Finite Element Analysis Into Eigenfrequencies of a Total Hip Stem with Different Levels of Loosening

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Abstract

1. Introduction
Loosening of total hip replacements (THR) is still the main reason for revision [1]. Approximately 36,000 revisions are necessary in Germany each year [2]. Due to suboptimal sensitivity of currently applied diagnostic methods, e.g. radiographs, the loosening status is often identified late [3]. To optimize the accuracy, an acoustic method was tested in an animal experiment using rabbits [4]. Thereby, small implants with integrated magnetic balls were inserted in the femoral condyles. The implants were excited externally using a coil to produce an impingement of the ball and thus perform a sound analysis. Promising results encourage the transfer of this principle to total hip stems. In order to identify adequate evaluation parameters, the acoustic behavior was investigated by finite element analysis.

2. Use of COMSOL Multiphysics®
In this paper the Eigenfrequency analysis is simulated in COMSOL Multiphysics (COMSOL Inc., Burlington MA). The assembly of the finite element model consists of a straight total hip stem (Z-Stem, Merete Medical GmbH, Berlin, Germany) and a SAWBONE (10pcf, SAWBONES, Malmö, Sweden) cylinder with gaps and aluminum pads as sensor mountings. Additional sensors are added as a rigid element with a defined mass.
Fixation of the total hip stem is provided on the distal region of the SAWBONE cylinder. Additionally, the implant was loaded with the body mass and the change in the Eigenfrequency has been determined.

2.1 Materials and Methods
The SAWBONE cylinder was equipped with different defects representing various states of loosening (Figure 1). For simulation three different states of loosening were created and analyzed by finite element analysis of the Eigenfrequency.
It is important to mention that the material of the artificial bone has homogeneous foam structure (Solid Rigid Polyurethane Foam) and therefore represents a simplification of a femoral bone.
For the Z-Stem the material parameters of titanium alloy Ti6Al4V were used. The pads as sensor mounting plates are made of aluminum.
The sensor domains are defined as a solid with a fixed size and a constant density. The values of the Poisson ratio and Young's modulus were adopted from aluminum which makes up the

largest part of the sensor. In addition, the senor domains are set as rigid object.

2.2 Modal analysis
With an Eigenfrequency study node the eigenvalue problem for a set of eigenmodes and associated eigenfrequencies are solved [5]. In the modal analysis a vibration of test specimen under a dynamic excitation is computed. The eigenvalues are used to determine the eigenfrequencies (or eigenmodes) of vibration. Modal analysis helps in calculating the values of these mechanical resonant vibration frequencies of the specimen.
In Figure 2 a mode of the THR system is shown. This includes bending, compressions and torsions modes each corresponding with a higher order harmonics of the fundamental frequency.

2.3 Results
The results of the modal analysis (Figure 3) show a decrease of the eigenfrequencies with larger loosening state and furthermore a decrease associated higher human body mass (Figure 4).

Reference

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[4] Ruther et al. Investigation of an acoustic-mechanical method to detect implant loosening. Medical Engineering & Physics 35 2013, 1669–1675

[5] COMSOL COMSOL Multiphysics Reference Guide 4.3a 2012 292-293

Figures used in the abstract

Figure 1: SAWBONE with different areas of defects

Figure 2: Mode 1, Eigenfrequency=424.42

Figure 3: Results of a modal analysis with the first 15 eigenmodes

Figure 4: Influence of the patient weight on Eigenfrequencies