Tunnelling and Underground Space Technology 62 (2017) 75–95

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Empirical models for tool forces prediction of drag-typed picks based on principal component regression and ridge regression methods

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ARTICLE INFO

Article history:
Received 23 November 2015
Received in revised form 14 October 2016
Accepted 11 November 2016

Keywords:
Drag-typed picks
Tool forces
Empirical models
Regression analysis

ABSTRACT

The forces acting on a single drag-typed pick are important parameters for excavation machine design and selection. For better prediction of tool forces including cutting and normal forces generally, a general model of cutting forces was proposed based on theoretical models. Also, a general model of normal forces was proposed using the ratio of the normal force to cutting force. Subsequently, the effect of relevant geometrical parameters on the cutting force was discussed. The friction angle between pick and rock, the cone angle and the attack angle were employed to develop the cutting force models of conical picks. The rake angle and the friction angle between pick and rock were included in the peak cutting force model of radial picks. Finally, the peak and mean cutting forces models of conical picks and the peak cutting force model of radial picks under unrelieved cutting mode were developed using principle component regression analysis and ridge regression analysis based on the raw data from linear full-scale cutting test. The results show the proposed regression coefficients and equations are more reasonable physically. Some empirical models used for practical application were then developed by introducing relevant modified coefficients considering tool wear, relieved cutting and complex shapes of picks. The results show a good agreement between the measured and predicted cutting force of sharp picks under unrelieved cutting mode. The performance of modified models using relevant modified coefficients would be decreased to a certain extent. However, they are all statistical valid according to the results of *t*-test. The models of this work can be used for preliminarily estimation of tool forces acting on drag-typed picks.

1. Introduction

Mechanical rock cutting has been applied widely in mining and similar underground excavation due to its high efficiency. Common tools used for cutting rock include conical picks (also named point-attack picks) and radial picks (also named chisel picks) which are collectively referred as drag-typed picks as shown in Fig. 1, and they are especially used in roadheaders, shearers and continuous miners. The rock cutting mechanism has been an important topic concerning the process of rock cutting. Extensive studies have been conducted regarding to different aspects, such as dust production (Fowell and Ochei, 1984; Achanti, 1998), friction and picks wear (Carbonell et al., 2013; Dewangan et al., 2014; Dogruoz and Bolukbasi, 2014), chips shape and size distribution (Rånman, 1985; Liu et al., 2009; Tuncdemir et al., 2008), rock cutting study based on fracture mechanics (Guo et al., 1992; Jiang et al., 2013), heat production and transmission in the process of rock cutting (Loui and Rao, 2005), joint auxiliary cutting (Ciccu and Grosso, 2010; Liu et al., 2014) and specific cutting energy (Tiryaki and Dikmen, 2006; Tumac et al., 2007). The single pick is the basic element of cutting machine and the tool forces acting on it play an important role in calculating the loads of working unit of excavation machine, and in determining the depth of cut which is a fundamental aspect in determining the cutting efficiency. Also, the tool forces acting on a single pick can be used for designing the cutting head (Mustafa and Bolukbasi, 2005), studying the stability of the machine (Acaroglu and Ergin, 2006; Ergin and Acaroglu, 2007), etc. Therefore, the model development of tool forces acting on drag-typed picks is one of the main topics on the studies of cutting mechanism.

So far, theoretical or semi-empirical models (Evans, 1962, 1965, 1984; Goktan, 1995, 1997; Nishimatsu, 1972; Roxborough and Liu, 1995; Goktan and Gunes, 2005; Kovrizhnykh, 2006; Bao et al., 2011), empirical models (Muro et al., 1997; Copur et al., 2003; Bilgin et al., 2006; Balci and Bilgin, 2007; Gunes et al., 2007;

