Assisted quality inspection for hip prostheses components

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Abstract. In the paper is presented a new method for quality analysis of some hip prosthetic elements, surface quality standpoint. First of all it is about the head, as spherical joint for the hip prosthesis. For best bio-compatibility is absolutely necessary that its surface to be well processed standpoint roughness, for lowest friction forces, as much as possible those in the case of the natural hip joint. For this reason, within our current research activities, we have developed a virtual instrument, as software interface for efficient assisted roughness deviations for spherical joints of the hip prostheses, reported to a reference hip prosthesis. This application could be very practical and useful for the stage of adjustment and grinding prostheses heads, increasing the productivity and reducing the number of scraps cases in production.

1. Introduction

Prototyping and orthotic elements in the context of aged or post-operatory persons are increasingly more used, especially due to the fact that the trend is to continuously improve performance in terms of robotic or non robotic biomechanical devices. Not only the prostheses or orthoses themselves are currently the subject of extensive studies and research, but also robotic systems, which can train certain muscle groups to stimulate and rehabilitate locomotor function, are of very high relevance [1], [2], [3], [4].

2. Importance of prosthesis in the lower limbs

Walking and running are daily activities for anyone, so that a proper locomotion system at the lower limbs is crucial. Related to this, adequate body equilibrium and balance could be strictly dependent on prostheses and orthoses used for joints and lower limbs [5], [6], [7].

Besides, it is well known that, the need for prosthetic implants in the joints increases sharply with age, especially for persons who in their youth practiced performance sports. Unfortunately, in the present there are many worrying statistics concerning the number of hospital admissions and operative interventions in this respect [8]. At the lower limbs joints, the most problems occur at the hip joints, so that the hip prostheses have seen a great deal in the last 20 years [9]. Considering this, the issue of ensuring the quality of the prosthetic elements of the joints, not only standpoint reliability but also regarding the biocompatibility is more and more addressed [10], [11], [12]. Lubrication and surface quality are both fundamental aspects in terms of functional prosthetic components due to the fact that these could influence not only the prosthesis reliability, but also the patient’s comfort. For instance, in case of hip prostheses, the aspect of surface quality of the head (with the third degree joint) is very important to ensure low friction, so that small wear [10], [11]. As a result, from this point of view, surface analysis and, more exactly surfaces roughness measuring could be essential for functional
quality evaluation.

3. Developed and proposed method for hip prostheses surface quality analysis

If, initially, the basic used method for a surface roughness determination consisted generally to use as main measuring device of some dedicated roughness apparatus, in the present performance digital microscopes are more and more wide-spread. These can be equipped with specific software environments that allow images and 3D charts acquiring, but also the reconstitution of all coordinates for roughness determination using dedicated software algorithms [13]. However, the main inconvenience of these methods is that not in all situations the expenses with the equipment and software licences are justified, so that not in any cases the solution being sustainable. As a result, the researches focused first of all to develop a new method that could lead to a considerable cost reduction without losing much of the efficiency and measuring precision, method that could be applied especially for quality insurance in prosthetic elements. Concretely, it is about using of some simple and low cost measuring devices, associated to flexible software interface which role is to generate and to process the measuring results.

The method was applied for two hip prostheses providing as rejected, different head dimensions. It has been used measuring device an incremental displacement transducer, which measuring resolution is 0.2 μm. For each prosthesis, one standard was used (with the surface of the corresponding prosthesis head of the roughness) the process and scanning conditions being the same between the standard and the studied models. As analysis method, it was taken the problem to analyze a surface element providing from the active area of the hip’s head prostheses. The picked area to be scan was about 3 x 3 mm, the length of each scanning vector being of 2.4 mm, according to the in force standards regarding the reference length of scanning, considering 10 equidistant scanning vectors (v_j), each one being analyzed in 10 equidistant points.

![Figure 1. Vectors disposing for defining the scanning surface area][14]

To ensure a high precision on the surface quality evaluation, to the touching rod of the displacement transducer it was adapted a special element, having a a special peak, which curvature radius is up to 0.5 μm. In this way it was possible to have a proper reproduction, by touching of the scanned item profile. Due to the roughness measuring, along the 10 scanning vectors, there were processed the results taking into account 10 equidistant measuring points for each per each vector [15], [16], the data being saved into EXCEL files, to be processed (figure 2).

![Figure 2. Example of roughness measured values in 10 equidistant points for the 1st scanning vector][1]

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[1]: https://example.com/image1.png
[14]: https://example.com/image14.png
For a fair, complete and effective interpretation of the results, in the research, there was taken the problem to develop a software interface (in Lab VIEW) as virtual instrument for determining and automatic displaying of all information referring to the scanned surface’s roughness. More exactly, the interface allow an immediate determination of all roughness parameters based on the values generated in EXCEL files: $R_a$ – averaged value of the roughness, $R_z$ – roughness averaged depth in 10 points, $R_t$ – total roughness value, $R_{max}$ – maximum roughness value [15], [16]. For each determined roughness, parameter on each scanning vector, it has been taken into account of the relationships (1) ÷ (4).

