CONCEPTUAL DESIGN OF A FRETTING FATIGUE TESTING DEVICE

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Abstract Fretting fatigue occurs in contacting parts which are simultaneously subjected to fluctuating loads and very small sliding movements. This phenomenon can significantly reduce the fatigue life of components. This paper focuses on the conceptual design of an advanced, especially in functionality and human engineering, test rig for fretting fatigue experiments. Different designs of test rigs are evaluated by weighing their advantages and disadvantages.

Keywords Fretting, fatigue, test rig

1 INTRODUCTION

When two mating components exercise a relative movement, in a loaded condition, wear can be caused. When these movements are relatively small, in the order of microns, this is called fretting wear. As a result, small cracks occur which will shorten the life span of the material. This relative movement can be caused by elastic deformation of the material or machine and construction vibrations [1][2]. In this paper, fretting is related to fatigue because both phenomena are important to the life span of materials and constructions.
A practical example, Figure 1, in which fretting fatigue has been observed is the connection of two plates by means of a bolt [3]. Fretting can occur between the bolt and the plates or between de plates itself. The bolted connection will typically be calculated to resist both static and fatigue loads. There are no simple means to take fretting wear into account. Figure 2 shows fretting wear observed on the thread of a bolt. By small movements, applied by elastic deformation of the plate material from fatigue or vibrations, the dimensioned bolt can premature break due to fretting in combination with fatigue. In this case the preload of the bolt was less than required.

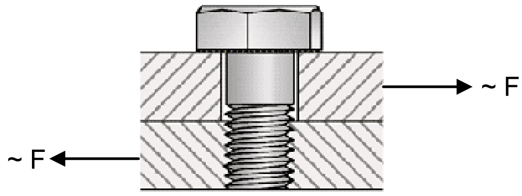

Figure 1: Two plates connected by a bolt and loaded in fatigue [4]

Figure 2: Fretting wear [5]

Apart from the described problem with the bolt connection, several other applications have been reported where fretting fatigue and failure appears such as leave springs [6], dovetail joints [3] used in the rotors of aircraft engines, prostheses [7]. This highlights the importance of the study into fretting and its properties and consequences. The aim of this work is the design of a test rig for fretting fatigue experiments, meeting the requirements postulated in section 4. As a source of inspiration, existing test rigs were studied and their major drawbacks evaluated. The future design is based on a coupon test rig which is a test facility used to perform universal research. This design is in contrast to full-scale test rigs which are limited to one application, such as dovetail joints.
In the next section the combination of the fretting and metal fatigue phenomena and their interrelations are discussed.
Section 3 addresses some existing test rigs and their limitations. In section 4 the main requirements for a new set-up are postulated. It further focuses on the current status of three conceptual designs and the last section gives a conclusion on the acquired knowledge.

2 COMBINING FRETTING AND FATIGUE

The loads and displacements corresponding to fatigue and fretting are independently illustrated for the case of a clamped beam (Figure 3). Hereby a fatigue load is imposed by an oscillating force F_{fat}. Apart from the fatigue load F_{fat} also a constant normal load F_N, perpendicular on the cross-section of the beam has to be introduced. To realize the fretting movement on the clamped beam, caused by the indenter (fretting pad), a micro displacement *d* must be available.

