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DESIGN AND MANUFACTURE OF A SAMPLE HOLDER DEVICE FOR FRETTING WEAR TESTS

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Abstract. Machine components used in the industry are constantly submitted to wear. Experimental studies on the wear phenomena are often conducted in the elastic regime using tribometers or studied using numerical models to assess the durability of mechanical systems. In this context, the main goal of this work is design a device that allows application of high levels of normal pressure and shear stress on a sphere-to-flat and a cylinder-to-flat contact configuration. This paper presents the modelling, stress field analysis, stiffness analysis and the fatigue life analysis for the device. The loads applied in the simulations were: a maximum compressive force of 10 kN and a maximum torque of 70,5 Nm. Graphic curves of the safety factor (FS) versus the compressive load applied have been made and the data from the stress field of the device body were acquired, which were later used in the fatigue analysis with the Smith- Watson- Topper method. It was established that the nominal load is 8 kN and the safety factor 2.5 for the device made of steel AISI 1045.

Keywords: Contact Mechanics, Wear test device, Mechanical Project

1. INTRODUCTION

Currently, several researches have been carried out in the field of contact wear in order to avoid its induced failure mechanisms, such as fatigue by fretting, and/or enhance parts and mechanical systems lifespan. In this context, this work will be developed with the purpose of enabling mechanical contact tests between Hertzian geometry solids in a controlled environment.

In the mid-nineteenth century, Heinrich Hertz developed a solution that combines the theory of elasticity and classical mechanics, aiming to analytically describe the stresses and deformations near the point of contact. In its formulation Hertz considered the contact problems: Sphere-Sphere, Parallel Cylinders and Crossed Cylinders (Hertz, 1882). These geometries have come to be known as Hertzian geometries.

The study of contact wear can have an influence on the lifespan of components such as: Bearings and gears, stock-bridge dampers and mooring systems chain links from a floating production storage and offloading unit (FPSO).

The main goal of this project is to design and manufacture an adaptive device to perform contact and wear tests, which will be attached to a tensile/torsional machine MTS 809, fulfilling rotative contact experiments with Hertzian geometry (sphere-plane and cylinder-plane). Build by MTS Systems Corporation the machine model number 809 can apply a maximum axial load of 100 kN and a maximum torsional load of 1100 Nm, making possible tests in much higher conditions. From these tests it is expected to obtain calibration parameters for numerical models of real engineering problems, for example, coefficient of friction, wear coefficient and volume removed, for several materials combinations.

2. DESIGNS STUDY

The project first step was a state-of-the-art analysis of commercial wear tests rigs. The equipment found were the tribometers: Anton Paar's MCR (Anton Paar, 2016), TE 77 (Phoenix Tribology, 2013a) and VCA-RR (Phoenix Tribology, 2013b) from Plint Tribology, where only one performed rotative contact test applying a maximum compressive load of only 50 N.

Then, designs for the adaptive device were proposed and the one presented in Fig.1 was chosen using a decision matrix. The matrix was based on the following features: adaptability to MTS 809, types of specimens, number of loose parts, fitting type and specimens stabilization mechanisms and their manufacturing costs and complexity. The final design

is shown at Fig. 1.

The holder has a cylindrical geometry which is easily manufactured using CNC technology. The specimens have a prismatic shape and chamfers to ensure an adequate fit inside the holder. They are also quite easy to produce. An elastomeric layer and an o-ring are recommended for surfaces with uneven shape or geometrical distortions.

