Development of morphological filtering method for specification and characterisation of hip replacement taper junctions

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Abstract

The introduction of modular large head metal-on-metal (LHMoM) hip replacements promised lower wear rates and reduced chance of dislocation coupled with an increased range of motion compared to conventional metal-on-metal hips. However, the 2010 National Joint Registry reports a 5 year failure rate of LHMoM hips of 7.8% compared to 6.3% for hip resurfacings and comparisons of well functioning hips have shown the LHMoM have significantly increased metal ion levels compared to resurfacings. This has led to a widely held hypothesis that the modular head/neck taper junction could be a site of secondary wear debris and indeed wear has been indentified in this area on a number of retrieved bearing tapers.

It is clear that the correct specification of this junction is vital to the optimum *in-vivo* performance of these bearings and that this could reduce the number of observed failures. This study will investigate the example of a number of newly manufactured total hip replacement femoral stems and will be the first to develop a method for specifying and measuring the underlying form of the textured surface of the critical neck taper which is characterised by a micro-thread. This was achieved through developing a filtering routine that allows for the extraction and isolation of the profile points that would contact the femoral head female taper counterface when in operation.

In this study a series of measurements were taken on each component, axially along the neck taper. The measurements were performed using a Talyrond 365 roundness machine with a 5µm diamond stylus. The subsequently extracted profiles were firstly levelled using a least squares method in a post-process routine and were then

processed using a newly developed morphological filtering routine to extract the envelope profile of contact points from the primary texture inherent in each profile.

1. Morphological filters

Morphological filters evolved from the traditional envelope filtration system (the E-system), offering more tools and capabilities [1]. Among morphological filters, the closing filter is most widely used. As illustrated by Figure 1, the closing are obtained by rolling the disk from above along ball the profile and taking the lower boundary of the disk. It is revealed that the closing filter suppresses the valleys which are smaller than the disk radius in size, meanwhile it remains the peaks unchanged.

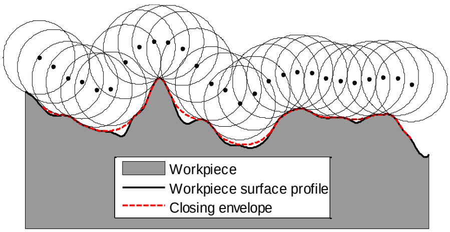

Figure 1. Closing envelope obtained by rolling a disk over the profile.

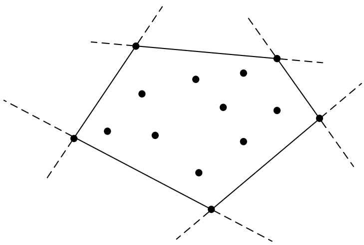

Figure 2. Pivoting an infinite large disk around the point set yields the convex hull.

The traditional implementation of morphological filters was developed based on the definition of morphological operations. It generates the dilation and erosion by calculating the extreme values in height which are determined by the mapping pairs of the disk ordinate and profile ordinates. The dilation and erosion are then combined to yield the closing and opening.

The proposed morphological filtering method differs from the traditional approach in that the algorithm sets out to compute the contact points as the ball is rolling over the profile [2]. The method is based on the link between the convex hull and morphological envelopes that the convex hull could be viewed as a specific morphological envelope generated by an infinite large disk. The graham scan algorithm, originally developed for computing the convex hull of the planar point set is adopted and modified to compute the morphological envelopes.

The algorithm handles the points in an incremental manner and a stack structure is maintained to hold the contact points by evaluating the coming point with those in the stack. To correct the end effect of filtration on the open profile, two ends of the profile are padded by reflection before the filtering process. At the final of computation, the stack contains all the contact points and the envelope ordinates are archived by interpolating points on the arcs determined by the adjacent contact point pairs.

In comparison to the traditional approach, the proposed method is efficient in performance and applicable to non-uniform sampled date set. More importantly it could accurately identify the contact points on the profile.

2. Case Study

It is a common feature of total hip replacement femoral stems for the interlocking male taper surface that mates with the femoral head female counterpart to have a structured micro-threaded surface. The specification of such is important as possible corrosion and wear at this interface has been identified as a possible source of debris that could cause tissue reaction and progress to implant failure. Analysis of this structured conical surface requires the extraction and examination of the underlying conical form and contact.

Measurements were performed axially relative to the aligned component axis, allowing the outputted value of profile straightness to then be used as a measure of conical form. Current industrial practice is to use a co-ordinate measuring machine (CMM) to perform this task. Such an approach is suboptimal as the accuracy required is at the limit of current CMM capability (< 1μm) and due to the relatively large measurement stylus there is difficulty in the accurate location of data points.

In this study a number of new hip replacement femoral stems were measured by performing a series of linear measurements axially along the neck taper of each component. The measurements were performed using a Talyrond 365 roundness machine (Taylor Hobson, UK) with a 5 μm diamond stylus and had a sampling length of 8 mm and sampling interval 0.25 µm. The profiles were levelled using the least squares method and the morphological closing filter is applied on the levelled data using the proposed method. This allowed for the envelope profile of contact points to be extracted from the primary texture as shown in Figure 3. The straightness of the profile is obtained by calculating the vertical distance between the highest contact point and lowest contact point.

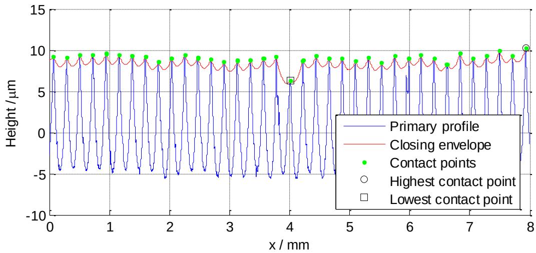

Figure 3. The extracted envelope profile with contact points (rolling element 5mm radius).

The morphological filtering method based on the contact point allows for the optimisation of the mechanical traversing process. Thus determining the equivalent stylus size that would be required to perform this task. The use of a roundness machine and morphological filter allows for data to be captured at a higher density and accuracy than is currently best practice (Gauge resolution ~30nm) with a greater level of control in the extraction of the true envelope profile.

3. Conclusion

The application of the unique morphological filtering method allows for the relationship between stylus ball size and the consequent measurement result to be investigated through application of different morphological filter sizes. The use of the morphological filter in this way allows for the production of a statement of the optimised measurement parameters for this critical and yet previously overlooked feature.

References:

[1] ISO 16610-40 Geometrical Product Specification (GPS)-Filtration, Part 40: Morphological profile filters Basic concepts (2010).
[2] S. Lou, X. Jiang, P. J. Paul, Algorithms for morphological profile filters and their comparison, Precis Eng (2012) doi:10.1016/j.precisioneng.2012.01.003.