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Development and performance analysis of new spade bit designs

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Abstract

The purpose of this work is to present the development and experimental performance assessment of a new generation of spade drill bits. Rigorous point geometry and drilling force models that describe the topology of the drill and its cutting behaviour have guided the development of these new drills with unique topological features. It is shown, both analytically through simulations and through a systematic experimental study, that the performance of the newly developed topologies exceeds that of the commercially available designs. The new spade bits yield lower thrust and torque over the whole range of pragmatic operating conditions. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Spade drills; Wood drilling; Spade drill geometry; Spade drill performance

1. Introduction

The spade drill bit is a very widely used tool for rough drilling in non-metallic materials in general and in wood and wood based products in particular. Its most widespread use is encountered in the home construction industry, predominantly for plumbing and electrical installations. A typical spade bit, the basic design of which has not changed for decades, is shown in Fig. 1 along with its major topological features. Moreover, spade bits have not received any attention in the technical literature, yet there is a pressing need to improve the performance of these tools. This need is dictated by the almost exclusive use of hand-held battery-operated cordless drills in conjunction with spade bits. The use of hand-held drilling units imposes the need to improve the performance of these tools in two respects: (1) reduced power consumption in order to prolong battery life, and (2) reduced thrust force to reduce operator fatigue. This, in turn, necessitates the examination of the suitability of the existing ubiquitous design and of the possibility of developing new bits with enhanced performance.

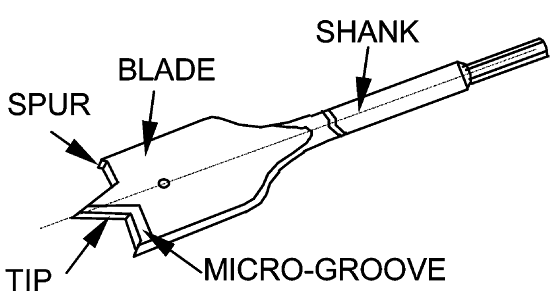

Fig. 1. The spade bit.

The aim of the present paper is, therefore, to develop new spade bit designs that outperform the tools currently on the market. In quantitative terms, in light of the above-stated requirements, performance will be judged in terms of the magnitude of drilling torque and thrust.

The task of developing more effective designs will be based on a systematic approach, rooted in a sound theoretical foundation consisting of two essential components. The first is a thorough understanding of the geometric and manufacturing characteristics of spade drills, while the second pertains to the ability to predict their cutting mechanics related behaviour.

The geometry of a generalized spade drill is shown in Fig. 2 [1,2]. The definition of the major cutting edge rake surface in the form of a helical surface has allowed for a great deal of flexibility in defining different spade bit topologies using the same analytical model. The conventional spade bit, based on a flat/planar rake surface, shown in Fig. 1, is just a special case of this general topological representation. Zhao and Ehmann [2] have

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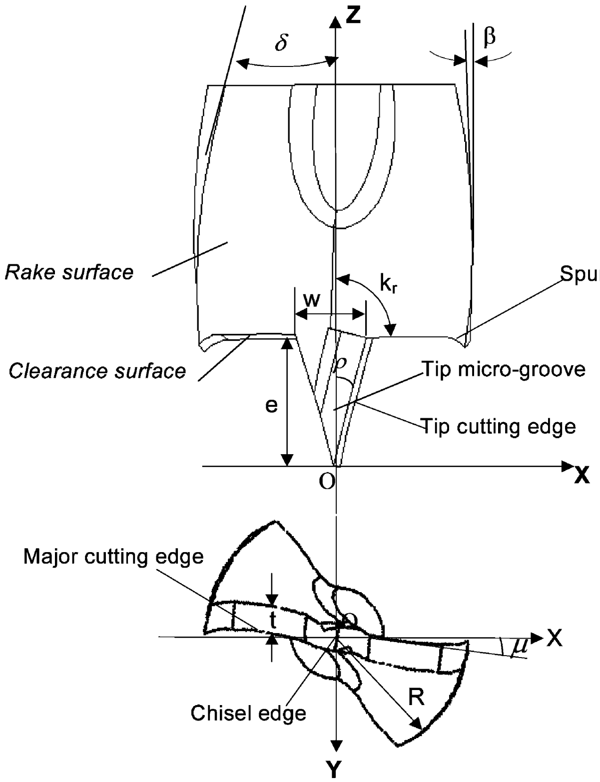

Fig. 2. Generalized helical spade bit geometry.

formulated the complete geometry of this drill as well as the geometry and kinematics needed for its manufacture.