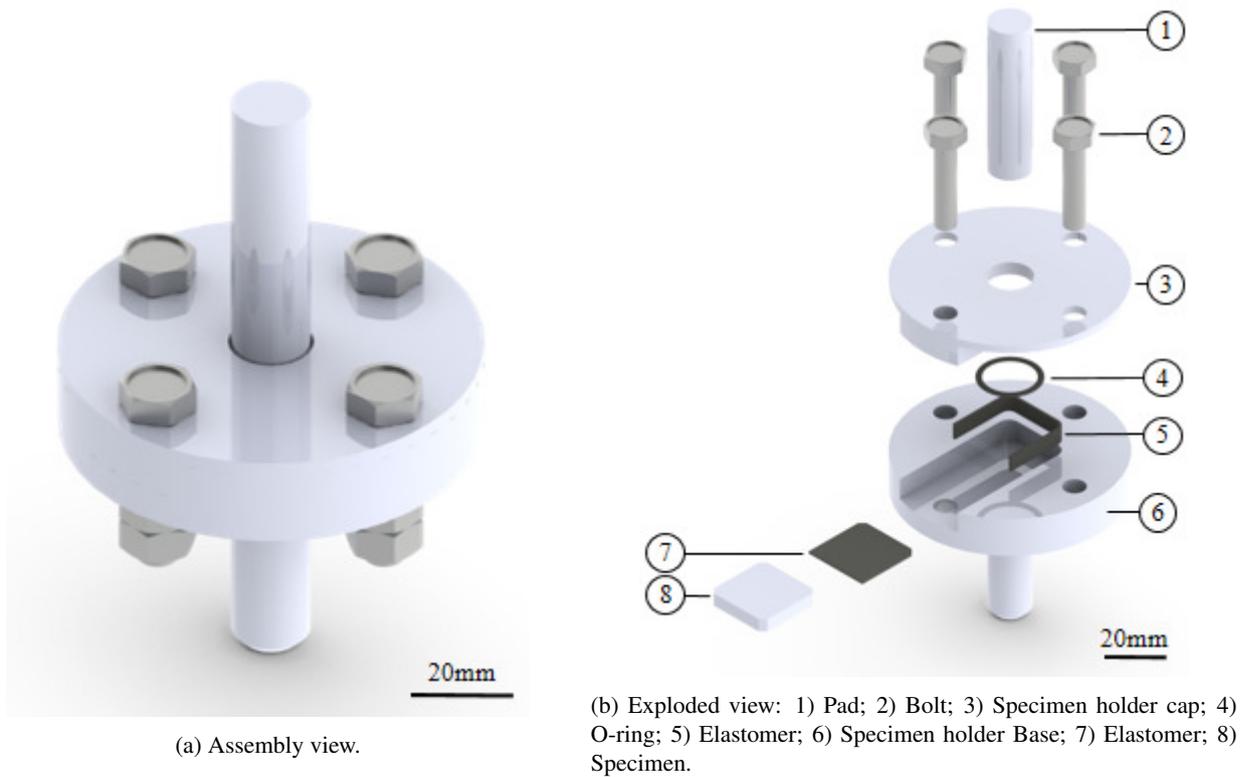


Figure 1: Final Design.

3. NUMERICAL FORMULATION OF THE CONTACT

Using the finite element analysis package, Abaqus 6.14, a numerical model was created to replicate the contact between the pad and the specimen. Two different tip pads are considered, a spherical and a cylindrical, both with a 50 mm radius tip and the compressive loads range from 2 to 10 kN. The materials assigned were AISI 1020 Steel and 2024 T3 Aluminium for the pad and specimen respectively.

Dynamic-Implicit steps were created for the compressive and torsional stages and the contact was defined between the two parts using the Finite Sliding formulation with a Surface-to-Surface discretization method due to the fact that minor errors are observed when using this method compared to Node-Surface (Abaqus, 2014). Hard Contact was chosen to describe the normal behavior using Penalty as contact constraint enforcement method.

The Mesh created in the contact region was structured so that better results would be obtained for the pressure distribution and stress field (Zegatti, 2016). The applied boundary conditions and constraints on the bodies intended to mimic two different restraints, the collet-grip and the sample holder.

To mimic the collet-grip effect a reference point was created above the pad and coupled to the upper half of the pad's outer surface where the load was applied. In addition, displacements and rotations of the centerline (parallel to the Y axis) of the entire pad, relative to the X and Z axes, were restricted.

Ideally, the device should be able to hold the specimen still during the test. Rotation restrictions were applied around all axes and displacement restrictions in the normal direction of all side faces. In the bottom face, displacement in the Y axis and rotation around the X and Z axes were prevented. The 10 kN result is depicted on Fig. 2.

From the simulation results, the contact area radius for several loads were obtained analysing the pressure distribution over the specimen as shown in Fig.3. The results are listed in Table 1. This data is used to define the torque applied on the device due to the generated friction.

