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Further Observations in Wiper design and Particle Transport Simulation in the Sealing Gap

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In the last ISC results with several wiper designs with regards to dirt insert rate into a sealing system was presented. Also, the simulation of the motion of such particles in the sealing gap was shown. Material wear resistance and fluid streamlines before the lip seems to have an influence on particle's ability to pass the gap between seal and rod.In this paper, starting from a standard wiper, lip design alterations were tested. By changing the wiper's lip design a change in the flow lines of the fluid and therefore the particle insert was intended. Among the lip design changes furthermore the improvement in simulation of particle flow in the wiper-rod interaction area is presented. The effects of the lip variation on the particle insert test results will be discussed and compared with simulation results.

1 Introduction

Debris particles in any machine are the main source for premature wear and failure. The costs of damage and reduced lifetime are impressive, as 70% of industrial equipment fail previously due to abrasive particles in the system [1]. Filters help strongly to avoid such damage, nevertheless, understanding the process of particle insert into systems is necessary to design elements that will avoid the contamination of machine systems. In hydraulic systems, one main source of insert is the rod of cylinders in motion. And here for, the wipers are the sealing elements responsible to keep particles outside the system and maintaining sufficient lubrication for the whole rod sealing system endurance. In past works, such particle ingress has been presented [3,4,5]. In previous studies, the mechanics of ingress mechanism based on friction between particle and rod and wiper material was presented [7]. Also, the filtering effects and change of particle size distribution of hydraulic wipers has been observed [5]. At the last ISC in 2022, results showing the potential lip design on particle ingress was presented [8]. Further studies to corroborate these first findings will be presented here: Variation of lip angles on insert behaviour has been done experimentally and analytically with the implementation of particle flow in the Reynold's equation.

2 Test Set Up and Test Procedure

2.1 Test Set Up

In the above-mentioned studies [3,4,5,8] different testing rigs have been used. Repeatability and reproducibility (R&R rate) shown that a simple test rig as shown in **Fig. 1** offers the best rate of approx. 30% which, considering multiple effects like rod surface, wiper variation (tolerances on material and design), particle concentration and distribution, etc., is a quite acceptable value. Additionaly, this setup represents a quite close field application depiction compared to other test rigs.

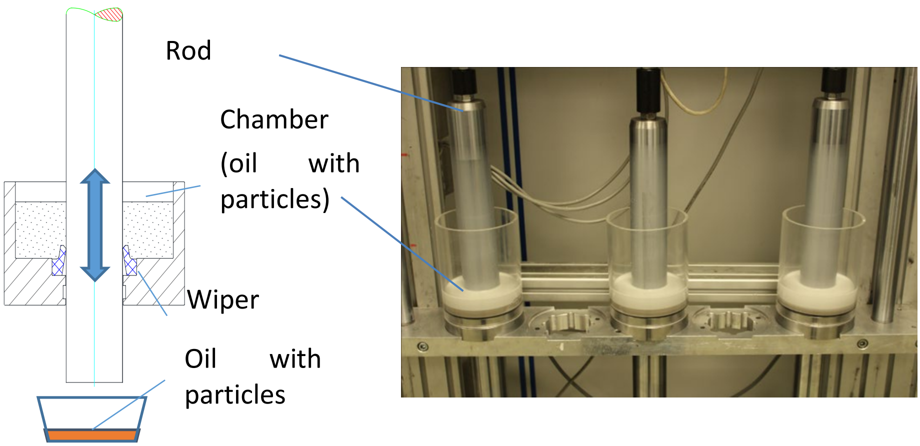


Figure 1: Wiper test arrangement with vertical rod

In this testing set-up, a vertically driven, chrome hard plated, Ø50 mm rod was reciprocating moved up and down (stroke 200 mm) through a wiper holding a defined amount of contaminated fluid, both part of a single fixture. For each tests, three rods were used parallel to have identically motion cycles on wipers. The chamber with contaminated fluid contained a mixture of 1:2 weight ratio (1 part HLP hydraulic oil and 2 parts Arizona sand class 2).

To avoid effects of wiper rocking in the housing detected in previous works [5,8] and so allowing wiper ingress through the outer diameter of the wiper and the housing, TPU wipers with metal cage were chosen. Using standard TPU wipers, the sealing lip was removed and the face angle towards the oil chamber was cut in different angles (110°, 80° and 60°), while the wiper contact zone to the rod was unchanged and is net-moulded with a radius (**Fig.2**). Wiper material: 94 AU 30000, a high performance TPU. The wipers were produced under series conditions and the lip angle alteration was done by mechanical trimming without altering the wiper lip edge.