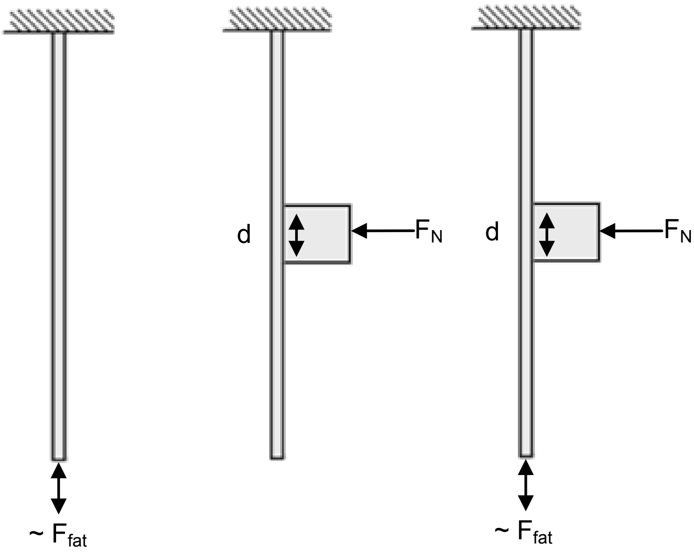

Figure 3: a) Fatigue b) Fretting c) Fretting fatigue

3 DISCUSSION OF EXISTING FRETTING FATIGUE SET-UPS

Literature on fretting fatigue clearly demonstrates that the test set-up based on the proving ring [8] is a widely used method for the creation of the normal force F_N (Figure 4).
Through a ring, which serves as a calibrated spring, and a clamping screw a force F_N is applied across the specimen. As a result of fretting wear, material particles will break loose from the test specimen. If these particles get caught between the test specimen and the fretting path, the applied normal force F_N will fluctuate. This is to be avoided what is necessary in order to obtain representative test results. Due to this test rig is displacement controlled, trough the ring mechanism, instead of force controlled a disadvantage is caused.
A similar construction exists where the normal force F_N is delivered by preloaded springs but it has the same disadvantages.

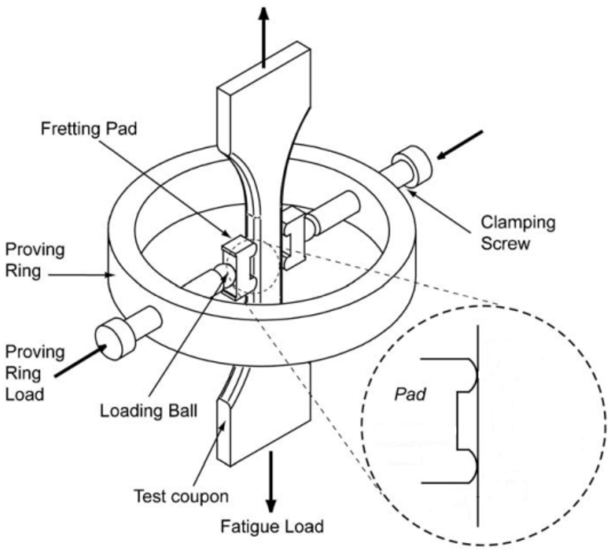

Figure 4: Proving ring test equipment

Fretting fatigue can only be accurately studied if the required slip, the relative displacement *d* of the fretting pad in relation to the specimen, is controllable and independent from the elastic deformation of the test specimen due to the fatigue load.
In the above figure (Figure 4) each pad is contains two contact surfaces. The elastic deformation (due to fatigue load) of the specimen creates frictional force between pad and test specimen. The deformation of the fretting pad influences the minuscule slip that takes place between the two parts. However, the achieved slip is hard to predict and impossible to control which is a drawback of this test rig. The shape and dimensions of the fretting pad are crucial.
In order to control the relative displacement *d*, once more calibrated and interchangeable springs have been used (Figure 5). The generated tangential force F_T, between pad and specimen, is absorbed by the spring [9] and causes a small additional slip. Here as well, the slip is hard to control and predict.

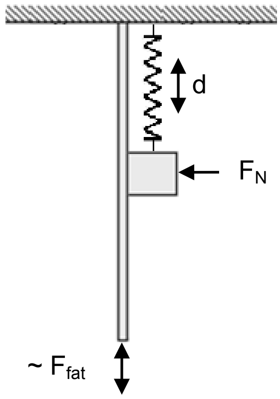

Figure 5: Impose of the relative displacement *d* through a spring system

This discussion clearly reveals the crucial attention points for the design of an advanced fretting fatigue test rig.

4 DESIGN OF THE FRETTING FATIGUE TEST FIXTURE

The main goal of this work is to design an advanced fretting fatigue test set-up which addresses the shortcomings of the existing set-ups. The concepts proposed in section 4.2 are based on a pad holder system with a very high tangential stiffness. The test coupon will be (elastically) elongated by the fatigue force F_{fat}, which has to be compensated by a global displacement of the test coupon. In contrast with the proving ring test rig, is the fretting pad in this case fully fixed and the fretting movement is realized by the global displacement of the specimen. These displacements can be controlled by means of one actuator that is force controlled and one that is displacement controlled respectively.

