Development Of a Novel Wiper Seal Test Rig and Validation of Wiper Seal Performances

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Although the choice of wiper seal is not paid attention to in applications, the wiper seal is one of the most important elements of the system which isolates the hydraulic or pneumatic system from the external environment. Contamination in hydraulic and pneumatic systems can cause significant damage to metal parts of the cylinder, sealing elements, and other components of the whole system. This is the reason why Kastas Sealing Technologies develops a new test bench to perform wiper seal performance tests. This paper provides us with a technical overview of the design of the wiper seal test rig and performance analysis according to environmental effects on the wiper seal.

1 Introduction

Sealing elements are one of the most important machine elements that ensure the healthy operation of the systems. Many different systems brought by the developing technology have brought new problems and solutions for sealing elements. The issue that creates the most problems in the sealing of hydraulic cylinders is that foreign particles in the fluid in the working environment escape into the system and cause it to not provide sealing. As a solution to this problem, in 1958, Sneed John developed a sealing set that prevents damage to the O-ring [1]. Later in 1997 one-piece lip sealing elements were developed [2]. The most commonly used wiper seal design today was founded in 2000 by Uwe Siegrist and Otmar Braun [3]. A test runs on a standard type of wiper seal by Nick Peppiatt in 2003 proved that a single lip wiper seal leaks more than a double lip wiper seal [4,5]. In another study conducted on wiper seals in 2018, test studies were conducted to determine the friction force in constantly developing hydraulic cylinders [6]. These tests on wiper seals are carried out by measuring the leakage amount by pressurizing after the seal is mounted in the cylinder and determining whether this amount is following the standards and customer demands [7-9].

In the ISO 4406.2 standard related to the counting of foreign substances, the liquid pollution code and scale numbers for hydraulic and lubrication systems are stated. In addition, the pollution level of the components of the NAS 1638 liquid systems (such as parts, lines, and fittings) has been classified in the NAS 1638 standard [10,11]. In the use of the ISO 4406 standard, ACFTD (Air Cleaner Fine Test Dust) is used as a different test powder and the value of the particles is given [10]. However, ISO 4406.2, NAS 1638 and ISO 4406 standards are general classifications and determinations, and there is no standardization specific to sealing elements [10,11].

In the literature reviews, it was seen that the tests on the wiper seals were carried out only to determine the amount of leakage, and the number of particles was not determined. For this reason, it is aimed to design and manufacture the test device to be used to determine and optimize the particle strength of wiper seals for the needs of the sealing elements market. The test device manufactured for this purpose will count the particles that have passed the wiper seals and passed into the system, ensuring that the wiper seals are in continuous development and studies will be carried out to standardize them.

2 Sealing Systems of Hydraulic Cylinders

A hydraulic cylinder is a circuit element that converts hydraulic energy into mechanical energy, and it is used to obtain linear and rotary motion. The hydraulic energy generated by the pump is converted into linear or angular motion with the help of a cylinder. Cylinders can be made in various structures, diameters, and strokes depending on the purpose of use. These are machine elements that are generally used in systems requiring excessive forces. [12]

Table 1: Hydraulic Cylinder Classes [12]

Application Parameter	Light Duty	Medium Duty	Heavy Duty
Pressure Range	<100 bar	<250 bar	>250 bar
Pressure Spikes	None or Low	Up to twice the maximum system pressure.	It can go up to several times the system pressure and takes a long time.
Temperature Range	-20/+70 ˚C	-30/+100 ˚C	-40/+110 ˚C
Contamination	None or Low	Operate in medium contamination environments	Operate in high contamination environments

Sealing elements with different functions, produced from different designs and materials, are used in hydraulic cylinders. Dynamic and static sealing elements are assembled into the system with a certain amount of preload force remaining on them.

The functioning types of sealing elements used in hydraulic cylinders are shown in the picture below. Therefore, the most suitable sealing configuration should be selected in consideration of the application in the choice of sealing elements. Otherwise, the incorrect selection of elements such as wiper and guide rings will affect the performance of the main sealing elements in the system and may cause damage to metal surfaces (bore, rod) and leakage.