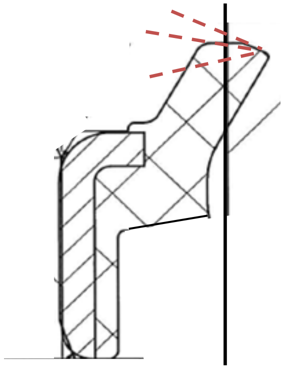


Figure 2: Wiper lip design variation

2.2 Test Procedure

Like previous work on wipers [5,8] three rods were used to test parallel three wipers of each type. The test consisted of two following steps or phases:

First step:

- 20.000 cycles
- Stroke: 200 mm
- Upstroke speed: 0.3 m/s
- Downstroke speed: 0.3 m/s
- Medium: HLP oil and Arizona Sand class 2 mixed in a 1:2 weight ratio
- Room temperature
- Atmospheric pressure

Second step (following to first step):

- Upstroke speed: 0.1 m/s
- Downstroke speed: 0.3 m/s
- Other conditions as in first step

This second step with slower upstroke speed was intended to show effects of stroke velocity on dirt ingress.

Rod surfaces roughness was measured before and after each test, using for every test new rods.

Also, the radial load of the wiper lips was measured before and after each test. The real wiper geometry was measured with a 3D microscope, these data was used to generate the FEM models for the FEA analysis.

The amount of contaminated oil that passes through the wiper was weighed every 5,000 strokes.

3 Test Results

The results show a high spreading of insert rate for each wiper. From three wipers of each variation, only one wiper showed insert rate, while the others showed no measurable insert rate.

As expected, the ingress rate increased at higher downstroke velocities (after 20,000 cycles). And also as seen in [8], a sedimentation effect lead to a decrease in the insert rate with longer operation time.

Wipers with 80° face angle did not show any insert at all. But considering, that each two wipers with 60° and 110° did also not show any insert at all, this cannot be taken as a better result. So, the data basis for a conclusion is still not sufficient at this point.

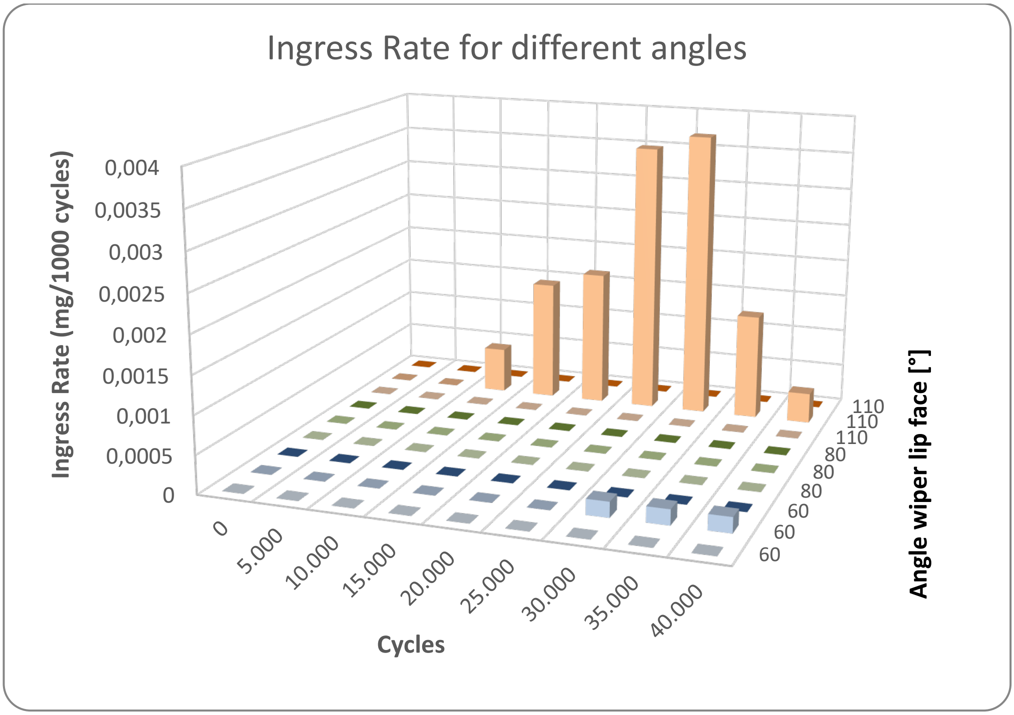
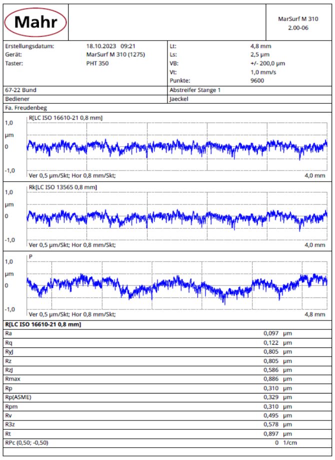


