HYDRAULIC FILTER PERFORMANCE UNDER VARIABLE FLOW CONDITIONS
– TEST SERIES WITH DIFFERENT FLOW PARAMETERS –

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ABSTRACT

The performance of hydraulic filters is generally rated using the standardized Multi-pass test with constant flow rate. This paper presents a variable flow Multi-pass test and introduces several test and flow parameters, which affect the filtration efficiency. The parameters were selected so that the efficiency can be defined under conditions, which represent the operating values of real hydraulic systems.

The presented results are examples of filter test series, in which over 60 elements were tested. The results show how flow form, flow amplitude and cycle rate, which can be defined from a real hydraulic system, affect the efficiency of filters. Some essential test parameters, which are intended for ensuring the reliability of testing and the quality of elements, are also presented with tests.

KEYWORDS: Fluid power, Filters, Filter tests

INTRODUCTION

The purpose of a hydraulic filter is to control the cleanliness level of hydraulic fluid so that the reliability target of the whole system can be achieved. This requires reliable data of the filter performance under real-like conditions. The performance of hydraulic filters is generally defined in laboratory conditions using the standardized Multi-pass test, ISO 16889 [1]. This is a revision of the original Multi-pass standard, ISO 4572 [2].

The purpose of the Multi-pass test is to define the relative performance of filters to enable the selection of most appropriate filter type. The selection of filter for a certain application is often based solely on the filtration efficiency and the dirt capacity that are defined during the test. The test conditions do not however match with real-life working conditions. The main difference affecting the reliability of test results in a real system is the flow rate. In Multi-pass test the flow must be constant and steady. In real hydraulic systems the filters are often exposed to highly variable flow, which decreases the filter performance.

The difference between the test and working conditions of hydraulic filters has been widely recognized [3...7]. The test standards have also been developed over the years, but there is still no generally accepted or used test method for evaluating the filter efficiency under variable flow conditions.

The Institute of Hydraulics and Automation (IHA) and Finn-Filter Division of Parker Hannifin have carried out several filter research projects, in which filter test unit and test procedures were developed for the testing of filters with variable flow. The goals of the project were to increase the knowledge of filter behavior, measure efficiency curves for the selection of filters and especially to develop more efficient filters for variable flow conditions. The main interest in the development and selection of test procedures was to find the essential test parameters that are corresponding to field conditions. In this paper the influence of different flow parameters on filtration efficiency is presented.

VARIABLE FLOW MULTI-PASS TEST

A modified Multi-pass test unit and testing procedures were developed during this project for the testing of filters under variable flow conditions. The main features and design principles of the unit were corresponding to the traditional Multi-pass test equipment. In addition it was possible in the new unit to use variable flow and control the injection flow.

Hydraulic Circuits and Testing

A simplified illustration of the hydraulic circuits of the developed test unit is presented in figure 1.

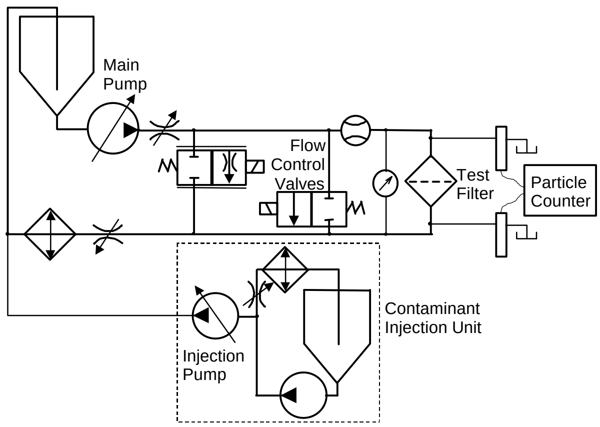

Fig. 1 The variable flow Multi-pass test unit (simplified).

The test unit consists of two hydraulic circuits, the contaminant injection unit and the main unit. In the injection unit oil with high contaminant concentration is circulated continuously in order to keep the concentration constant. The contaminant used is ISO Medium Test Dust (ISO MTD). During testing a constant injection flow is pumped from the injection unit to the main unit.