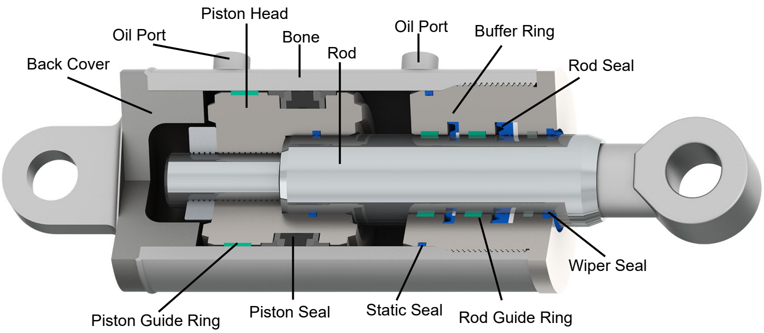

Figure 1: Illustration of the basic hydraulic cylinder

2.1 Importance of Wiper Seal

Wiper seals are used to prevent foreign particles such as dust, mud, water, etc. may enter the cylinder from the outside. There are many types of wipers made of different materials and designs that prevent foreign particles adhering to the rod surface from entering the system.

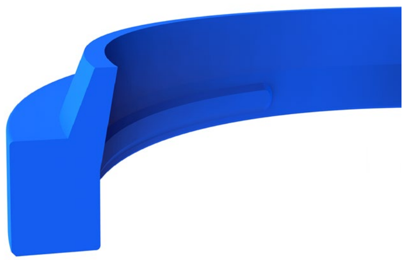

Figure 2: Kastas K06 wiper seal cross-section

3 Contamination Standards of Hydraulic Fluids

The cleanliness level of the hydraulic fluid is routinely measured for the control of the filtration system in the hydraulic systems and the removal of contamination or oil change if needed.

ISO 4406, NAS 1638, and SAE AS4059 standards are used to determine the cleanliness level of hydraulic fluids.

3.1 ISO 4406

The most widely accepted standard for measuring particle size is ISO 4406, which provides a three-digit format reporting the number of particles greater than 4, 6, and 14 microns in a given volume.

Table 2: Allocation scale numbers according to ISO 4406

Number of particles per millimeter		Scale Number
More Than	Up to and Including	
2.500.000	-	>28
1.300.000	2.500.000	28
640.000	1.300.000	27
320.000	640.000	26
160.000	320.000	25
80.000	160.000	24
40.000	80.000	23
20.000	40.000	22
10.000	20.000	21
5.000	10.000	20
2.500	5.000	19
1.300	2.500	18
640	1.300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2,5	5	9
1,3	2,5	8
0,64	1,30	7
0,32	0,64	6
0,16	0,32	5
0,08	0,16	4
0,04	0,08	3
0,02	0,04	2
0,01	0,02	1
0,00	0,01	0

The results should be presented as three numbers separated by slashes, such as 22/18/12. This result would refer to:

- more than 20 000 and up to and including 40 000 particles equal to or larger than 4 µm
- more than 1300 and up to and including 2500 particles equal to or larger than 6 µm
- more than 20 and up to and including 40 particles equal to or larger than 14 µm

ISO 13/12/9 ISO 16/15/12 ISO 18/16/13 ISO 19/17/14 ISO 23/22/19

Figure 3: Visuals of different ISO 4406 classes of hydraulic fluids.

3.2 NAS 1638

NAS1638 is defined as the classification of contamination levels for hydraulic components used in aerospace. Table 3 indicates the values of NAS standards. The maximum number of particles in 100 ml fluid is specified according to the relevant particle size class.