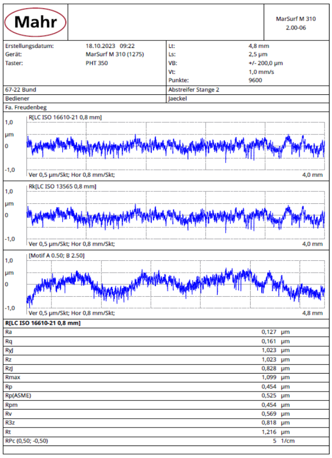
Figure 3: Ingress rate for different wiper lip face angles

It is also remarkable that only the middle rod showed ingress.

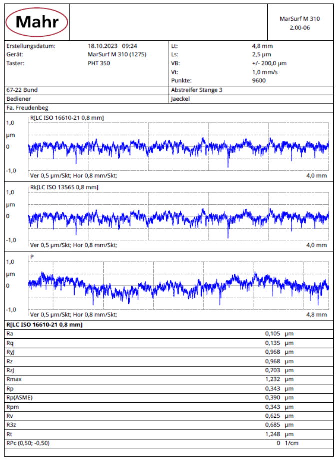
Looking at the rod surfaces roughness before the test, we see also some differences: for 60°, all three rods were very similar:



Rod 1 60°

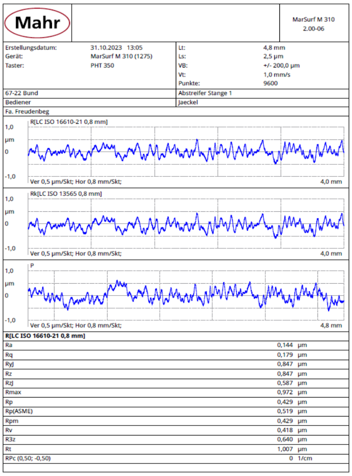


Rod 2 60°

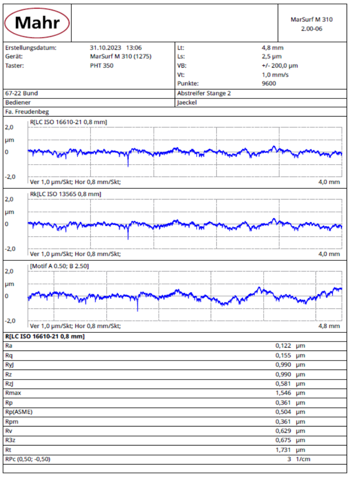


Rod 3 60°

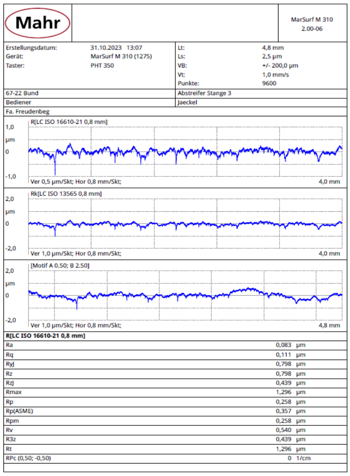
The rods used for the 80° face angle wipers:



