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Realistic Filter Performance Evaluation -Cyclic Stabilization Test-

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ABSTRACT

The Multi-pass filter test is the most common method to evaluate the performance of hydraulic filters. The test is conducted at a constant flow rate at constant temperature and very high dirt ingression in order to evaluate filter performance at accelerated test condition. This standard test does not represent operating condition of the modern hydraulic control systems. In order to precisely represent filter performance in the field in the laboratory, the Cyclic Stabilization Test (CST) has been developed. The CST can reliably measure the ability of the filter to control contamination in an even lower ingression environment. It also simulates cyclic flow condition to measure filter performance. In this paper, the CST is proposed as a more effective method for filter performance evaluation method.

KEY WORDS

Hydraulic fluid, Cyclic flow, Stability, Filter performance, Cyclic Stabilization Test

INTRODUCTION

Solid particulate contamination in hydraulic fluid causes component wear, valve sticking, fluid life shortage, resulting in shorter component and fluid life, lower system reliability, lower efficiency, lower stability. Hydraulic filters are designed to control hydraulic fluid cleanliness to accomplish reliable system operation and longer system lives.

Modern hydraulic control systems are required to be operated with higher pressure, and very sophisticated control systems as well as higher reliability and higher energy efficiency. These systems need cleaner hydraulic fluids. Filters for these systems are usually exposed to flow surges, repetitive cyclic flow, vibration, and cyclical thermal conditions.

IMPORTANCE OF CLEAN FLUID ON RELIABILITY AND LONG COMPONENT LIVES

A significant part of the DTI research studied the effects of solid particulate contamination on working systems and also quantified the relationship between the fluid cleanliness level and the reliability level experienced by those systems. The relationship between cleanliness levels, as represented by the ISO 4406 coding system [1], and the mean time between failures is presented in Figure 1.

Figure 1 clearly shows a direct relationship and demonstrates that high levels of reliability and long component lives can only be achieved by operating with clean hydraulic fluids. The report stated that, generally, very clean hydraulic fluid was achieved by the use of 'fine' filters (3 or 6 μm) but its cleanliness level that the filter achieved was dependent on its rating and how it performed in the system concerned. The report cited instances where nominally "identical" filters gave significantly higher ISO cleanliness levels when the duty cycle of the system was more severe. Hence, the need to select filters on a system-to-system basis with consideration of a number of factors was emphasized.

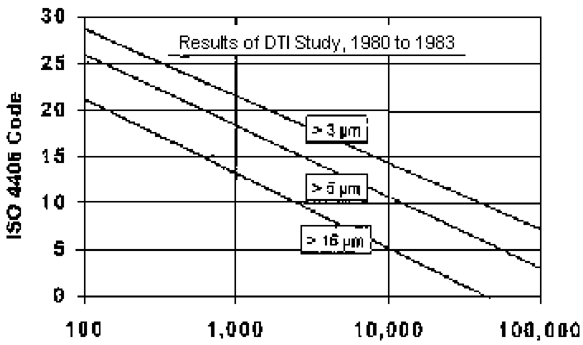

Figure 1 Effect of cleanliness level on the reliability of hydraulic systems

CURRENT FILTER TESTING METHOD

The filtration performance characteristics of hydraulic filters are determined by the ISO 16889 Multi-pass test [2]. The Multi-pass filter test is conducted at a constant flow rate of contaminant at constant temperature. The contaminant is dispersed in the reservoir and circulated to challenge the filter. Contaminant that isn't removed is returned back to the reservoir where it mixes with the incoming contaminant and is re-offered for further chances to capture. The test circuit is shown in Figure 2.

LIMITATIONS OF MULITI-PASS TEST METHOD

Although the Multi-pass test is a much better than previous nominal method, there are many deficiencies in the test that reflect actual condition.

- One of the primary defect of the Multi-pass test is the steady state condition under which test is conducted.
- Contamination concentrations are 1,000 to 10,000 times higher than actual in order to evaluate filter performance at accelerated test condition.
- Test element is not exposed to cold startup condition or vibration which can be expected in actual applications.