The design has to meet certain requirements to obtain efficient operation and results:
- (i) the ability to produce a constant normal force F_N of maximum 5 kN between pad and specimen (value based on research of existing fretting fatigue set-ups),
- (ii) very high stiffness of the fixture in order to minimize pad movements to a few microns,
- (iii) visibility of the pad and the specimen,
- (iv) high precision techniques to measure forces, displacements and fretting slip.

A general view of the available frame and an impression of the future test set-up design is depicted in. The set-up consists of 5 parts : (i) the load frame, (ii) the hydraulic group, (iii) the two specimen grip systems, (iv) the fretting fixture, (v) the measuring tools.

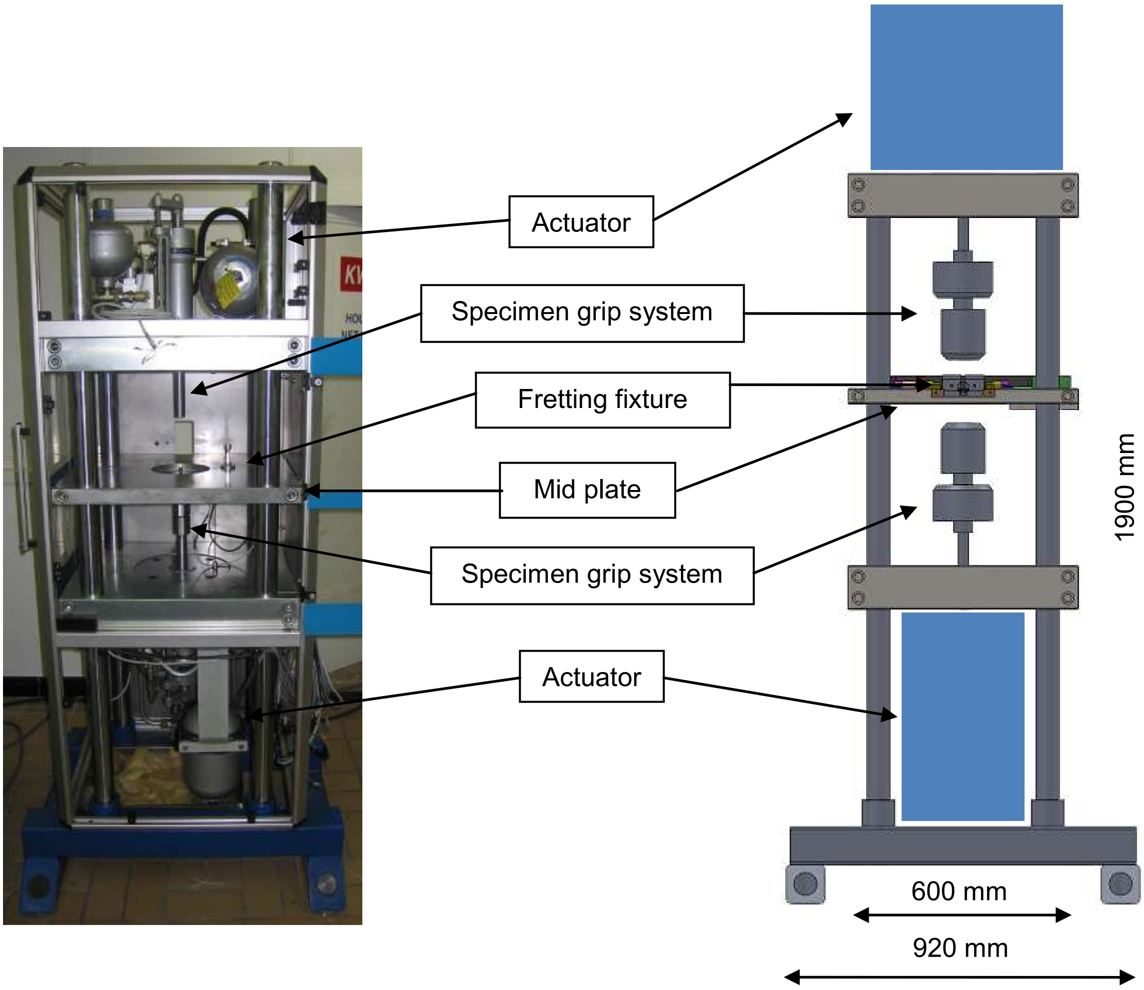

Figure 6: General view of the available machine and the future test fixture

The future design is based on an existing construction; a tablet press machine (Figure 6) will be rebuilt and expanded. The frame, the hydraulic group delivering the pressure needed in the actuators and two actuators for the realization of the fatigue load and the global vertical displacement of the test coupon are already available., A third actuator to apply the normal force on the fretting pads, the pad holder system and the test coupon fixtures has to be designed.

4.1 Specimen grip system

The grip systems at the top and the bottom of the framework are similar and consist of a piston, a load cell and wedge grips assembled with appropriate adaptor pieces (Figure 7). Wedge grips ensure proper alignment of the specimen and are self-clamping. The initial gripping force at specimen insertion is applied by means of a spring, during the actual test it is achieved by the wedge effect.

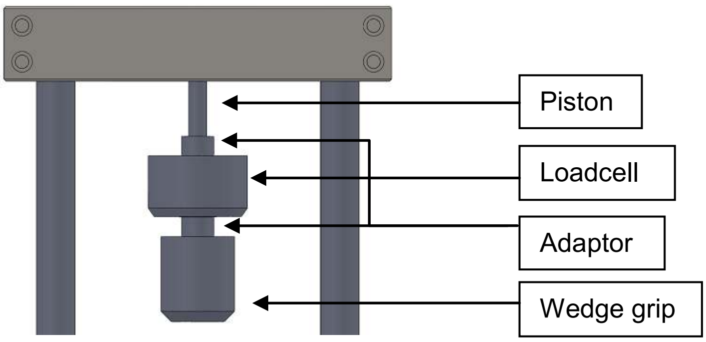

Figure 7: Specimen grip structure

In this application a consideration has to be made between hydraulic and mechanical wedge grips. Hydraulic wedge grips have excellent repeatability as they clamp symmetrical onto the specimen test after test The grips maintain a constant gripping force on the specimen regardless of the test forces acting upon it. This adjustable gripping force prevents damage to the specimen from the grip or specimen slippage during tests. Hydraulic wedge grips can withstand both tensile and compressive forces unlike mechanical wedge grips which can only be used for (static or cyclic) pure tensile loading. Mechanical wedge grips have advantages such as their compact nature and self-tightening behaviour during a tensile test, which avoids slipping of the specimen from its grips. The gripping pressure will be proportional to the tensile force due to the sliding wedges.