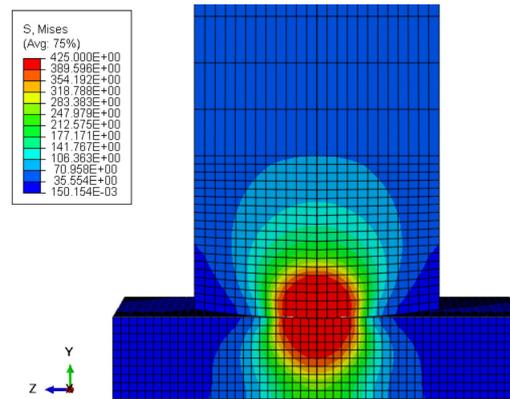
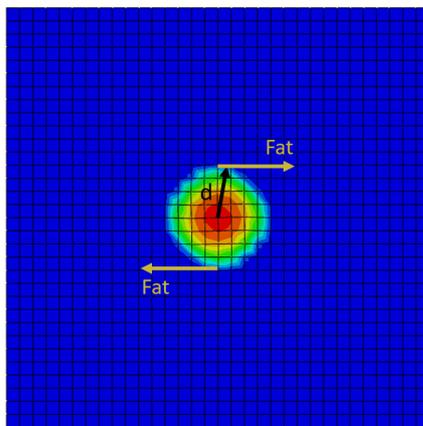
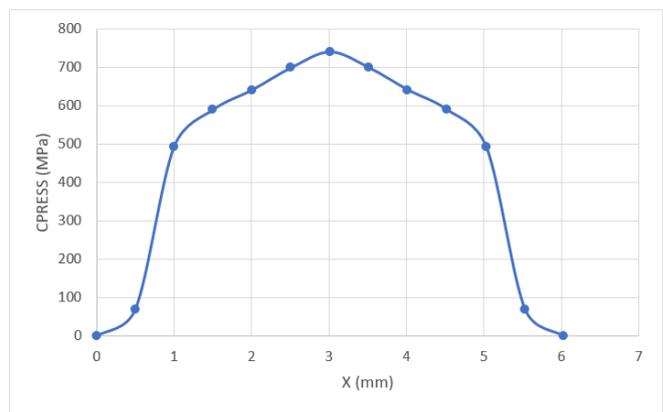


Figure 2: Von Mises stress distribution for a 10kN load.



(a) Pressure distribution for the specimen



(b) Pressure plot for the contact area diameter

Figure 3: Simulation results for a 10 kN Load

Table 1: Contact area radius for $R = 50$ mm

Load	Contact area radius
2 kN	1.5 ± 0.25 mm
4 kN	2 ± 0.25 mm
6 kN	2 ± 0.25 mm
8 kN	2.5 ± 0.25 mm
10 kN	3 ± 0.25 mm

4. PROJECT METHODOLOGY

Once the design was chosen, before the practical test, simulations were made to ensure that the device would perform safely in the MTS 809. Therefore, the minimum safety factor for this project was defined following Collins (2016) such that Np_i are the penalty factors and SF the safety factor.

$$SF = 1 + \frac{(10 + \sum_i Np_i)^2}{100} \text{ for } \sum_i Np_i > -6 \quad (1)$$

$$SF = 1,15 \text{ for } \sum_i Np_i \leq -6 \quad (2)$$

The penalty factors considered for this project were:

- Load limits knowledge: $(Np)_1 = 0$
- Precise tensile calculations: $(Np)_2 = 1$
- Precise knowledge of the material maximum tensile strength: $(Np)_3 = 1$

- Precise knowledge of the materials to be tested: $(Np)_4 = 2$
- Failure seriousness: $(Np)_5 = 1$
- Fabrication labor quality: $(Np)_6 = -2$
- Operation conditions $(Np)_7 = -1$
- Inspection and maintenance quality: $(Np)_8 = 0$
- Technical Capacity: $(Np)_9 = 0$

The numerical model results provided data for a static and a rigidity analysis, and further a dynamic analysis using the Smith-Watson-Topper method (SWT) coupled with a *MatLab* subroutine. The inputs for the SWT simulation are the static tensor for each nodal element in two situations: the mean compressive load and the cyclic torque generated by the friction forces, both obtained by the static analyses.