Table 3: Scale numbers according to NAS1638

Maximum number of particles in the specified range (µm) / per 100 ml

NAS Class	5-15 µm	15-25 µm	25-50 µm	50-100 µm	>100 µm
00	125	22	4	1	0
0	250	44	8	2	0
1	500	89	16	3	1
2	1.000	178	32	6	1
3	2.000	356	63	11	2
4	4.000	712	126	22	4
5	8.000	1.425	253	45	8
6	16.000	2.850	506	90	16
7	32.000	5.700	1.012	180	32
8	64.000	11.400	2.025	360	64
9	128.000	22.800	4.050	720	128
10	256.000	45.600	8.100	1.440	256
11	512.000	91.000	16.200	2.880	512
12	1.024.000	182.400	32.400	5.760	1.024

Visual examination of the fluid is not adequate since even particles that are too small to be seen with the naked eye can damage the hydraulic system. The conventional methods used to analyze fluid include gravimetric, laboratory analysis, and inline particle counters.

Gravimetric: The gravimetric method involves passing a sample of the fluid through a patch that captures the particles, then weighing and examining it with a microscope. This method is time-consuming and has a high margin of error rate.

Laboratory Analysis: Another option is to collect a bottle sample and submit it to a laboratory for analysis, which can check the particle count, viscosity, water content, composition of the contamination, and several other factors. The results of the inspection are comprehensive and accurate, but it may take several days for the results to come in. For example, if a sample is taken and two days later the report shows a problem with the fluid, then all cylinders tested within those two days are at risk of contamination

Inline Particle Counters: An inline particle counter directs a laser through a flow of fluid and sensors detect the size and number of particles, providing continuous and immediate detailed particle count reports and ISO cleanliness codes. This real-time information can be used to guide actions, for example, waiting to test until the fluid quality has improved. The test of a specific cylinder may also be used to determine the cleanliness level of the fluid inside the cylinder. This may be useful in the event of a warranty claim. The data can help to evaluate the effectiveness of continuous improvement initiatives to improve cleanliness.

In this study, ISO4406 was used to determine the cleanliness level of hydraulic fluid and an inline particle counter was used to count particles passing through the wiper into the test rig system.

4 A New Approach to Wiper Seal Test Rig

Designing a new test rig requires a specific operating principle needs to be determined. To simulate a standard wiper seal working condition, the mechanical design, whose schematic design is exemplified below, has been carried out. During this design, the following limit conditions were determined.

- Rod Diameter: 50 mm
- Operating Stroke: 15 – 600 mm
- Fluid: HLP46
- Linear Velocity: 0 – 0.5 m/s,
- Operating Temperature: 20 – 60 °C,

The test device operates according to the following principle.

The test sample selected in the dimensions suitable for the test apparatus is mounted in the groove per the working conditions. The standardized powders and sands with predefined particle rate distribution to be used for the test are filled into the contaminant chamber. After the test parameters are determined, all necessary settings are uploaded to the software in the PLC specially designed for the test device via the HMI.

Before operating the test, the system starts to heat the hydraulic fluid until the current temperature reaches to set point. By blowing filtered compressed air into the specially designed powder chamber, a dust cloud is created in the chamber. New hydraulic fluid is used in each test to ensure repeatability. Before the mechanical movement is performed, a pre-test particle measurement of the hydraulic fluid is made by the particle counter. Thanks to the linear drive cylinder, the vertically positioned test shaft starts to cyclic move. The hydraulic scheme established with specially designed hydraulic equipment automatically manages the oil flow according to the commands given by the PLC. To measure the performance of the wiper seal, oil is poured around the test sample in a specially designed groove. In this way, the performance of the test sample is measured cumulatively over the specified test period. According to the distance determined by the software, the system periodically measures the particles. Particle measurements, linear velocity, oil flow rate, and temperature data collected during the test compared to distance are recorded and reported.

At the end of the test, the oil discharged from the test device is used in other hydraulic machines after filtering with the required filters to avoid waste hydraulic fluid.

Figure 4: Scheme and photo of the test rig

A superior particle counting device was used to carry out the tests in these harsh conditions. Particle measurement is possible in eight size channels:

- 4 μm(c),
- > 6 μm(c),
- 10 μm(c),
- >14 μm(c),
- 21 μm(c),
- > 25 μm(c),
- 38 μm(c) and
- > 70 μm(c)

RS485 communication method has been chosen to provide a fast and lossless data flow between the particle measuring device and the PLC. In this way, the results of the volumetric flow value and particle measurements are all processed efficiently.