These operating conditions that differ in actual service from the controlled laboratory test, tend to reduce the performance of the filter element in actual service.

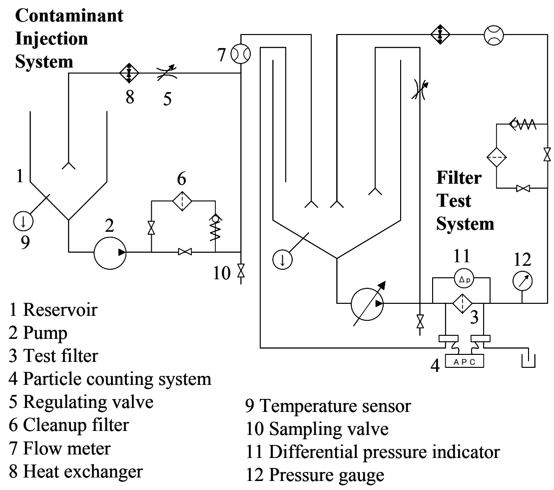

Figure 2 Multi-pass filter test schematic

NEED FOR REALISTIC TESTING CONDITIONS

Unfortunately, filter selection and comparisons are usually made primarily on the basis of the filtration ratio and contaminant holding capacity obtained from a single Multi-pass test. However, there are many other parameters vital to maintaining filter element integrity and desired performance in actual operation. These include the strength and stability of the filtration medium, the dominant mechanism of particle captures, and the filter's ability to withstand flow and pressure surges, as well as those conditions induced by cold start-ups. Using Multi-pass performance as the sole filter specification is inadequate as often weaknesses or deficiencies in performance are overlooked or not exposed because of limitations in the scope of testing. Furthermore, the effect of dynamic operating conditions on filter performance has yet to be addressed by an ISO standard.

IMPACT OF OPERATING CONDITION ON MULTI-PASS PERFORMANCE

Impact of Unsteady Flow

A survey of hydraulic equipment manufacturers revealed that nearly all filter installations are subjected to some type of variable (cyclic) flow [3]. And many studies also have been conducted relative to impact of unsteady flow on filter performance. Generally, the results indicate that the filtration (Beta) ratio was found to decrease as a function of increasing cycle rate [4].

Impact of Reduced or No Contaminant Ingression

As we mentioned already, the contaminant ingression rate during the ISO 16889 Multi-pass test are 1,000 to 10,000 times higher than the average ingression in actual service. This high ingression rate tends to overshadow performance degradation and particle unloading. When clean-up tests are conducted on a previously contaminated system with no ingression, the performance of filter, measured in terms of efficiency, generally degrades as the system becomes cleaner. In fact, the system contamination level stabilized at some measurable level and does not go to zero. This is one of the primary flaws in the interpretation of the basic Multi-pass test, where the filtration ratio is assumed to be roughly constant in any ingression rates. In reality, when the system contamination level stabilizes, the Beta ratio approaches a value of one and the upstream level is roughly equal to the downstream level. For a system clean-up test with constant flow, the stabilization level is related to the quality of the filter and the degree of particle unloading [1].

THE CYCLIC STABILIZATION TEST

In order to address the deficiencies in the Multi-pass test, Pall Corporation has developed the Cyclic Stabilization Test (CST), which provides a more realistic measurement of filter performance. This laboratory test examines a number of areas of operation: steady state performance, cyclic flow performance, and the effects of contaminant loading on the retention and unloading characteristics of the filter.

The test stand utilized is basically the same as a standard Multi-pass test, except an electrically controlled valve is installed to allow the test flow to be cycled from zero to full flow. The cycle rate chosen for the test was 0.1Hz. Although the test could be conducted with any cyclic condition, the rate chosen was based on a survey [3].