4.2 Fretting fixture

A fretting fixture design will consist of several specific parts, including a structure to fix the fretting pads, aligning elements and a construction to load the pads against a flat 'dog bone' tensile test specimen. In order to reach an equal normal force F_N at both sides of the test coupon, whilst limiting the required space and component cost, a spindle or hydraulic piston is directly connected to only one pad. The second pad is connected to the actuator through an U-guidance to apply a similar load to the specimen. Three concepts have been put forward and their feasibility to meet the above mentioned requirements evaluated.

4.2.1 Fretting fixture based on linear guides

A first conceptual design, shown in Figure 8, implements linear guides (in particular full ball types with wide rail) fastened on the mid plate. Linear motion guides are a simple and effective manner to move the pads towards the specimen. The pad holders are mounted on these linear guides. The ability to slide the pad holders backwards improves the visibility of the pad and specimen. The regained space significantly simplifies the removal and replacement of the specimen and the pads. In order to achieve the needed range of results, the height of the linear guidance becomes an obstacle as it increases a lot when the radial clearance decreases to the needed level.
The constant normal force F_N applied through the pads on the 'dog bone' test piece is induced by a spindle which is driven by a gear attached to an electric stepper motor and is measured using a load cell. The spindle will first push the right pad towards the specimen. Once a specific load is reached, the U-guidance (Figure 8) and the spindle housing connected to it, will start moving to the right. In this way, the pad at the left also approaches the specimen and induces an equal load at the specimen's left side. The load cell ensures that the proper contact loads are induced. The use of a spindle with servo control allows to define the position of the pad at all times without the need for an additional extensometer.