Figure 5: Particle measurement device used in the test rig

5 Comparative Test Results of Wiper Seals

Kastas K06 Wiper seal and a competitor wiper seal widely used in the market were tested to compare the amount of contamination. Each test sample in the same dimensions was installed in appropriate housing and tested precisely under the same test conditions. After heating the hydraulic fluid to 60°C, the rod started to cyclic motion. The linear velocity of the test rod was set as 0.4 meters per second. At the end of the 25 km test duration, all the test data was examined. During the test, it was observed that the test temperature was in the range of 55 - 60°C.

The test was repeated 3 times for both products. At the end of the all tests, average values are taken into consideration. In the light of these results, the data shown in the graph below was obtained.

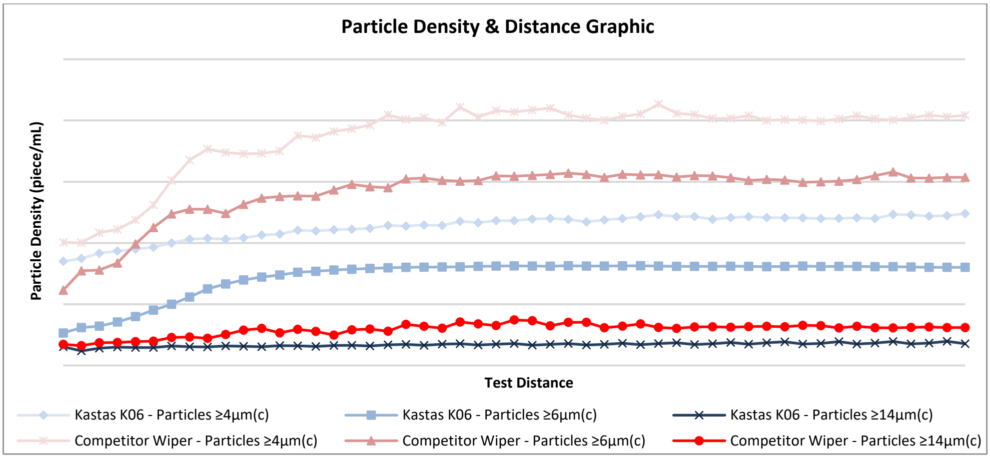

Figure 6: Test results

Thanks to the standardized powders and sands with predefined particle rate distribution, it is possible to estimate that the wider the particle range, the numerically the scale will be higher. With this estimation, the result of ≥4μm is more than ≥14μm result, indicating that the test results are reliable.

When the graph above is examined in three different values, the Kastas K06 wiper seal showed superior performance by allowing less entry of contaminant particles into the hydraulic system despite the high temperature and intense polluting environment.

6 Summary and Conclusions

In this study, six samples were tested in total to compare the performances of wiper seals against standardized powders and sands with predefined particle rate distribution. The similarity of results between identical test samples creates confidence in the test rig and its repeatability. Kastas K06 wiper seal, which has been improved in material properties and design, has shown superior performance compared to its equivalent competitor product. In this way, it offers long working life as well as keeps the whole system safe.

Industries such as mining, construction, and agriculture where wiper seals used in hydraulic and pneumatic cylinders are vital. In these systems where environmental pollutants are more aggressive, particles that may enter the system may damage the cylinder and rest of the hydraulic equipment, as well as cause operational losses. At Kastaş Sealing Technologies, the performances of existing wiper seals are evaluated, and new product developments are studied with the new test rig manufactured with the intention of continuous development and improvement studies.

In the future of this study, performances of the wiper seals will be measured under different test conditions and the effects of different operating conditions on product performance will be examined. In this way, the design requirements created by the challenging working conditions on the product will be determined and new generation product developments will be paved the way.

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