The initial parameters for the simulations considered were: a minimum safety factor of $SF = 2.45$, a pad made of steel AISI 1020, a specimen made of Aluminium 2024 T3, a maximum compression load of 10 kN, a dynamic coefficient off friction between steel and aluminium of 0.47, a contact radius between the spherical wear tool and the specimen of 3 mm, and that the cylindrical pad has 15 mm length. The table 2 shows the material properties needed for the simulations.

Table 2: Materials mechanical properties (Source: T. Doca, F.M. Andrade Pires, 2014)).

Properties	Aluminium 2024-T3	AISI 1020 Steel
Young Modulus, E (GPa)	71	206
Specific Mass, ρ (g/cc)	2,78	7,87
Poissons Ratio, ν	0,32	0,29
Tensile Strength, Yield, σ_e (MPa)	275	350
Resistance Index, A (MPa)	400	600
Strain-Hardening Coefficient, b	0,21	0,24

5. DEVICE SIMULATION

The model was created with the obtained parameters and estimated dimensions, which were iteratively varied up to the final values. The applied constraints and boundary conditions replicated the effects originated from the collet-grip restrains and the reaction forces of the specimen on the device body as shown in Fig.4.

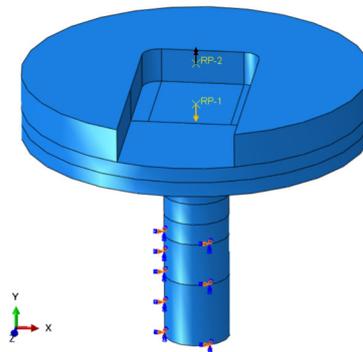


Figure 4: Boundary conditions applied to the model.

The worst case scenario was observed when a cylindrical pad was employed. Due to the higher contact radius, with a 10 kN compressive load. A torque was applied on the device's internal chamber and its magnitude given by the relation of the friction coefficient, contact area radius and load.

As shown in Fig. 5 the maximum stress is located at the thinnest segment, more accurately at the point right above the represented collet-grip, which is a physical limitation of the test machinery.

Other loads were used in subsequent simulations for both pad types, in order to investigate the safety factor tendency. The Tab. 3 shows the results. Since the minimum admitted project safety factor is $FS = 2.45$, the most critical situation allowed is a spherical pad with a 8 kN compressive load applied.

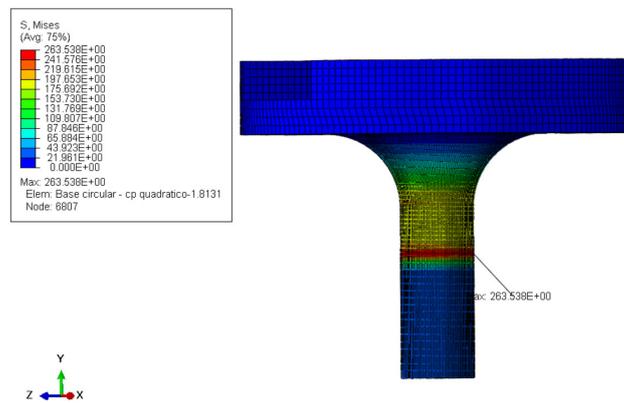


Figure 5: Von Mises stress distribution for a cylindrical pad.

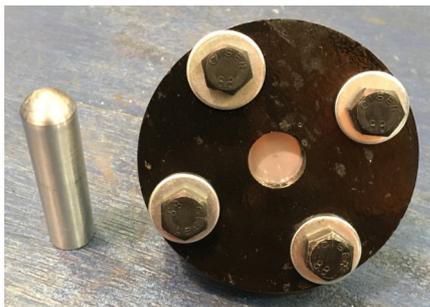
Table 3: Yield safety factor for different loads.

Axial Load (kN)	Spherical pad		Cylindrical pad	
	σ_{mises} (MPa)	SF_{yield}	σ_{mises} (MPa)	SF_{yield}
2	14.5	36.6	52.7	10.1
4	34.0	15.6	105.4	5.0
6	51.0	10.4	158.1	3.4
8	79.7	6.66	210.0	2.5
10	99.6	5.32	263.5	2.0