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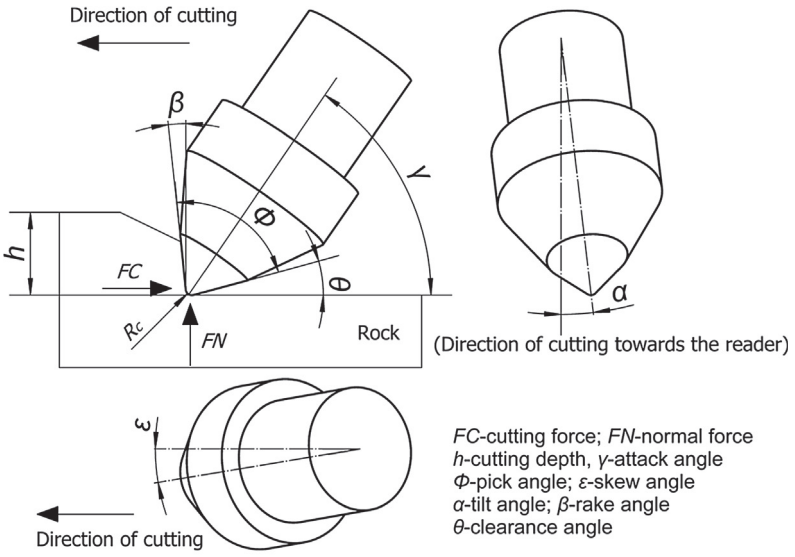
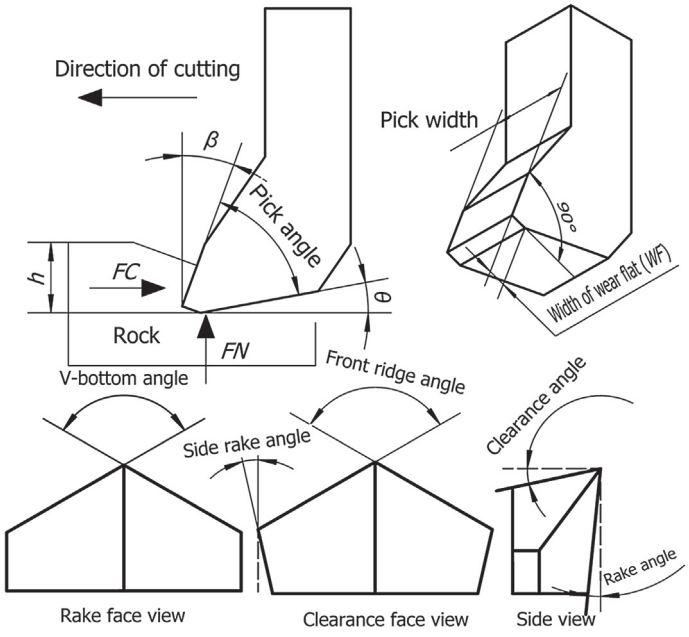
http://dx.doi.org/10.1016/j.tust.2016.11.006
0886-7798/



(a) Conical pick



(b) Radial pick

Fig. 1. Some parameters affecting cutting performance of drag-typed picks.

Tiryaki et al., 2010; Copur, 2010; Abu Bakar and Gertsch, 2013; Kim et al., 2012a, 2012b) and numerical models (Kou et al., 1999; Rojek et al., 2011; Su and Akcin, 2011; Van Wyk et al., 2014; Menezes et al., 2014a, 2014b) are commonly used to evaluate tool force values by engineers. These studies have led to a better understanding of rock cutting mechanism with priority of convenient usage with low cost. Widely-accepted theories include Evans' (1962, 1965, 1984) for conical picks and radial picks, and Nishimatsu's (1972) for radial picks. However, the cutting forces predicted by theoretical models in many cases are not in a good agreement with measured values due to heterogeneous and anisotropic nature of rocks (Bilgin et al., 2006). Numerical models may provide relatively accurate cutting force values when the applied model was reasonable and the relevant parameters were appropriately determined. In addition, some studies that are difficult to be carried out by theoretical or experimental methods can be done easily with numerical modeling techniques. For example, Menezes et al. (2014a, 2014b) investigated the rock fragment morphology and the characteristic of fragment formation in the process of rock cutting using the explicit finite element method, and the effect of cutting speed was also involved. However, experienced engineers are required to evaluate the correction of simulation results. Although direct measurement can provide accurate values, sophisticated test facilities and intensive labour force are required, corresponding to a high volume of material consumption as well as high cost. For practical purpose, reliable empirical models based on enough test data are preferred in evaluating cutting forces, and many empirical models have been developed using single factor regression (Copur et al., 2003; Bilgin et al., 2006), multiple regression (Gunes et al., 2007; Tiryaki et al., 2010), regression tree and neural network method (Tiryaki et al., 2010). However, neither the theoretical models nor the modified ones can implement the estimation of the normal force acting on