The actual testing is performed in the main unit in which oil is circulated through the tested filter. The test is continued until the terminal pressure drop of the element is reached. The number of particles both in the upstream and in the downstream of the filter are measured throughout the test. This was done using optical laser sensors and automatic 2 x 16 channels particle counter. The filtration efficiency is presented as the filtration ratio or β_X-value (Equation 1).

$$b_X = \frac{\text{no. of upstream particles} (\geq \text{x}\ \mu\text{m}) / \text{volume}}{\text{no. of downstream particles} (\geq \text{x}\ \mu\text{m}) / \text{volume}} \quad (1)$$

The main features of the modified test unit that differ from the standardized Multi-pass equipment were:

1) The main pump was a flow controlled variable displacement axial piston pump. The flow of a piston pump has some pulsation also with constant flow. This was considered consistent with most hydraulic systems.

2) Two flow control valves were connected in parallel to the filter for the producing of variable flow.

3) Dynamic flow transducer was used in the upstream of filter to measure the actual test flow.

4) ISO VG32 hydraulic oil was used in test units instead of MIL-H-5606 oil.

5) The injection pump was a metering pump with a stroke length controller.

Test and Flow Parameters

The test procedures and flow parameters that were used in filter tests were selected so that the filtration efficiency could be defined as a function of flow amplitude, rise time of the flow change and cycle rate. These are parameters that can be defined for a real hydraulic system and have an effect on the filter performance. The quality of filters and the reliability of testing were reviewed by combining constant and variable flow phases during the same test.

The tested elements represented different filter ratings, dirt capacities and manufacturers. The test and flow parameters that were used are presented in table 1.

Table 1. The flow and test parameters of filter tests.

Parameter	Test values
Flow rate	70, 70..50, 70..30 and 70..10 lpm
Rise time	50, 500 and 1000 msec
Cycle rate	0.1, 0.2 and 1 Hz
Filter rating	3µm, 5µm and 10µm
Filter media	Several
Dirt capacity	Several
Manufacturer	Several

The rated flow of all elements was 70 lpm and the terminal pressure drop was 4 bar. An example of different flow amplitudes is presented in figure 2.

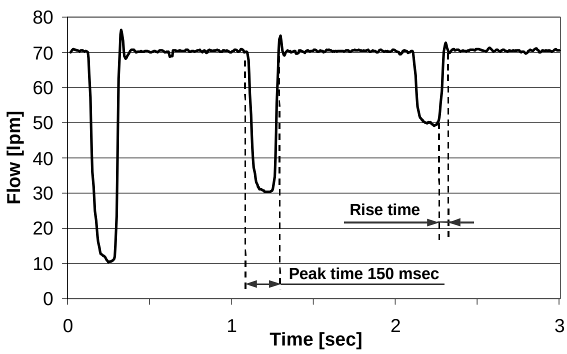

Fig. 2 Actual flow patterns 70..10, 70..30 and 70..50 lpm. [7]

In the flow pattern the flow changes from one level to another only for a short period of time and can be described as surge flow. During a single test only one amplitude was used. In figure 2 the peak time is 150 msec and the rise time is 50 msec.

TEST RESULTS

In the following are presented some results of filter tests that were performed using different test parameters. These element types were rated as 5μm and 10μm pressure line filters. So far over 60 elements have been tested. The particle sizes presented are based on calibration according to standard ISO 4402 [8].

Continuous or Combined Variable Flow

In figure 3 are presented the β_5-values of three 5μm elements as a function of test time. These elements were tested using three different flow forms. In the reference test the flow was constant 70 lpm. In the second test the flow was constant 70 lpm for 4 minutes and after that 70..10 lpm with cycle rate of 1 Hz. In the third test the flow pattern was a combination of constant flow phases (4 minutes) and variable flow phases (4 minutes). This was considered corresponding to real systems where the filter is subjected to variable flow only part of the time and operates in between under ideal conditions.

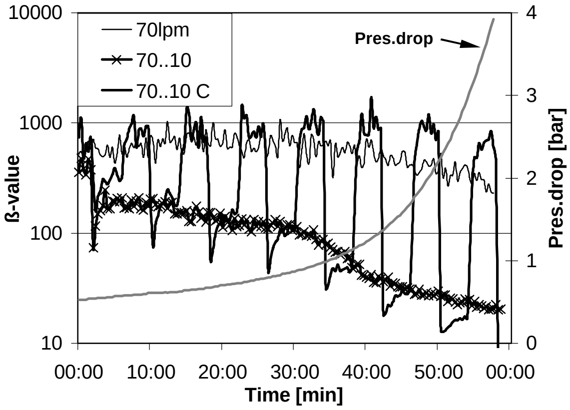

Fig. 3 The β_5-values and pressure drop of 5μm elements tested with constant, variable and combined (C) flow.