Rod 1 80°

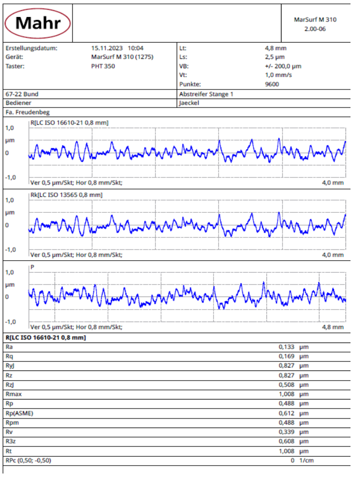


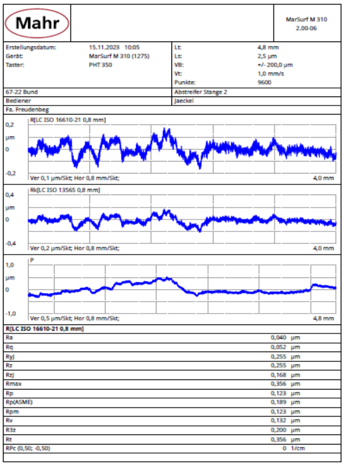
Rod 2 80°

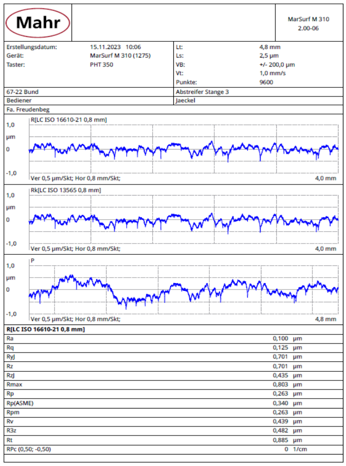


Rod 3 80°

And the rods used for the 110° face angle wipers:







Rod 1 110° Rod 2 110° Rod 3 110°

Summarizing some roughness values for all rods (***Table 1***), we see that the rod with the highest insert rate had at the beginning of the test the smoothest surface:

	Ra	Rmax	Rp	Rv
Rod 1 for wiper 60°	0,097	0,886	0,310	0,495
Rod 2 for wiper 60°	0,127	1,099	0,454	0,569
Rod 3 for wiper 60°	0,105	1,232	0,343	0,625
Rod 1 for wiper 80°	0,144	0,972	0,429	0,418
Rod 2 for wiper 80°	0,122	1,546	0,361	0,629
Rod 3 for wiper 80°	0,083	1,296	0,258	0,540
Rod 1 for wiper 110°	0,133	1,008	0,488	0,339
Rod 2 for wiper 110°	0,040	0,356	0,123	0,132
Rod 3 for wiper 110°	0,100	0,803	0,263	0,439

Table 1: Surface roughness of tested rods before test

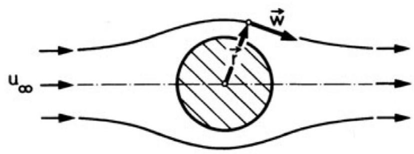
This result leads to the need of further testing to statistically corroborate the correlation between surface and particle insert. A possible explanation for this behaviour could be obstacles that surface roughness represents for a particle trying to pass the gap between wiper lip and rod.

4 FEA on Particles in Sealing Gap

The simulation of a particle in a sealing gap was presented in [8]. There, a possible effect of flow lines in a fluid on the particle migration through the sealing gap, was postulated. To corroborate this hypothesis, a deeper understanding of the fluid flow in the gap and around the particles is provided.

But here, the initial assumption, that the Reynolds differential equation would deliver sufficient basis for solving the problem, faces its limitations: The fluid flows around the -assumed as a spherical body- particle not in a 2-dimension field anymore but from all sides.

Additionally, it makes a difference if the fluid is stationary flowing around a fixed particle or if the particle itself is in motion in the instationary fluid (**Fig. 4**)



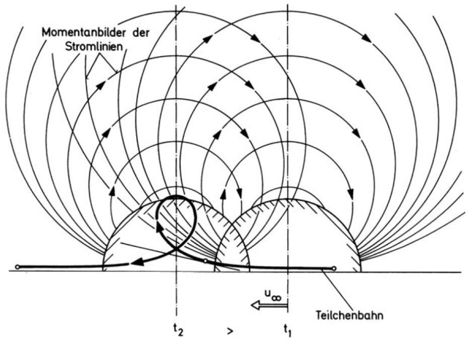


Figure 4: Flow lines around bodies [10]: Left: fixed spherical body being passed by a stationary flowing medium. Right: a cylinder body in motion in a not stationary flowing surrounding

So, the solving of this problem requires adaptions on the Reynolds differential equation which delivers a 2-dimension pressure field around the particle to be able to generate results.