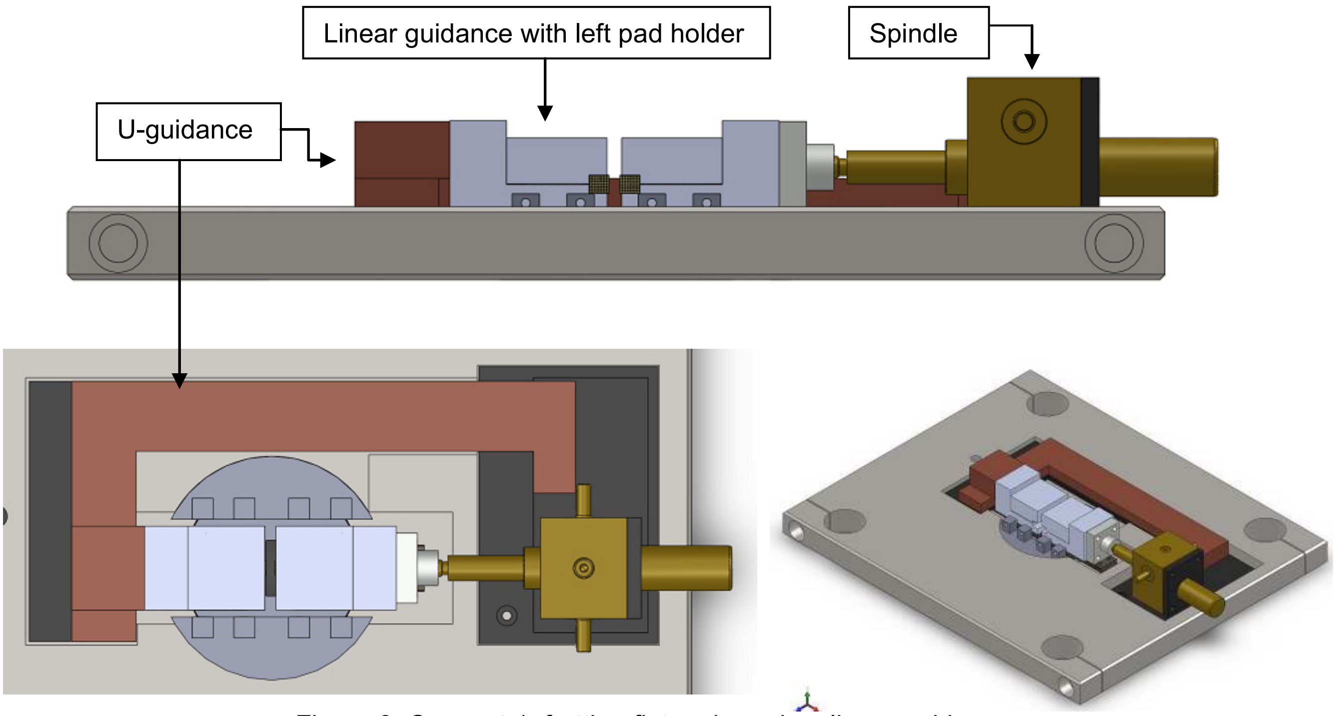

Figure 8: Concept 1: fretting fixture based on linear guides

4.2.2 Fretting fixture based on wedges

In Figure 9 a second conceptual design is depicted. The moveable pad holders are replaced by a structure fixed to the mid plate. The lower plate of the right and left pad holder is made out of one piece so no extra mechanism is needed to align the pad holders relative to each other. In this concept the pads are driven instead of the pad holders. The pad is restrained and guided between a slot in the lower plate and a wedge at the upper side of the pad (Figure 10). Two wedges slide against each other to adjust the clearance. The space between the pad and the lowest wedge is adjustable through two bolts in order to get zero clearance. The contact between pad and guidance causes a friction which is unfavourable for the needed precision movement.