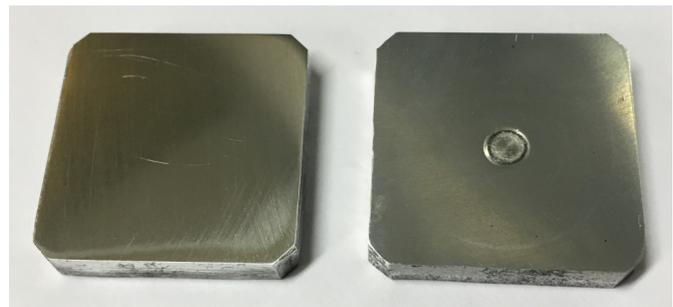
6. PROTOTYPE BUILD AND FIRST TEST

Once the sizing was finished, manufacturing technical drawings have been made and then it was built using a numeric control cut machine (CNC) to guarantee the dimensions precision.

For the validation test an aluminium specimen and indenter were built and installed in the MTS 809. The machine was then set up with: a displacement of 1 mm from the position in which the contact is identified (non zero axial load), a rotation frequency of $0.2Hz$ and 1000 cycles. The Fig. 6 shows the assembly prototype and the specimen pre and post test and the Fig. 7 shows the prototype assembled in the MTS machine.



(a)



(b)

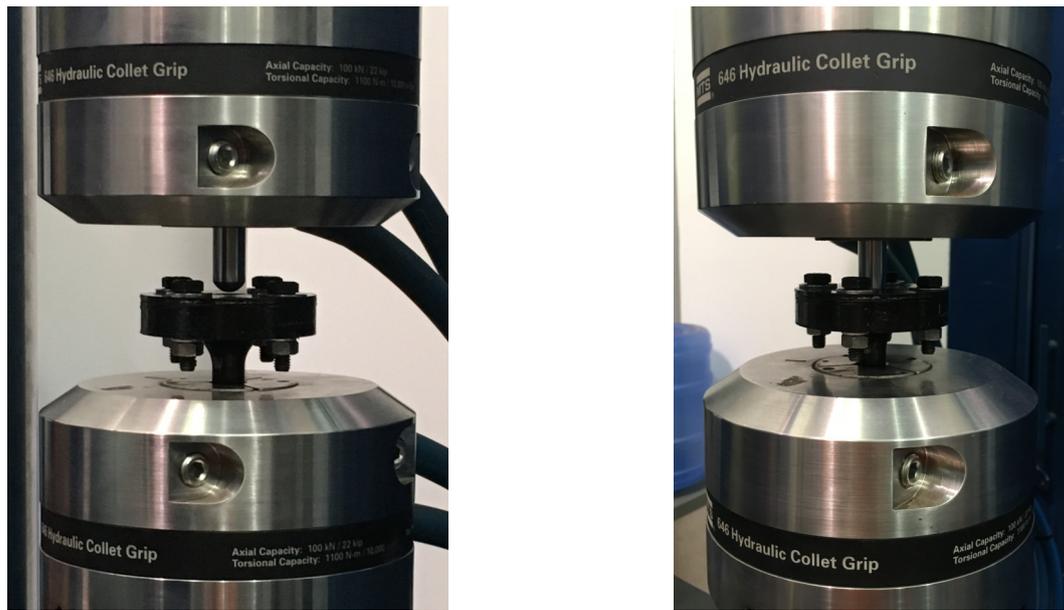
Figure 6: (a) Device prototype (b) Pre and post test specimens.

7. CONCLUSIONS

The projected device gives the possibility to run wear tests in the MTS 809 machine applying compression loads up to 8 kN for cylindrical pads and up to 10 kN for spherical pads with a safety factor of 2.5. Using a confocal microscopy to evaluate the wear crater, it is possible to determinate parameters such as: materials friction coefficient, wear coefficient and the volume of material removed due to the forces generated by the contact between different materials. These parameters can be later used as inputs for contact wear simulations of real engineering problems.

The prototype was fabricated in steel AISI 1045 using CNC technology and costed approximately US\$ 181,02. From its first test results it was evident that the device works as predicted by the simulations and an evident wear crater could be visualized on the specimen.

The sample holder allowed an experimental approach in ongoing wear studies. About 25 uniaxial compression and



(a) Test assembly

(b) On going test

Figure 7: Assembly (a) on going wear test (b) in MTS 809.

torsional wear tests were successfully carried out on different materials. An article is being developed based on these results and will be published in the near future.

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9. RESPONSIBILITY NOTICE

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