DESIGN OF A TRIBOLOGICAL BALL JOINT TESTER

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Abstract: The automotive industry uses ball joints in the suspension systems of cars. These ball joints are subject to various forces and relative displacements which inevitably invoke wear. The same happens in other applications that use ball joints, for example human hip joints. Nowadays there are only a few test rigs that can correctly simulate wear in these joints or test the joints according to a realistic loading cycle. This paper focuses on the design of a test rig that allows parametric research on these ball joints in order to increase the performance.

Keywords: Machine design; Wear; Ball joint; Tribometer

1 INTRODUCTION

Ball joints are important components in the suspension system of all kinds of automotive applications. They are typically situated near the front wheels and allow the wheels to swivel so the driver can steer. Ball joints, in combination with springs and different links, are the components responsible for the suspension of the car. More precisely, there are different types of ball joints each serving a different purpose. Some ball joints are mainly loaded in the radial direction, such as the outer tie rod. Whereas inner tie rods are mainly loaded axially. The design of the car influences the positioning of these ball joints. In figure 1 the Short-Long Arm (SLA) suspension system is shown. Tie rod ends are linked to the steering mechanism and provide the transition between the linear motion of the steering system and the rotary motion of the wheel by an eccentric crank mechanism. Both axes are perpendicular. Inner ball joints are also part of the steering mechanism but have collinear axes. Lower and upper ball joints are important in the suspension system of the car. Figure 1 shows some of these components in a typical SLA setup. The red arrows indicate places where ball joints are used.

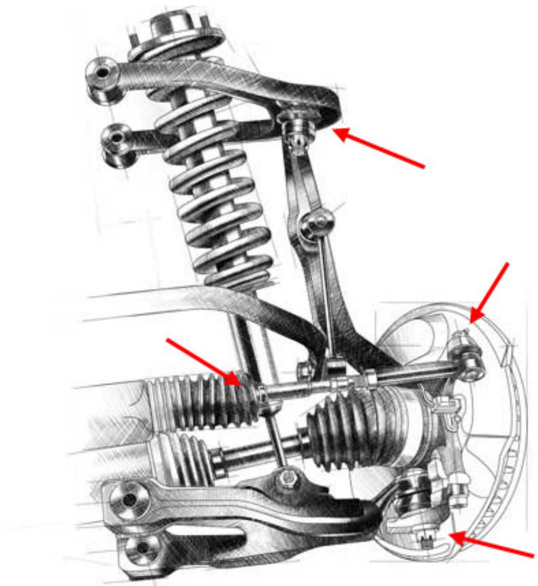

Figure 1: Toyota FJ Cruiser front suspension [1]

Ball joints consist of a socket, a polymer insert, a ball connected to a pin and an elastomer sealing which is shown in figure 2. The performance of these ball joints can make the difference in the overall quality of the car. When wear becomes too high, clearance increases and results in less smooth steering and overall discomfort when driving. It is important to check the ball joints once in a while to ensure they are still fit for use. Ball joints are subject to a wide range of loads, rotations and frequencies. Those are dependent on the driving conditions, e.g. driving on a highway compared to driving up the pavement at high speed having the front wheels positioned at maximum steering angle. The worst case scenario is that the ball is pulled out of the socket, causing total dysfunction of the car. It can be concluded that the wear of ball joints is a very common phenomenon and regular coupon scale test rigs, such as a pin on disk setup, are not capable of predicting this long-term behaviour. These test rigs most often only apply a force in one direction and are able to perform one rotational movement. More complex test rigs nowadays are able to apply two forces and three movements, but still lack the ability to apply the third force component. In this master's dissertation a fatigue and wear test rig is constructed for research purposes.

Figure 2: Cutaway section of a ball joint

2 BALL JOINT TEST SETUP

2.1 Kinematic and dynamic analysis

In any application that uses a ball joint, it is often required that the joint can perform a motion in all directions. These are a rotational movement around its axis and two tilting movements. Due to this type of joints, the pin can move in a three dimensional space. The ball joint can be loaded along three main axes: one axial and two radial directions. The axial direction is situated along the axis of the pin. Figure 3 give a schematic overview of the possible movements. The picture on the left represents a guide joint control arm for the front axle support. The picture on the right shows a stabilizer link.

