

INTEGRATION OF PLANTAR PRESSURE MEASUREMENTS IN A FINITE ELEMENT MODEL FOR THE OPTIMIZATION OF SHANKPIECE DESIGN FOR HIGH-HEELED SHOES.

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INTRODUCTION

The shankpiece is a steel piece used to improve the resistance of high or medium high-heeled shoes. On the one hand, the shankpiece must offer high resistance, but on the other hand, excessive rigidity could cause discomfort. This problem needs an optimal solution which combines structural rigidity with a functional design.

A methodology combining biomechanical instrumentation, design of experiments, finite element analysis, statistical study and a multi-criteria decision method was used in order to reduce the experimental cost due to prototype construction. Design criteria were obtained from a statistical study of results. An optimal solution was obtained from the combination of design parameter levels.

REVIEW AND THEORY

Footwear manufactures have detected a problem related to shankpiece design, on the one hand, the shankpiece must offer high resistance, but on the other hand, an excessive rigidity could cause discomfort due to high deformation gradients over the insole in the shankpiece border. This problem needs an optimal solution which combines structural rigidity with a functional design that reduces and smooths the deformation gradients.

Instrumented insoles for the measurement of plantar pressures has been used in many research works for diverse intentions: to detect gait disorders (Alexander *et al*, 1990) or study gait patterns (Stokes *et al*, 1974). There are few studies concerning the integration of these measurements in a finite element analysis but most of them are 2D simplifications (Lemmon *et al*, 1997; Verdejo and Mills, 2002).

Several design solutions use simulation to reduce costs due to prototype construction and experiments. Simulation is widely used in some other field of industry but is relatively new in footwear design.

PROCEDURES

As a first step on the way of the optimal design solution, a reduced number of design parameters were selected in order to prepare a parametric approximation of the problem. These parameters were obtained from opinions obtained from an expert focus group in which there were people skilled in manufacturing, footwear design and in biomechanics.

Three design parameters were modified for this study, these were: the orientation angle between the shankpiece and the insole's rear axis, the shankpiece transverse position and the longitudinal position of a joint that divides the shankpiece into two parts. Each design parameter was divided into five steps covering all possible design ranges.

As a load condition, plantar pressures distributions were obtained from *in vivo* measurements using Biofoot®. Six women (age: 34.5±8.66 years, weigh: 58.05±5.15 kg, high: 158.76±2.38 cm) wearing a shoe with a heel height of six centimeters were tested. Then, dynamical measures were obtained while they were walking on a horizontal floor. These measures were statistically treated with an in-house software program to obtain a spatial load field which could be included in a finite element analysis (Zienkiewicz, 1977). Finite element design optimization was used to obtain results about deformation levels on the insole covering all design possibilities.

Design objectives were fixed as to reduce the deformation level and to smooth its gradient. A sensibility analysis was made with solution variables to study their influence in design options. A multi-criteria decision method (Aragonés, 2001) combined with Saaty weighting method (Saaty, 1994) was used to obtain an optimal solution from the three design variables.

RESULTS AND DISCUSSION

Deformation fields were obtained as result of a simulation process. Then the maximum pressure, its situation and gradients in four axes were calculated (Figure 1, right).

Design criteria were obtained from differences shown in the sensibility analysis data due to variations in the shankpiece's transversal position, orientation angle, and joint longitudinal position (Figure 1, left). An optimal solution was obtained from the combination of design parameter levels in order to reduce the maximum deformation and to smooth its gradient.

This *in vivo* measurement integrated with simulation for design gives an important and wide opportunity to quality improvements in the design of human related products. This method takes into account human-product relationship before product construction. The arrangement of this "measure to analyze" chain permits an important reduction in the launching time and cost of products on which design depends, to a large extent, on the human-product interaction, as in the case of footwear.

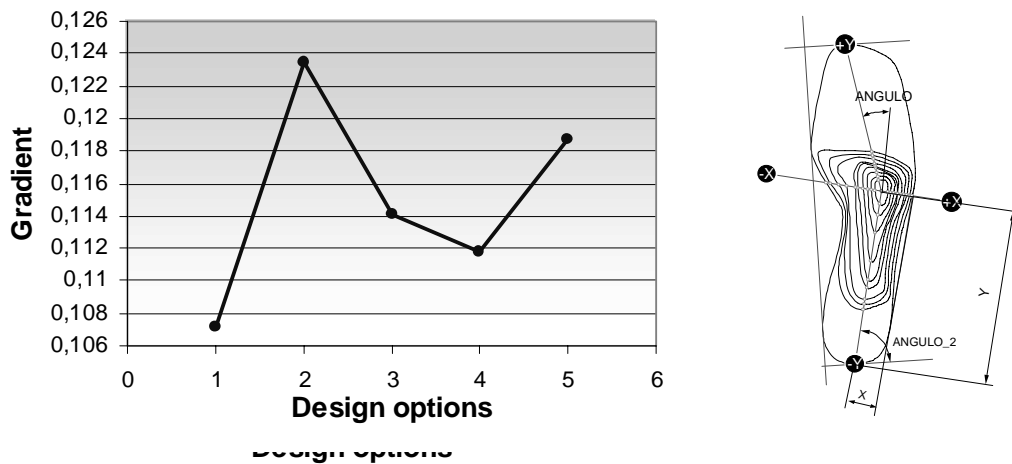


Figure 1. Left: gradient variations in -X axe due to angle position of the shankpiece. Right: Solution variables used in the multi-criteria decision method.

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