The average β_5-value of the constant flow test was as good as 500. In both variable flow tests the average β_5-values were equal: 55.

The effect of pressure drop on the filtration efficiency can be seen in all tests. With constant flows the element is most efficient in the middle of test but after 30 minutes the efficiency starts to decrease. With variable flows the efficiency decreases continuously along with time and raising pressure drop. This and the average β-values show clearly how the efficiency is reduced when the filter is used with variable flow. The effect of pressure drop is the reason why a high dirt capacity may result in low efficiency.

It is also evident that when a filter is used with variable flow the average efficiency gives too positive an impression of the actual performance. In the end of the test the momentary values are far below the average efficiency.

Even though the average efficiency of both variable flow tests was the same the combined test has some major advantages. In the beginning of the test the use of constant flow gives an important reference between different elements and ensures the reliability of testing. The later constant flow phases reveal if the filter media has been weakened by flow surges. Examples of these can be seen in figures 4 and 5.

In figure 4 the β-values of elements tested with different amplitudes have the same efficiency during the constant flow phase in the beginning. This proves that the differences in efficiency with variable flow are caused by different flow amplitudes, not by measurement errors or component failures.

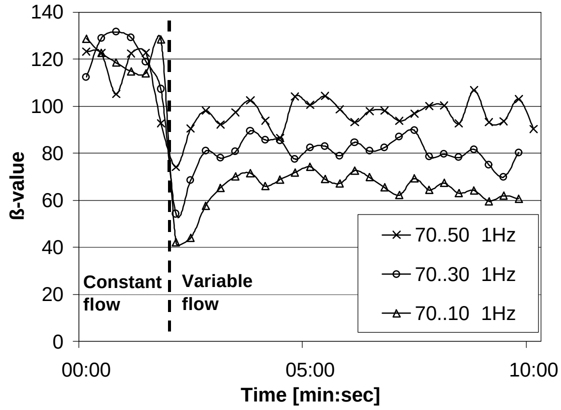

Fig. 4 The β-values during the constant flow phase in the beginning of variable flow tests.

In figure 5 are presented the β-values of two 5μm elements, which were tested using combined flow form 70 lpm and 70..50 lpm, 1Hz.

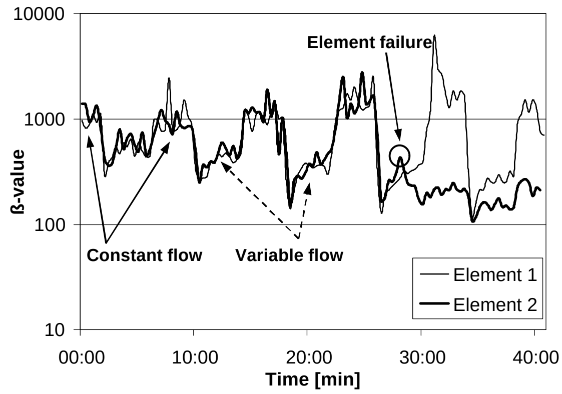

Fig. 5 The β-values of 5μm elements with combined variable flow. Element 2 had a material failure.

The element 2 suffered a material failure during the fourth variable flow phase. Before that point the efficiency of elements was similar. After that the efficiency collapsed totally when compared to element 1. If only variable flow had been used, the results would have given wrong information about the filter behavior.

This is why, even though the element is tested using variable flow, reference phases should be included in the flow pattern. Reference values can be obtained in several points as presented or having just one constant flow phase in the beginning and one in the end of the test.

The Effect of Flow Amplitude

Several filters were tested during the project using constant flow and three different flow amplitudes as presented in table 1. The average results of 5µm element type A are presented in figure 6. In these tests the cycle rate was 1 Hz and elements were tested using both continuous and combined (C) variable flow as described earlier.

