Measuring Nano and Micro Wear on Spherical Surfaces at the Example of a Metal-on-Metal Artificial Hip Joint

C. Maul [1], M. Tuke [2], A. Taylor [2]

[1] *RedLux Ltd, United Kingdom*

[2] *Finsbury (Development), United Kingdom*

C.Maul@redlux.net

Abstract

It has long been an issue to measure wear in the order of nano- or micrometres on large spherical objects, such as artificial hip joints. This is generally because the quantity to be measured is very much smaller than the overall dimensions of the object under study.

By bringing together the advantages of a CMM, a roundness tester and non-contact measurement, a new type of form measuring instrument, capable of scanning the surface of large spherical objects (up to 150 mm in size) has been designed. This new technique is compared to more traditional approaches to nano- and micro-scale wear measurement on artificial joints, such as by gravimetric methods, 2D roundness measurement and CMMs.

1 Introduction

An artificial hip joint is a ball-and-socket joint that can replace the arthritic human hip. The spherical head of the femur (thigh bone) moves inside the hemispherical socket of the pelvis. This movement at a rate of typically 1 – 2 million cycles per year causes the implant to wear, with linear wear rates in the order of 2-10 µm per year [1].

Figure 1: Metal-on-metal hip joint

Current metal-on-metal artificial hip joints may have a life expectancy of 15 to 20 years based upon historic devices that are now being used as evolutionary design models and there is a drive to prolong this period. Key to an increase in their longevity is a method to reliably quantify wear in order to compare different designs.

2 Current Methods

At present, there are a number of different techniques used to evaluate wear on artificial hip joints. The most common techniques are the gravimetric method, roundness measurement and measurement with a coordinate measuring machine.

2.1 Gravimetric Methods

As the hip joint wears, material is eroded from the surface of the ball and cup. This loss of material can be measured by weighing the components before and after the wear process. The challenge here is to measure weight loss in the order of milligrams on a component that can weigh a few hundred grams.

Because of possible contamination from the fluids surrounding the joint, gravimetric methods generally show an increase in mass before showing a decrease and additional techniques have to be employed to compensate for this error [2]. The gravimetric method cannot give information on the shape of the wear patch and can only be used on joints that are being evaluated in so called wear simulators but which are in reality comparators. This is because the method itself is comparative.

2.2 Roundness Measurement

A better way of measuring wear uses a roundness tester to measure deviations from roundness. This is a two dimensional method that gives the user information on a trace around the surface. A typical graph is shown later in section 4.

Such a machine can measure with a resolution of 10 nm, and because it can evaluate discrete surface traces, the original unworn areas can be compared with the worn ones. Thus the wear of clinical retrievals can be evaluated.

The roundness tester is well suited to measuring linear wear, provided enough measurements in various planes around the joint are made and the deepest point of the wear scar is found. Kanada [3] calculates that for a ball of up to 38 mm (1.5”) in diameter an average of 9 measurements are required, while for a ball above 50 mm (2”) in diameter, 18 or more measurements can be necessary to characterise its roundness.

2.3 Coordinate Measuring Machines (CMMs)

Recent studies have used CMMs to measure wear on artificial hip joints [2]. A coordinate measuring machine gives a three dimensional image of the joint by scanning the surface with a stylus. The CMM can scan the whole spherical area of a hip joint, but it has a lower resolution of typically 4 µm, when compared to a roundness tester, and is considerably slower. The programming of such a machine must be carefully observed, as it is usually used to map a shape by applying best-fit techniques to a series of points and is thus taking averages.

3 Methodology

To overcome the limitations of the techniques described above, a new form measuring instrument has been designed. This instrument combines the high resolution of the roundness tester with the high coverage by the CMM, while at the same time using a non-contact sensor for increased speed of measurement.

It is capable of scanning the surface of large spherical objects (up to 150 mm in size). Unlike other optical instruments, it can scan the whole useable surface of an artificial hip joint (220º) in a single measurement taking only a few minutes. The resulting data set describes the form of the sphere in 3D with a resolution of 20 nm and allows the evaluation of small wear volumes, as can be found in metal-on-metal hip joints.

This new technique is now compared to the roundness tester at the example of a worn metal-on-metal hip joint.

4 Results and Discussion

Figures 2 and 3 show the results obtained by a roundness tester (left) and the new technique (right).

The graph of the roundness tester shows the deviation of the surface from an ideal circle. The 'original' surface has been added manually to be able to measure the depth of the wear scar, in this case around 50 µm.

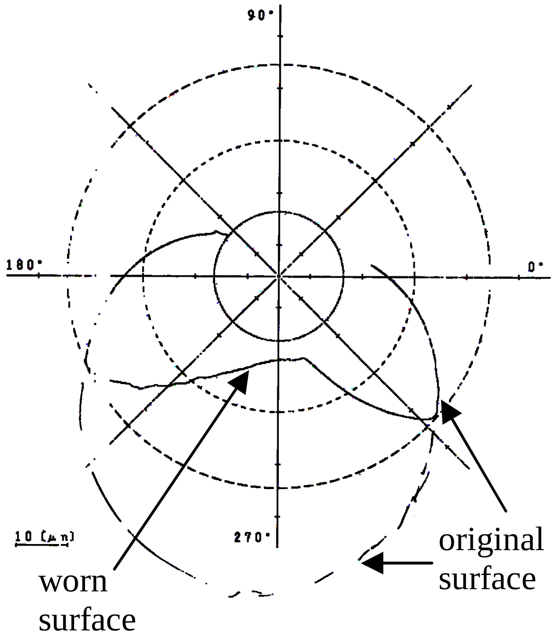

Figure 2: Trace by a roundness tester

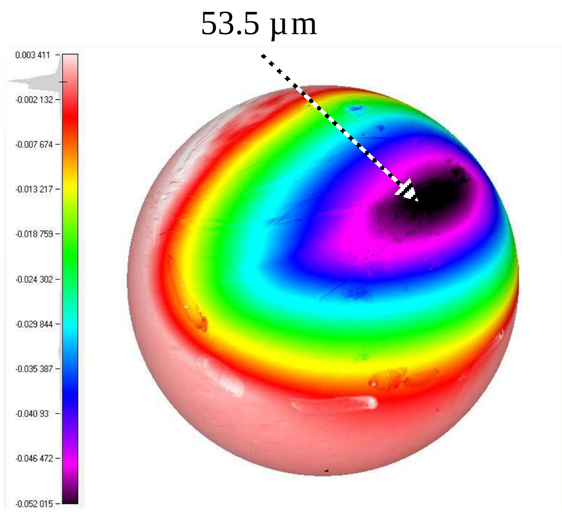

Figure 3: 3D data set by new technique

In contrast, the new technique provides a full 3D data set characterising the shape of the ball after wear. After fitting a sphere to the original surface, the unworn area (pink) can clearly be distinguished from the worn area (red, yellow, green, blue, purple and black) and the depth of the wear scar can easily be measured as 53.5 μm.

5 Conclusions

A new method for measuring wear on artificial hip joints has been introduced. This method allows high-resolution wear analysis in three dimensions. It has been shown that the linear wear measured with this technique is comparable to values obtained from a roundness tester, but without the associated long measurement times due to multiple measurements. Future work with this instrument will be concerned with measuring the exact shape of the wear patch.

6 References

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