CST Result for Filter "A"

During the test procedure, clean up and stabilized particle count levels at the upstream and downstream of a test filer are measured for both steady and cyclic flow condition at different stages of the filter's life. The result of particle count levels in each stage are shown as "stabilized clean" during steady flow and "stabilized clean", "stabilized 2.5%ΔP" and "stabilized 80%ΔP" during cyclic flow in Fig. 3 and Fig. 4.

A great deal of information can be gathered from a CST. This includes:

- Measurement of the initial steady flow filtration ratio.
- Measurement of the initial cyclic flow filtration ratio.
- Initial clean-up and stabilization measurement (with the filter in a clean condition) – both with steady and cyclic flow.
- A measurement of cyclic flow filtration ratio throughout the remainder of the test.
- Clean-up and stabilization measurement as the filter is loaded.
- Clean-up and stabilization measurement at 80% of terminal pressure drop (with the filter in a nearly completely loaded condition).
- A measurement of retained dirt capacity under cyclic flow conditions.

Figure 3 shows the upstream particle counts greater than 5 μm(c) obtained while conducting a CST on a test filter "A". At each step the initial particle concentration is very similar, but cleanup is reduced with the introductions of cyclic flow, and further reduced as the filter becomes more plugged.

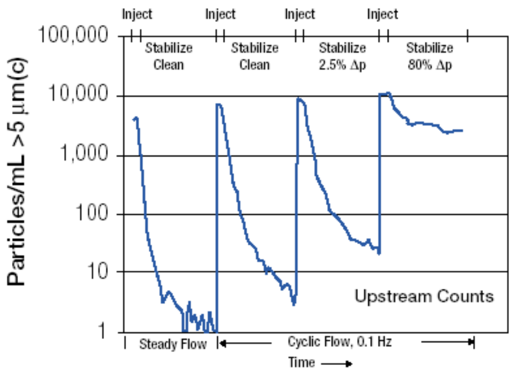

Figure 3 CST result – upstream particle counts >5 μm(c)

The stabilized contamination level at 2.5% pressure drop, Δp, is 11 times that of the steady flow value. At 80% pressure drop, Δp, the stabilized contamination level is 1,200 times that of the new filter steady flow value. These increases are indicative of the inability of the filter to retain contaminant under these conditions.

Figure 4 shows downstream contamination data for the same test filter "A". Hence, stabilized counts increase substantially during flow cycling and filter loading. The data represents a final Beta ratio at 5 µm(c) of 1.8 compared to the initial steady state Beta ratio of 310.

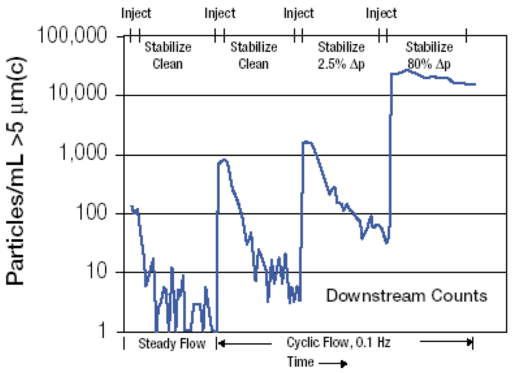

Figure 4 CST result – downstream particle counts > 5 µm(c)

CST Result for Various Filters

The CST provides a much clearer picture of a filter's performance throughout its life in a fluid system.

In order to demonstrate the ability of the CST to discriminate among similarly rated filters, tests were conducted on filters from several manufacturers. Figure 5 shows the 5 µm(c) downstream particle counts for these filters. These test demonstrate that although the filters provide good control of particles >5 µm(c) when new or with steady flow, their ability to control particles changes substantially when they become loaded and are under cyclic conditions. For example, Filter "B", which was one of the best performers under steady flow, exhibited the worst particle control under cyclic and loaded conditions.

When comparing filter performance, one should focus on the stabilization data at 80% of terminal pressure drop. This is where the greatest performance drop-off occurs, and the point in the filter's life where any hydraulic system can be most at risk.