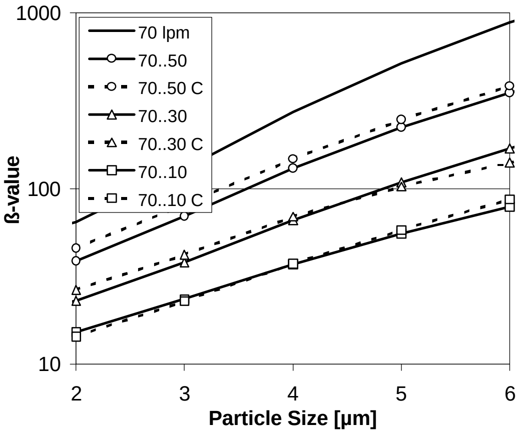

Fig. 6 The average β-values of 5µm element type A tested with different flow profiles.

The curves in figure 6 show clearly how the flow amplitude affects the filtration efficiency and should be used as a selection criteria for a filter. As stated earlier the average efficiencies are similar in both continuous and combined variable flow tests.

In figure 7 are presented the β-values of 5µm element types A and B with constant 70 lpm and variable 70..10 lpm flow.

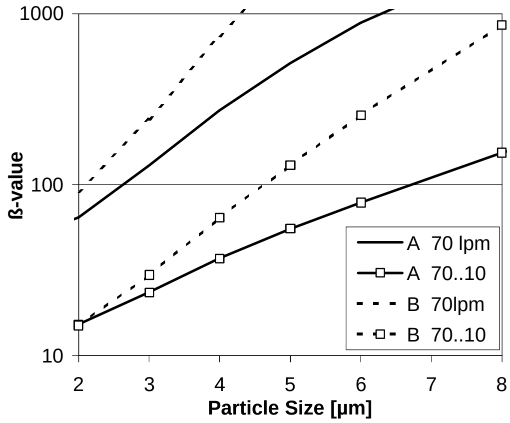

Fig. 7 The average β-values of 5µm element types A and B.

In figure 7 in can be seen that as there are differences between filters in performance with constant flow, there are essential differences with variable flow. If β-value 100 is used for filter selection, the filter A cannot be considered as 5µm filter for variable flow conditions even though it is clearly better with constant flow. Filter B has a good efficiency also with variable flow. The comparison of different element types showed that the efficiency of all tested filters decreased significantly under variable flow conditions.

The Effect of Cycle Rate

All previous elements were tested using cycle rate of 1 Hz. In figure 8 are presented the β_8-, β_{10}- and β_{12}-values of 10µm elements as a function of cycle rate.

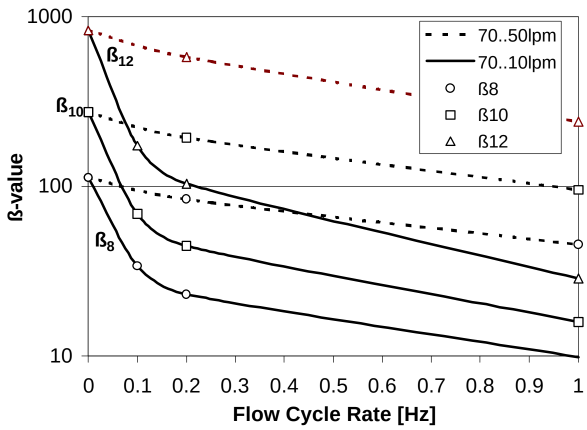

Fig. 8 The β-values of 10µm elements as a function of cycle rate.

In figure 8 the cycle rate 0 Hz represents the efficiency with constant flow. The results show that if this filter type is used in system, where the flow changes mainly on the area 70..50 lpm, the filter has still β_{10}-value 100 even with 1 Hz. On the other hand with flow changes

70..10 lpm already the cycle rate of 0.1 Hz causes a significant drop in the efficiency.

CONCLUSIONS

The Multi-pass testing of hydraulics filters under constant flow conditions gives valuable information for the comparison of different filter types. In real hydraulic systems the operating conditions are often much more demanding, which may result in unexpectedly low filtration efficiency. This is why there is need for data of the filter performance under real-like conditions.

In this paper several flow and test parameters affecting the filter performance and reliability of testing were introduced. The presented test results showed examples of the effects of different parameters. On the basis of these the dirt capacity and flow profile together with the cycle rate define the actual filtration efficiency.

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