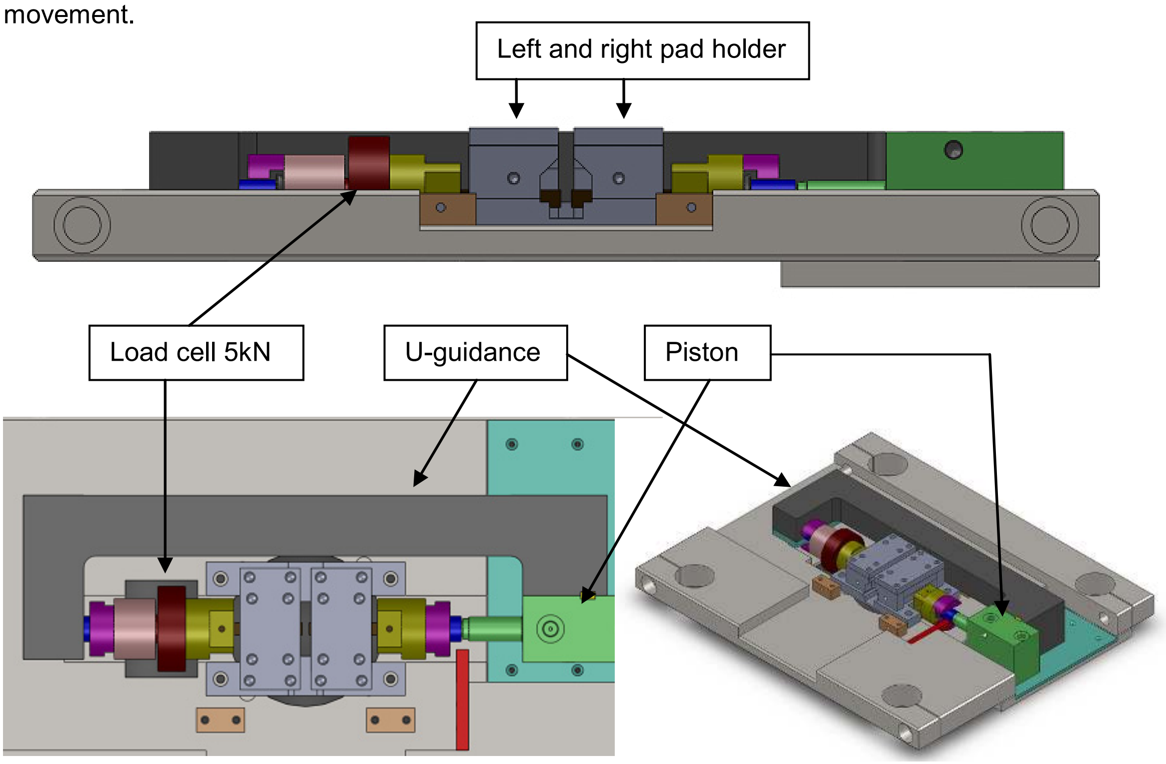

Figure 9: Concept 2: fretting fixture based on wedges

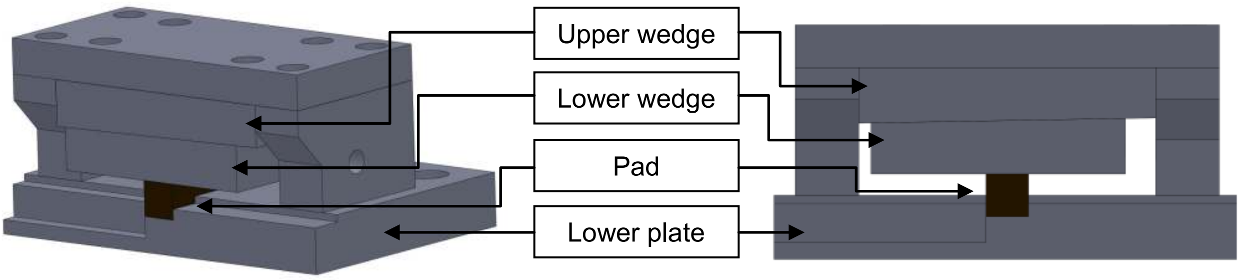

Figure 10: Pad holder system

The back of the pad is clamped into a holding device which is connected to a hydraulic piston. The reason for replacing the spindle of the first design with a piston is to make the fretting structure force controlled instead of displacement controlled. Due to this adaptation the applied normal force can be controlled in closed loop.
Again just one piston is used, the system with the U-guidance (section 4.2.1) is being reused in this design.

