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Machine-vision-based identification of broken inserts in edge profile milling heads

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ABSTRACT

This paper presents a reliable machine vision system to automatically detect inserts and determine if they are broken. Unlike the machining operations studied in the literature, we are dealing with edge milling head tools for aggressive machining of thick plates (up to 12 centimetres) in a single pass. The studied cutting head tool is characterised by its relatively high number of inserts (up to 30) which makes the localisation of inserts a key aspect. The identification of broken inserts is critical for a proper tool monitoring system. In the method that we propose, we first localise the screws of the inserts and then we determine the expected position and orientation of the cutting edge by applying some geometrical operations. We compute the deviations from the expected cutting edge to the real edge of the inserts to determine if an insert is broken. We evaluated the proposed method on a new dataset that we acquired and made public. The obtained result (a harmonic mean of precision and recall 91.43%) shows that the machine vision system that we present is effective and suitable for the identification of broken inserts in machining head tools and ready to be installed in an on-line system.

1. Introduction

Tool wear monitoring (TWM) systems have been widely developed over the last decades for the evaluation of the wear level of inserts, also known as cutting tools. In this paper, we present a method to identify broken inserts in a milling machine. This is an important application in the field of face milling as broken inserts pose a threat to the stability of milling heads. An unnoticed broken insert may go on working without being detected, and can cause a decay of the quality of the final manufactured product or a breakage of the milling machine itself [1].

Fig. 1 shows the machine used in this study, which manufactures metal poles of wind towers. Milling is performed in a single pass across very thick and long plates (up to 12 cm and 42 m, respectively) which is not common in standard milling machines.

The current state of the art in TWM comprises two approaches known as direct and indirect methods. Indirect techniques can be applied while the machine is in operation. These methods evaluate the state of the inserts through measurable quantities (e.g. cutting forces and vibrations) that are typically affected by noisy signals [2345]. On the contrary, direct techniques monitor the state of the inserts directly at the cutting edge when the head tool is in a resting position [6]. As to direct methods, image processing and computer vision techniques are the most popular ways for measuring flank and crater wear [5]. Ongoing progress in the fields of machine vision and computing hardware has permitted the implementation of reliable on-line TWM systems [78]. The method that we present falls into the direct approach category. Many machine-vision-based systems have dealt with the detection of parts or imperfections in production environments [91011].

The problem that we deal with here presents two challenges: (i) the localisation of inserts and their cutting edge and (ii) the identification of broken inserts. Fig. 2 shows a milling head tool that contains indexable inserts. In this case, each insert has four edges, with the cutting edge being the (nearly) vertical one on the left hand side.

1.1. Related work

There is a large body of work in the literature that evaluates the state of given inserts without having to localise them in images [2121314]. Other methods capture images directly on the head tool but they are focused on ball-end milling cutters [5] or microdrills [61516], in which only two flutes and therefore two inserts are present. The others deal with face milling heads where it is easy to set the acquisition system to only capture one insert per acquired image

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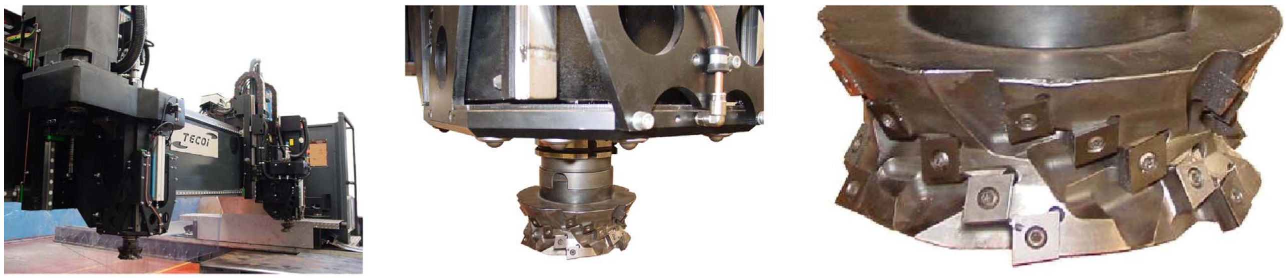

(a) (b) (c)

Fig. 1. Machine tool for machining of metal poles of wind towers. (a) General view. (b) Detail of the milling head. (c) Close-up of the milling head. The rhomboidal inserts are fastened with screws.