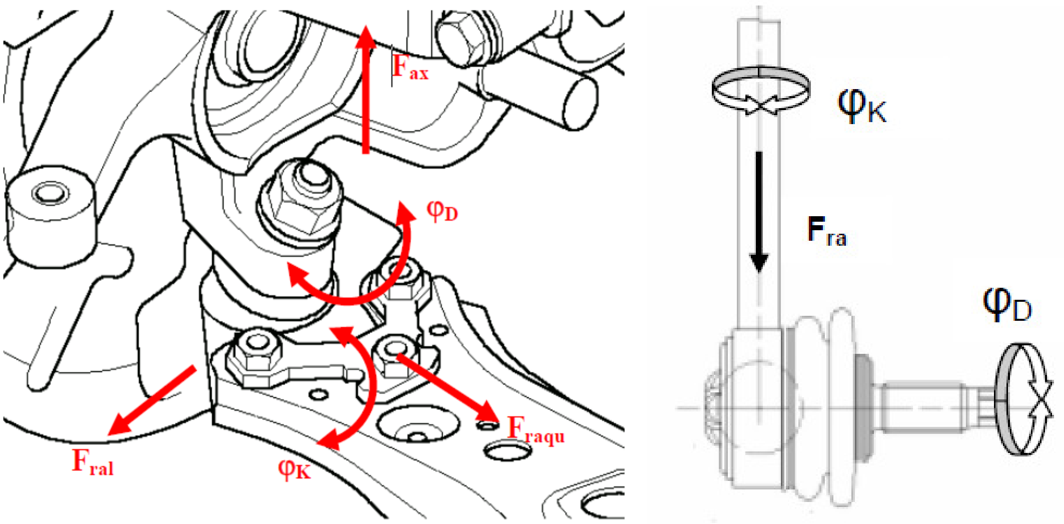

Figure 3: rotational and tilting movements of a ball joint in an automotive example [2]

The forces are induced by either the steering of the driver or bumps in the road. The driver will rotate the steering wheel which introduces a change of a rotational movement to a linear motion. The mechanism to convert this motion is beyond the scope of this paper. The linear motion is then used to rotate the wheels in the desired direction. Due to this motion, the ball joint is loaded along a radial direction. When driving over a bump in the road the wheels of the car tend to jump up which introduces an axial force in the ball joint. The loading in the second radial direction happens when a car for example drives over a speed bump. The wheels are then pushed upwards and backwards with and axial and radial loading as a consequence.

This analysis shows that a ball joint rotates in three directions and has is loaded in three directions. The fatigue test rig should have six axes to correctly simulate the working conditions of the ball joint.

2.2 Existing designs

Most test rigs nowadays extract one certain motion or one certain loading direction and perform tests neglecting the other movements and loading directions. A ball joint durability test from an Indian company to do an oscillating test under severe environmental conditions exists. This system lacks the ability to test a ball joint in the same severe conditions with movements and loading patterns based on reality [3]. A company from the United Kingdom possesses a five axis testing rig. This test rig can perform loading in all three directions, but can only rotate in two directions. These are a rotational movement around the axis and a rocking or tilting movement. The second tilting movement is absent [4]. A large company form the United States owns a four axis testing rig to test ball joints by loading in two directions and move in one direction. Another company from the United States made a five axis test rig which lacks a third movement [5, 6].

Most existing test rigs to test ball joints are limited to maximum five axes. This is often a limited approximation of the problem and is mostly not an accurate simulation of the occurring conditions. To test ball joints in representative conditions a new test rig should be constructed which can synchronously apply three orthogonal rotations and three orthogonal forces.