REPEATABILITY AND REPRODUCIBILITY

Repeatability tests were performed at both Pall Corporation and an independent laboratory using various sets of identical filters. Stabilized 80% Δp downstream particle counts at 4, 6, and 14 µm(c) taken, and an ISO 4406 code was provided for each filter. Tables 1 and 2 present the data from these tests.

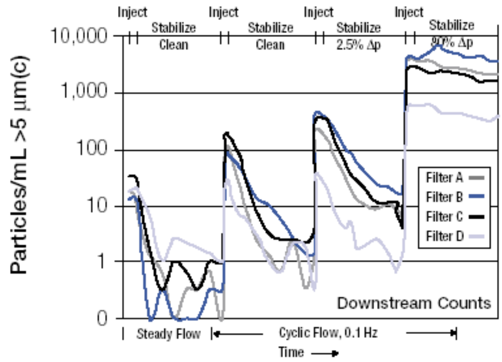

Figure 5 Downstream CST results from four "3µm " filters

Table 1 shows the results of test on four different sets of filters: A, B, C and D. Two filters of each type were tested in Lab 1. The data in Table 1 shows excellent repeatability of the stabilization results, with nearly all data for a given filter agreeing within one ISO 4406 code. Table 2 shows excellent repeatability I Lab 2 for filter groups E, F, and G. The only exception is in the 14 µm(c) ISO code, where there is more variability. This is because accuracy is lower due to particle counting statistics.

Table 1. Repeatability Data from Lab 1

Filter	4 µm(c)	6 µm(c)	14 µm(c)	ISO4406
		(particles/mL)		
A1	78	2.4	0.09	13/8/4
A2	69	2.7	0.07	13/9/3
B1	166	6.5	0.07	15/10/3
B2	149	4.7	0.10	14/09/4
C1	395	34	0.15	16/12/4
C2	447	42	0.12	16/13/4
D1	932	363	0.27	17/16/5
D2	1061	402	0.39	17/16/6

Table 2. Repeatability Data from Lab 2

Filter	4 µm(c)	6 µm(c)	14 µm(c)	ISO4406
	Average of 2 or more tests (particles/mL)			
E1	399	20	0.0	16/12/0
E2	410	23	0.5	16/12/6
F1	229	38	0.0	15/12/0
F2	187	29	0.0	15/12/0
G1	76	1	0.0	13/7/0
G2	96	4	0.0	14/9/0

The sets of E, F, and G filters were also used to verify reproducibility between Lab 1 and Lab 2. For each set, two filters were tested in Lab 1, and two identical filters were tested in Lab 2. Stabilized 80% Δp downstream counts at 4, 6, and 14 µm(c) were taken, and an ISO 4406 code was provided for each filter. Table 3 supplies the data from these tests.

Table 3. Repeatability Data from Labs 1 and 2

Filter	4 µm(c)	6 µm(c)	14 µm(c)	ISO4406
Average of 2 or more tests (particles/mL)				
E-Lab1	480	57	0.00	16/13/0
E-Lab2	404	21	0.25	16/12/5
F-Lab1	82	2	0.00	14/8/0
F-Lab2	208	5	0.00	15/9/0
G-Lab1	115	4	0.08	14/9/3
G-Lab2	86	2	0.00	14/8/0

These results demonstrate that the CST procedure is quite reproducible. This is especially true when one considers that the test equipment in both labs was different, as were the operators.

CONCLUSIONS

Conditions such as varying flow, cold starts, shock, and vibration can potentially reduce the effectiveness of a filter in an operating system. This may cause the filter to release previously held contaminant, and consequently make it less effective at removing the critically sized particles.

The data from an ISO Multi-pass test is often used by procurement agencies as the key performance factor in the process of selecting filters, and sometimes as the sole criterion. This test has the potential to exaggerate a filter's capabilities. The CST examines the effects of cyclic flow conditions and contamination loading on the capture and retention characteristics of the filter. The result is an improved filter performance reporting method that provides a much more realistic measure of how a filter performs in actual service.

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