Having x as the rod axis, y as the circumferential axis and z as the radial axis, the particles will be flowing in a pressure field, which is in radial direction (z-axis) constant. Around the particle, we will have four areas in which the pressure field will be constant in radial direction: before, after, below and above the particle. These need to be analyzed individually.

In [8] the particle motion in the gap was described: Particles do not only move in x and z direction, but they also rotate in their y- axis due to different pressure distribution around the particles, especially on the upper and lower side of the particle.

To generate the flow lines or the velocity vector field, we need to use the 2-dimensional results from the Reynolds differential equation to generate a 3-dimensional field with the velocities u, v and w corresponding to the coordinates x, y and z.

The approach to gain results for the velocities u and v consists in using the pressure distribution in x and y direction and the velocity boundary conditions which are the rod velocity, the particle's velocity and its rotation (Fig. 5 and 6).

Furthermore, the continuity equation with the velocity boundary conditions of the particle's velocity and rotation in the field will help us to obtain the velocity w in z direction.

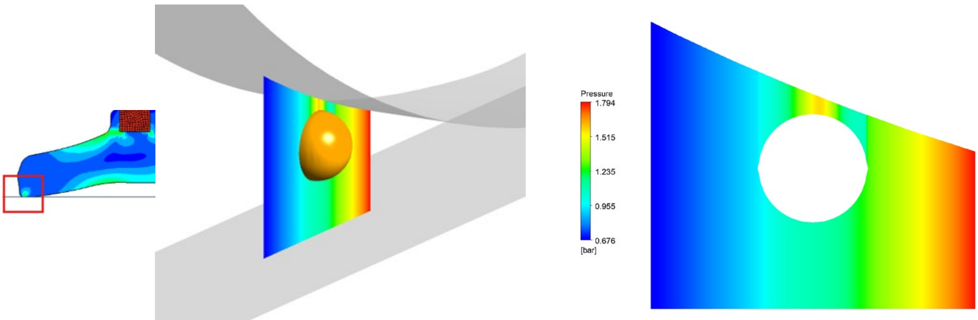


Figure 5: Lip detail and pressure distribution in the x-z field around a particle in the gap

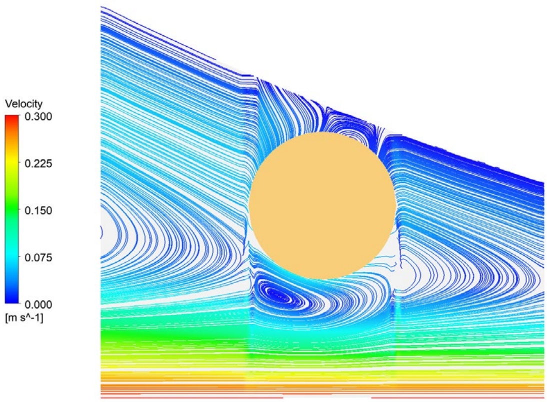


Figure 6: velocity field around the particle in the gap in the x-z field

Fig.6 shows how the strong discontinuity of the oil film thickness generated by the particle in the gap causes dramatical changes on velocity vector field near to the particle. There is a strong influence of the numerical accuracy in the velocity vector field calculation results. This leads to a quite high amount of simulation time and care of the numerical deviations (i.e. gradients calculation) to avoid wrong results.

This calculation must be done for every time step and areas around the particle to generate a full 3-dimensional field.

This is quite time-consuming, and a simplification of the process is being investigated. Nevertheless, the results lead to a 3-dimensional vector field. The effects on wiper lip design on particle ingress are still in the simulation works.

5 Summary and Conclusion

The continuation of the work regarding particle transportation in a gap between an hydraulic wiper lip and a rod in motion reveals still some questions regarding the reproducibility of results in the testing area. Data gathered is not sufficient to postulate relationships between design variables and particle insert. Further testing is still necessary to confirm the relationship between wiper lip geometry and flow line generation and particle insert into the hydraulic system.

Also, the FEA of the velocity field vector around the particle has shown that numerical problems arise around the particle, as the pressure distribution and the particle rotation during the motion in the gap deliver a highly gradient sensibility leading to numerical related inaccurate results. High awareness during the calculation is needed to gather useful results.

The momentaneous 2-dimensional results are the basis to develop a 3-dimensional velocity field around the particle in motion.

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