2.3 UGent test rig design

The test rig should be able to apply three rotations and loading patterns along the main axes. In order to achieve a constructible mechanical structure, it is recommended to split the forces and movements. This prevents that an actuator has to constantly adjust its stroke in order to apply a constant force. All rotational axes must coincide in the center of the ball joint in order to get the wanted rotations of the test specimen. Figure 4 shows the mechanical construction for the application of the three rotations. The rotation is managed by a servo on top of a tilting pad (red). One tilting movement is performed with another servo motor (black). This part also contains the servo for the rotation along the axis of the pin. The last rotation is performed by a four bar linkage system which is driven by a third servo motor (gray). These three servo motors control the motion of the ball joint in the center. The project is currently in the design phase, this means that the following figures may not represent the final design of the test rig. The main principles of rotating and loading will remain in further design steps.

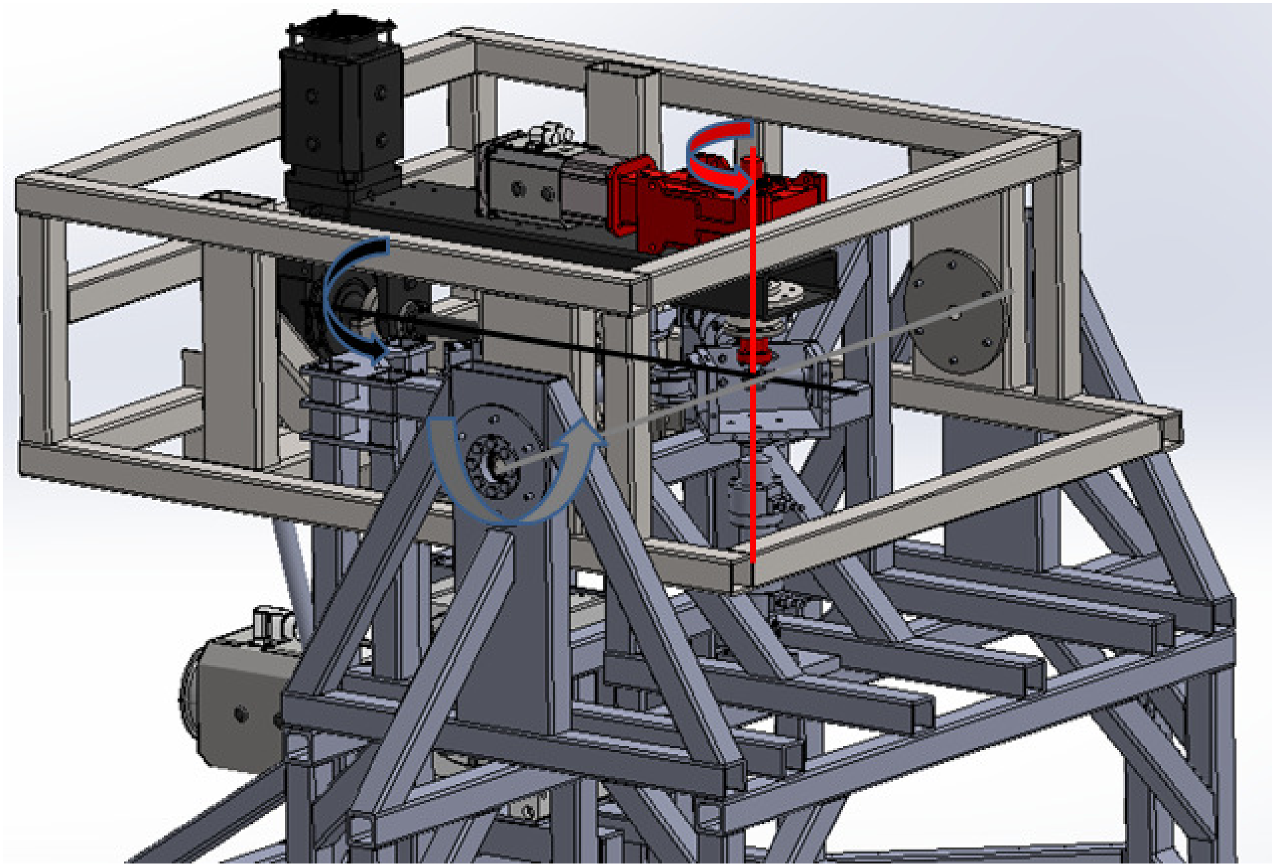

Figure 4: motion of the test rig

The three forces are applied by hydraulic actuators. The hydraulic pistons are mounted orthogonally so that the centre point of the ball coincides with the intersecting force components of the actuators. Figure 5 shows this setup. Due to this setup, the movement and loading are completely separated. The actuators will be force controlled during the tests.