4.2.3 Fretting fixture based on a flexure mechanism

A flexure mechanism can be used to overcome the friction problem which is inherent to the construction of the pad holder in the previous concept. Linear guiding is realized by means of parallel leave springs. A schematic presentation is shown in Figure 11. To obtain a parallel displacement u, the stroke has to be small so the transversal displacement can be neglected.

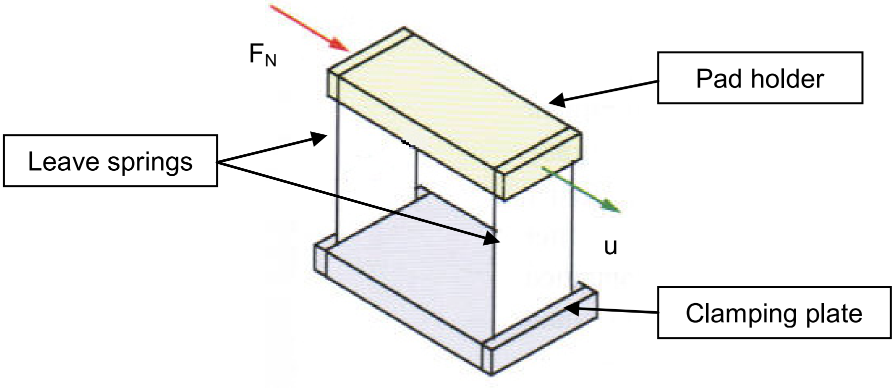

Figure 11: Fretting fixture based on a flexure mechanism [1]

Since the displacement is obtained by elastic deformation, the stroke is limited by the strain at the material's yield point. The stiffness of this system will cause that not all applied normal force F_N is transferred to the test coupon. Since there exists a linear relationship between applied force and displacement of the springs, calibration can avoid this inaccuracy. Unlike the previous design this principle offers the advantage that friction and mechanical play are not applicable. This concept will be developed in detail in the following period of time.

4.3 Instrumentation

The applied dynamic forces are measured by two 50 kN load cells, one on every side assembled between the piston and the wedge grip. The difference between the two registered values results in the sum of the tangential forces F_T among pad and specimen. The resolution of the specimen displacements is in order of 10Hz. A 5 kN load cell is mounted between the fretting pad holding device and the U-guidance of the contact pressure assembly.
The friction force and slip, created by the applied normal force and sliding movement between specimen and pads, are measured by an extensometer. An LVDT measures the position of the axial pistons.

5 CONCLUSIONS

Following a literature study on fretting fatigue and existing test set-ups, some improved conceptual designs have been proposed. Several crucial problems such as fluctuating normal force F_N, low stiffness, poor visibility and controllable slip were found and treated during a thorough evaluation of fretting fixture concepts based on linear guides, wedges and leave springs. Based on this evaluation and an improved understanding of the needs related to testing fretting in combination with fatigue, a third and final concept for controlling the fretting pads is proposed. By making a trade off of the different designs, a detailed final design will be developed. The friction problem encountered in design two can be eliminated using an elastic moveable structure.

The movement of the pad and loading of the test coupon will be realized by a hydraulic cylinder at one side and using a U-guidance to apply an equal force at the other side. Future work consists of finishing the detailed design (components selection, calculations, drawings) and constructing this specific testing device.

6 NOMENCLATURE

F_{fat}	fatigue force	kN
F_N	normal force	kN
F_T	tangential force	kN
d	relative displacement	µm
u	pad displacement	mm

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