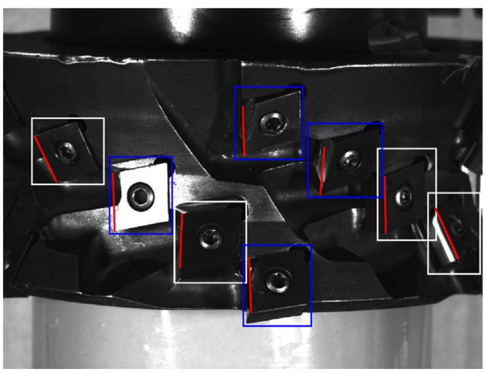

Fig. 2. Head of an edge profile milling machine. The white rectangles mark intact inserts whereas the blue rectangles mark broken ones. Red line segments mark the ideal (intact) cutting edges. All markers have been provided by a human observer. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

[171819]. In our application, the head tool contains 30 rhombohedral inserts leading to 8–10 visible inserts per image, which makes the localisation of the inserts a new and challenging task. In our previous work [20], we introduced a method to localise inserts in images of such head inserts and here we improve it and propose a new method that evaluates the status of the inserts.

As to the identification of broken inserts, approaches based on texture analysis have been widely used in the literature for wear monitoring when dealing with machining operations [7]. Tool wear or degree of tool wear have been determined by using GLCM based texture analysis in turning and milling in [21222324252627]. Barreiro et al. [28] estimated three wear levels (low, medium, and high) of the tool insert by means of the Hu and Legendre invariant moments. Datta et al. [29] used two texture features based on Voronoi tessellation to describe the amount of flank wear from machined surface images. The machines that we are dealing with in this study, however, use an aggressive edge milling in a single pass for the machining of thick plates. This may cause the breakage of inserts, such as the examples marked with a blue rectangle in Fig. 2. Part of a cutting edge may be torn without harming the texture of the remaining part of the insert. For this reason we believe that texture features are not suitable for the concerned application.

Other approaches use the contours of the inserts to determine the state of the inserts. For instance, Atli et al. [30] classified drilling tools as sharp or dull using a new measure namely DEFROL (deviation from linearity) to the Canny-detected edges. Makki et al. [31] captured images of a drilling tool at 100 rpm rotation speed and used edge detection and segmentation methods to describe the tool wear as the deviation of the lip portion. Also, Chetan et al. [32] compared image areas of the tool obtained through a texture-based segmentation method before and after cutting in order to determine the state of a drilling tool. For turning operations, Shahabi and Ratnam [33] applied thresholding and subtraction of worn and unworn tool images to measure the nose worn regions.

Some papers also deal with micro-milling or end milling in this line of work. Otieno et al. [34] compared images captured before and after the usage of two fluted micro and end mills thresholded by an XOR operator. Neither edge detection, nor tool wear quantification and nor wear classification was performed. Zhang and Zhang [5] also compared images of ball-end milling cutters before and after machining process in order to monitor the state of the tool. Liang et al. [35] presented a method based on image registration and mutual information to recognise the change of nose radius of TiN-coated, TiCN-coated and TiAlN-coated carbide milling inserts for progressive milling operation. They perform logic subtraction of two images before and after milling. The mentioned works share one common requirement; they all must have an image of the intact tool to evaluate any discrepancies of a new image of the same tool.

In this paper we propose a novel algorithm that evaluates the state of cutting edges without requiring image references of intact inserts. This avoids calibrating the system each time an insert is replaced and allows to free memory after each monitoring. It automatically determines the ideal position and orientation of the cutting edges in a given image and computes the deviation from the real cutting edges. This means that from a single image we can determine the broken inserts.

The paper is organised as follows. First we explain the method in Section 2. In Section 3 we present the publicly available dataset that we created for an edge profile shoulder milling head and describe the experiments that we carried out. In Section 4 we discuss the results and certain aspects of the proposed method, and finally we draw conclusions in Section 5.

2. Method

In the method that we propose, we first localise cutting edges in a given image, and then we classify every cutting edge as *broken* or *unbroken*. From the image analysis point of view, an unbroken insert is one which has a straight cutting edge (Fig. 3b), while a broken insert has a curved or uneven cutting edge (Fig. 3c).

Fig. 4 presents a schema that shows the proposed method. First we localise the inserts and the cutting edges and then, we evaluate the inserts using a three-stage method: applying an edge preserving smoothing filter, computing the gradient of the image and finally using geometrical properties of the edge to assess its state. Below we elaborate on each of these steps.

2.1. Detection of inserts and localisation of ideal cutting edges

We use the algorithm that we introduced in [20] to detect inserts and localise the respective cutting edges. We apply the contrast-limited adaptive histogram equalisation (CLAHE) method [36] in order to improve the contrast quality of the images and facilitate the detection of edges. In Section 3.2.1 we provide the parameter values that we used