$$R_{a\_vj} = \frac{1}{n} \sum_{i=1}^{n} R_i \quad [15]$$

where:
$R_{a\_vj}$ – averaged roughness for each scanning vector ($j = 1+10$);
$R_i$ – roughness measured for all point of the current scanning vector ($n = 10$ – number of scanning points / each vector);

$$R_{z\_vj} = \frac{1}{5} \left( \sum_{i=1}^{n} R_{2k} - \sum_{i=1}^{n} R_{2k+1} \right) \quad [15]$$

where:
$R_{z\_vj}$ – roughness in all measured points for each scanning vector;
$R_{2k}$ – positive measured roughness in all point of the current scanning vector;
$R_{2k+1}$ – negative measured roughness in all point of the current scanning vector;

$$R_{t\_vj} = \text{Max}(R_{2k}) + \text{Max}(R_{2k+1}) \quad [15]$$

where:
$R_{t\_vj}$ – total roughness in all measured points for each scanning vector;

$$R_{max\_vj} = \text{Max}(R_i) \quad [15]$$

where:
$R_{max\_vj}$ – maximum roughness in all measured points for each scanning vector;

For the calculus algorithm programming as a part of the software interface, the relationships (1) ÷ (4) have been used, also so that all roughness parameters can be automatically determined referring to the entire scanned surface, it was applied the equations (5).

$$R_a = \frac{1}{m} \sum_{j=1}^{m} R_{a\_vj}; \quad R_z = \frac{1}{m} \sum_{j=1}^{m} R_{z\_vj}; \quad R_t = \frac{1}{m} \sum_{j=1}^{m} R_{t\_vj}; \quad R_{max} = \frac{1}{m} \sum_{j=1}^{m} R_{max\_vj} \quad [15]$$

where:
$R_a / R_z / R_t / R_{max}$ – averaged / all points / total / maximum roughness for entire scanned surface.

3.1 Software interface presenting

For an efficient data processing and all necessary information on the verdict on the evaluated head hop prosthesis, surface quality standpoint, the user has to run the software interface, following the next steps: first of all a control LED of state allow to set the data reading from files, if necessary (figure 3) (green means that data reading option was chosen and gray means no data reading. As programming, a case structure was associated to the Boolean LED of state.

![Reading measured values?](image1)

![Reading measured values?](image2)

Figure 3. Option for data reading
In case of reading from files, during running the interface, the user has to select all files from which the data must to be processed.

Another aspect related to the user is to specify the dimension of the hip prosthesis’s head dimension, depending on which the limit value of the tolerance for roughness deviation is automatically determined (figure 4).

![Figure 4. Example of graphical programming of the calculus algorithm for maximum admissible roughness depending on the hip prosthesis’s head dimension](image)

In red, there are all text boxes and dialog referring to the inputs (settings, numeric values etc.) and in blue are shown all generated information after software running. The fist obtained information are the following: maximum admissible roughness, averaged value of the roughness, roughness averaged depth in 10 points, total roughness value and maximum roughness value for each scanning vector. Besides is displayed a chart roughness distribution for each vector, together with the limits of roughness high and low tolerances (figure 5).

![Figure 5. Example of generated information on roughness parameters for the 1st scanned vector](image)

Applying the equation (5), the programming addressed the sequence of algorithm for roughness parameters concerning the entire scanned surface (figure 6).

A 3D chart allow also allows a spatial view of the roughness distribution chart of the scanned surface (figure 7). In terms of programming, a 3D Chart function was defined, being addressed as inputs the index of the scanned point per each vector, the index of the scanned vector and all roughness values for all scanning points.
Figure 6. Programming routine for displaying the roughness parameters values referring to the entire scanned surface

Figure 7. Example of 3D roughness chart obtained generated after interface running

However the most important information is on the verdict on the hip prosthesis surface quality standpoint (figure 8). Two LEDs of state and a selective text message inform the user if the hip prosthesis corresponds or not. Both LEDs are in gray if turned off, while the first one is green if turned on and the second is red if turned on. The first LED turns green together with the message *Hip prosthesis head surface corresponds* if all determined roughness values are lower than the imposed limits. The second LED turns in red together with the message *Hip prosthesis head surface does not correspond* if at least one of the roughness parameters is greater than the imposed limit (figure 8). To transpose this algorithm, when programming there was used a Case structure, containing a string text control with the positive message (case True) and another Case and a string text control with the negative message (False case). As output string variable, a text indicator was defined to receive either the positive, either the negative text, besides both LEDs (figure 8).

Figure 8. Example of negative verdict on a hip prosthesis evaluation

4. Results and conclusion
The method, together with the software interface has been successfully used for two hip prostheses, one for children (which head is 15 mm in diameter) and another for adults (which head is 18 mm in
diameter). Both hip prostheses providing as rejected from an orthopaedic clinic, these proved to be non adequate neither surface quality standpoint. However, from the point of view didactic and research, the hip prostheses proved in all circumstances to be very useful.

Regarding the software interface, it proved to be very efficient and useful for a critical and objective analysis, providing in a very short time all the necessary information. As a result it could be widely used even in the stage of manufacturing. Besides, the proposed method, together with the interface could be used for any type of biomechanical joint prosthesis, not only for lower limbs.

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