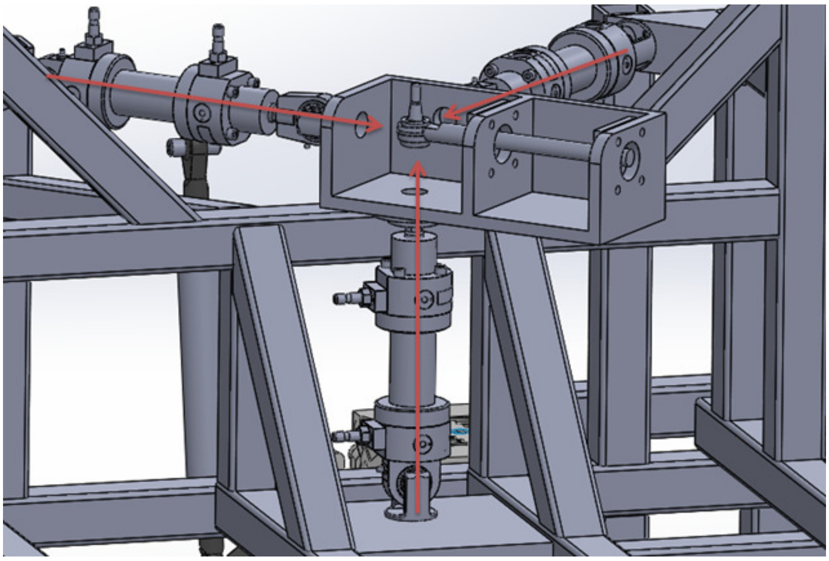

Figure 5: Loading of the ball joint

2.4 Versatility

Ball joints are used in more than only automotive applications. Some other examples are hip joints, joints in part of dolls to move their limbs or in applications where steel pipes can expand excessively due to heating. This test rig should also be able to test ball joints for these applications. The hydraulic actuators can deliver a wanted loading cycle and the servo motors can easily give a desired angle of rotation. This makes it ideal to test these other applications. Figure 6 shows a simplified hip joint. It can be seen that it is necessary to have a six axes machine to test these joints.

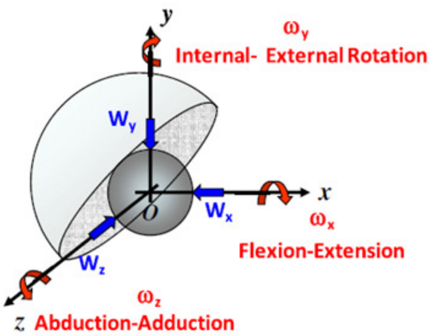

Figure 6: Loading and movement of a hip joint [7]

Most test rigs ignore a movement when it's small and leave this axis out of the test setup. With the extra axis, which is often absent in the existing designs, small movements and forces can be simulated as well as large movements. This can for example show effects as a consequence of vibrations due to very small movements of the specimen.

3 CONCLUSIONS

Ball joints are used in a lot of applications and are almost always loaded along the three main directions and can rotate around these three axes. These joints nowadays are often tested with a three, four or five axes test rig. These setups make the assumption that one axis (force or movement) is small and negligible. This is only an approximation of the reality. To simulate real loading conditions, a six axes test rig is necessary. Ball joints for several applications can be tested by adjusting the force and angles in the hydraulic actuators and the servo motors. This test rig is aiming at performing parametric research on ball joints in the automotive industry. With the results, the performance of the joints can be increased. In a second phase, the machine can be used to test hip joints.

4 ACKNOWLEDGEMENTS

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