6.2 µm	6.0 µm
ISO/CD23369 Test Results		
	Hy-Pro	Filter X
β≥1000	7.2 µm	10.6 µm
β≥2000	8.1 µm	12.9 µm
β≥4000	9.2 µm	17.7 µm

But that is where the similarity ends. The Hy-Pro DFE rated filter element shifted from 6.2µm during static testing to 8.1µm during dynamic conditions – a shift of only 1.9µm. Filter X shifted from 6.0µm to 12.9µm, from static to dynamic conditions – a 6.9µm drop, 6 times greater efficiency loss at Bx ≥ 2000 than Hy-Pro. And these differences dramatically increased at higher Beta ratios with Filter X falling to 17.7 µm at β ≥ 4000.

Hy-Pro DFE rated filter elements are optimized to deliver and maintain the lowest real world, in-service ISO fluid cleanliness codes even in industry's toughest systems. This is what separates Hy-Pro from the rest and how we improve your reliability, efficiency and keep your fluids cleaner and always in spec.

Figure 3: ISO16889 & ISO23369 Avg Beta vs Particle Size

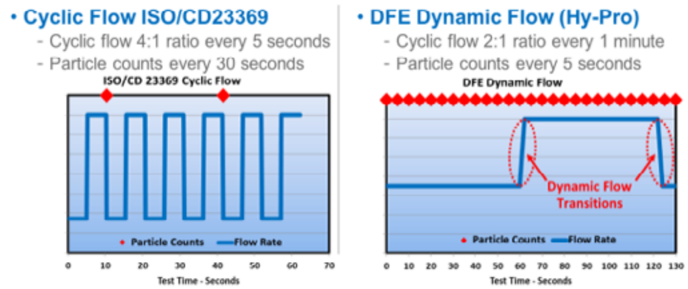


The DFE Testing Method

DFE Multi-Pass: Cold Start Contamination Retention

Hy-Pro utilizes DFE to bridge the gap between lab and real world filter performance for hydraulic, lube and fuel systems. The DFE restart test challenges a filter's ability to retain the contaminants it has captured in a worst-case scenario, once the filter is near the end of its life. Once the filter is heavily loaded the DFE test main flow and particle injection systems are stopped for a short dwell time, then full flow is restarted without injection to measure what comes out of the filter. After restart the DFE cycle is repeated several times all while the downstream particle counts are monitored in real time. The developmental value of the DFE test is the continuous, real time particle counts that occur concurrently every 5 seconds measuring actual retention efficiency during flow changes and restart (Figure 4). This is the advantage of DFE over ISO/CD23369 Cyclic Flow Multi-Pass test, where several high frequency flow changes are normalized over 30-60 second particle counts. ISO/CD23369 would miss the short-term particle events captured by the DFE test.

Figure 4: ISO/CD23369 vs DFE Multi-Pass



Restarts in hydraulic, lubrication and fuel systems are one of the toughest conditions for a filter and for this reason Hy-Pro includes it in the DFE test. A filter that doesn't properly retain is a dangerous source of concentrated contamination in front of critical components and bearings. Figures 5 and 6 depict the particles released during restart for Filter X and Hy-Pro. The DFE rated Hy-Pro element has much higher retention efficiency than filters designed and validated only to ISO16889 multi-pass or ISO23369. In the real world this means that Hy-Pro DFE rated elements provide lower ISO codes (consistently cleaner oil) and better protection of your critical equipment and uptime.

Figure 5: Filter X DFE Restart Test

Released 1810 particles/ml ≥4µm[c]

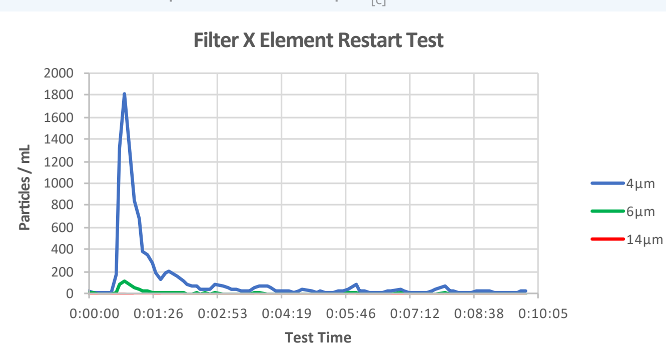
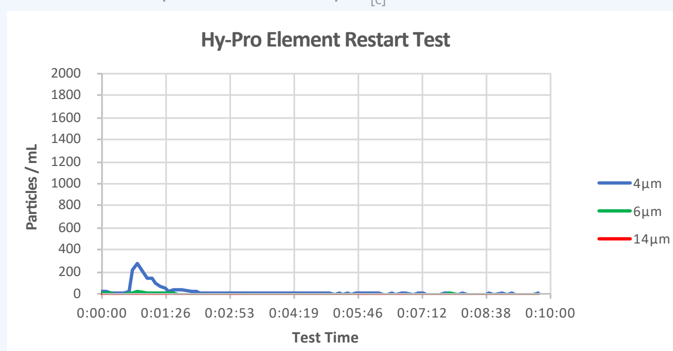


Figure 6: Hy-Pro DFE Restart Test

Released 283 particles/ml ≥ 4µm[c]



Downstream Particle Counts / mL During Restart Test

	≥4µm[c]	≥6µm[c]	≥14µm[c]	ISO Code per ISO: 4406:1999	ADHC
Hy-Pro Element	283	29	1.8	15/12/8	54.17g
Element X	1,810	117	1.2	18/14/7	53.27g

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