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Differences between the Stress and Reliability Analyses of the Ceramic Head of the Total Hip Joint Endoprosthesis with the Shape Deviations

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Abstract – The paper deals with the problems of ceramic head of hip joint endoprosthesis destructions, and with assessing the impact of shape deviations of conical surfaces on the stress distribution in the head and on the head's reliability. Concerned are the shape deviations from the ideal conical surfaces of the stem and the head of the endoprosthesis, which - when the head is put on the stem and the endoprosthesis loaded under ISO 7206-5. The shape deviations may be modelled at the macro-level – (deviation from the nominal degree of taper, ovality, and their combination), or, possibly, at the micro-level - when the stochastic distribution of unevenness on the contact areas is respected. The problem of stress in ceramic heads was solved using the algorithm of the finite element method (FEM). The probability of the head's failure is based on the Weibull weakest link theory and depends on the tensile stresses in the head, on the volume in which this stress acts and on the material parameters of the ceramics.

The failure of the hip joint endoprosthesis ceramic head (made of Al_2O_3) has always traumatic consequences for the patient, since a part of or even the whole endoprosthesis has to be re-operated. Hence, it is desired to reduce the number of implant re-operations to the minimum. Therefore the computational modelling of the stress and reliability of the head was realised. The shape deviations of the ideal contact cone areas of the head and stem are parameters that significantly influence the stress in the parts of hip joint [1] and its reliability. These macro shape deviations (different taper of the head's and stem's cones is 5'8'' - the head cone angle is greater than that of the stem) and micro shape deviations of the contact areas were measured using the IMS-UMPIRE measuring equipment. The Fig. 1 shows the micro shape deviations of the head's cone. The state of stress and the reliability of the ceramic head of endoprosthesis can be strongly affected by the process of endoprosthesis implantation, when the surgeon fits the head on the cone of the stem. For this reason, a series of computations will be made for analysed pair and for various positions of the head towards the stem. The system is loaded in accordance with the ISO 7206-5. The strength behaviour of ceramic material can most frequently be described by the Weibull probability model which is based on the "weakest link theory".

The distribution of maximum values of tensile stresses in the ceramic head (σ_{max}), in dependence on the value of the head' s load, is shown in Fig. 2. In the same diagram are plotted the S-shaped curves of head failure probabilities, which are unmistakable with the stress course curves in the head. The variant which assume only macro shape deviation is represented by a red broken line - VAR. CON. The values σ_{max} for a given pair and for various positions of the head to the stem form a belt of relationships, the width or the height of which vary in the course of loading, and are related with the extent the dispersion of values σ_{max}. The red curves for VAR. CON show small values of the stress in the head and therefore high head's reliability which is not real. It is necessary to assume both shape deviations of the cone contact areas of the head and the stem (micro and macro).

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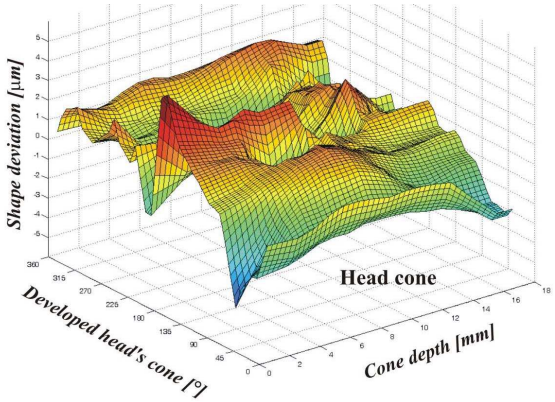

Figure 1: Measured shape deviation from ideal conical shape of the head cone.

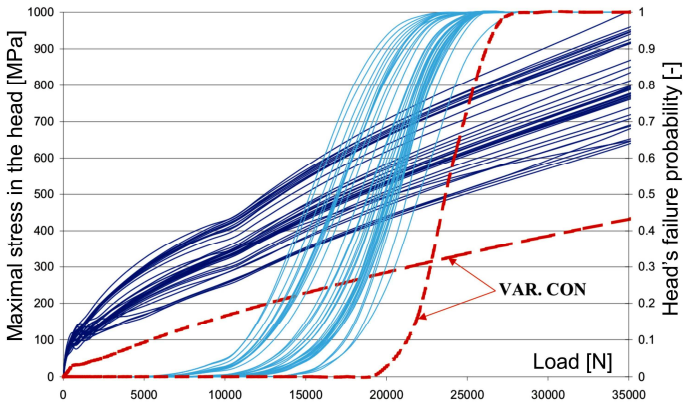

Figure 2: Curves of maximum head's tensile stress and head's failure probability in dependence on loading.

[1] Andrisano A.O. Axisymmetric mechanical analysis of ceramic heads for total hip replacement, J. Eng. Medic. 204, pp.157-167, 1990.