In regard to cutting performance, Zhao and Ehmann [3] have developed a mechanistic model for force and torque prediction throughout all phases of the spade drill's penetration into the material. The model includes the cutting actions of the chisel edge, drill tip and of the major cutting edges. The geometric and force models, together, have facilitated the development of a comprehensive software package that allows the simulation of all aspects of the spade drilling process [1]. This software will be used as the basis for the developments to be reported in this paper.

In the subsequent sections, the design decisions and analysis of new spade drills will be outlined and their performance experimentally confirmed.

2. Design of new spade drills

An examination of Fig. 2 suggests that an infinite number of possible topologies exist that could result in viable new designs. To reduce the possible choices in the current work, potential manufacturing constraints imposed by complex geometries were chosen as the principal criteria. In this context, manufacturing constraints included both technological as well as cost limitations. Two important additional factors were also considered:

1. The results of a systematic experimental benchmarking study performed on a set of commercially available and specially modified commercial drills that was conducted to (a) create a baseline for comparing the performance of the newly designed drills and (b) to experimentally assess the influence of the principal topological features (e.g., major cutting edge and tip geometry and angles, spur, margin, etc.) of the spade bit [1];
2. The results of a systematic simulation study, using the developed software mentioned above, of the influence of the geometry of the principal topological features on the magnitude of the thrust and torque [1,3].

Based on the above outlined considerations a decision was made to explore only the very basic rake face topologies defined by linear and circular (S-shaped) helical rake surface generators, shown in Fig. 3a, with zero and non-zero helix angles, δ. Drills with a linear generator were modeled as drills with a circular generator with a large radius, r. An additional feature that had to be taken into account, in particular for the drill's tip and for the major cutting edge in the case of zero helix rake surfaces, was the introduction of a micro-groove to improve the rake angle distribution along the tip and the major cutting edge [1,2].

The choice of clearance surfaces was also limited to planar surfaces for the same reasons as above. Fig. 3b shows the clearance/flank surface generators used that

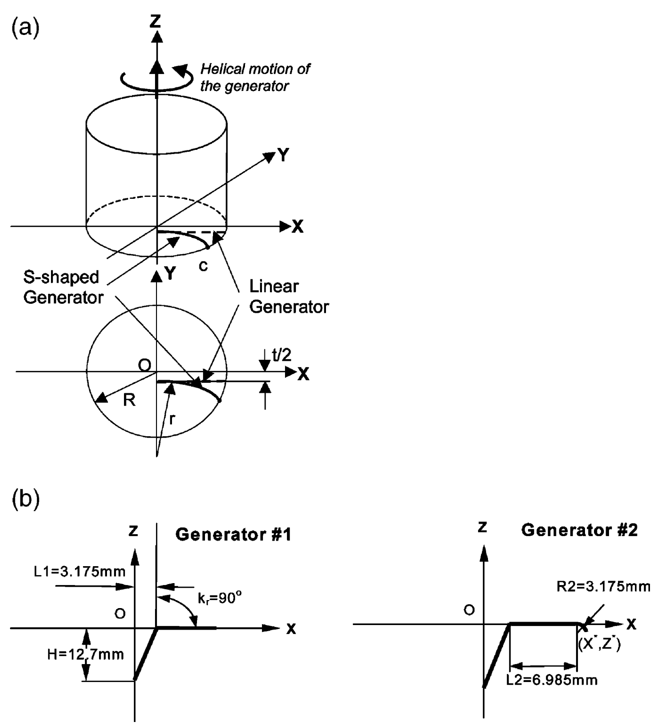

Fig. 3. Definition of generators: (a) helical rake surface generator, (b) clearance/flank surface generators.

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