Ineffective Rock Breaking and its Impacts on Pick Failures

Y. Sun and X.S. Li

[a] CSIRO Earth Science and Resource Engineering, PO Box 883, Kenmore QLD 4069 Australia

E-mail: yong.sun@csiro.au, xing.li@csiro.au

Abstract -

Picks are critical components in excavation machines used in civil and mining industries. Any failures of picks in an excavator directly affect the reliability and productivity of the machine. Pick tip wear, pick tip crack, pick body wear and pick body bending are common failure modes of picks in production. Among various failure causes, ineffective rock breaking during a cutting process is a major cause which can result in most of these failure modes. In this paper, the mechanism of ineffective rock breaking is investigated and the influences of ineffective rock breaking on pick failures are studied. It shows that apart from pick tip geometry, pick installation angles on a drum and rock properties, pick lacing space is a major factor that affects the effectiveness of rock breaking. More importantly, it is a more controllable parameter in the drum design stage. The results of this research can be used to reduce pick failure probability, and automate optimal drum design.

Keywords -

Pick failures; Rock cutting; Reliability, Drum design; Rock breaking; Cutting interaction

1 Introduction

Excavation machines equipped with picks such as continuous miners, longwall shearers and roadheaders have been widely used to cut rocks in civil and mining industries. As critical components in these machines, any failures of picks during production is of major concern because pick failures can pose significant negative impacts on machine operators and owners. On the one hand, picks are not cheap. Consuming a large number of picks can be a big cost to the operators or owners. In fact, pick usage per ton of coal is one of KPIs (key performance indicators) in coal mining industry; on the other hand, pick failures will normally cause machine shutdown and production interruption, often resulting in a significant production loss. Therefore, it is important to understand the failure mechanism of picks and reduce pick failures.

However, research on pick failures is so far inadequate. While most existing researches about picks either focused on analyzing and predicting these forces [1-8], some studies have also been carried out on determination of attack angle and tilt angle of a cutting pick [9], cut interactions [2], new tip materials [10-12], and frictional ignition risk [13].

Regarding pick failures, Sun and Li developed a model to analyze the impact of the property variation of pick tip material on the failure probability of the tips [1]. Li and his colleagues investigated and compared the wear characteristics of cutting tips made of TSDC (thermally stable diamond composite) and WC (tungsten carbide) in abrasive cutting operation [12, 14]. McNider et al suggested that pick life could be prolonged through using capped tips [13]. A significant gap in existing pick failure research is that the interaction between rock breaking and pick failures has not been investigated yet, although rock breaking or cutting patterns have attracted the attention of researchers for a long time [15, 16].

During rock cutting, a pick indents into rock body in a certain angle and causes a certain amount of rock to break out and then be removed from the rock body as rock chips. Given that, for any excavation machine, a number of picks are installed on a drum and work together to cut rocks, investigation of rock breaking of any individual pick should consider the collective influences of its adjacent picks. Hurt and MacAndrew [16] pointed out that if the ratio of line spacing to depth of cut into a pre-existing groove is too large, over-deepening (also called groove-deepening) may occur. While most existing research on rock breaking patterns focused on cutting efficiency and forces, this study focuses on its impacts on pick failures.

2 Pick Failure Modes and Causes

Picks have various failure modes. Some examples are demonstrated in Figure 1. Typical pick failure modes include pick body bending (Figure 1-a), pick body wear (Figure 1-b), pick tip fracture (Figure 1-c), pick tip wear (Figure 1-d) and a combination of these (Figures 1-e and 1-f). Different failure modes could be caused by different mechanisms. For example, tip wear could be caused by the high frictional force during cutting hard and abrasive rock and insufficient wear resistance of the tip material; pick body wear could be caused by the rubbing between pick body and hard rock surface, flying rock chips against body and body's contact with corrosive materials; tip cracks could be caused by excessive impact force exerting on the tip, thermal fatigue and/or defects in tip material; pick body bending could be caused by excessive bending force due to inappropriate attack angle, inappropriate tilt angle, inappropriate lacing space and/or incorrect pick body design. However, there is a common cause which can result in most of these failure modes. This common cause is ineffective rock breaking during a cutting process.

Figure 1. Examples of pick failure modes

3 Phenomenon, Causes and Effects of Ineffective Rock Breaking

Effective rock breaking and ineffective rock breaking are relative concepts. Previously, they are mainly differentiated in terms of cutting efficiency [16]. However, this criterion is still vague and hard to apply in practice. To address this issue, here they are differentiated in terms of the cutting perimeters in cutting patterns. A cutting perimeter is an envelope of all picks tips on the same sequence cutting into rock in one cutting cycle (corresponding to that a drum rotates one revolution, refer to Figures 2 and 3). This means if a drum has n sequences, there are n perimeters in one cutting cycle. If the whole rock before the cutting perimeter of the previous cutting sequence has been effectively removed by the cuts in the current cutting sequence, the rock breaking of the current cutting sequence is said effective. If any rock areas before the cutting perimeter of the previous cutting sequence are still left after the cutting of the current cutting sequence, the rock breaking of the current cutting sequence is not effective, or more specifically, the cuts which are supposed to remove these rock areas in the current cutting sequence have an ineffective rock breaking. Figures 2 and 3 illustrate an example of effective rock breaking and an example of ineffective rock breaking respectively. In both examples, the drum is assumed to have one sequence only.

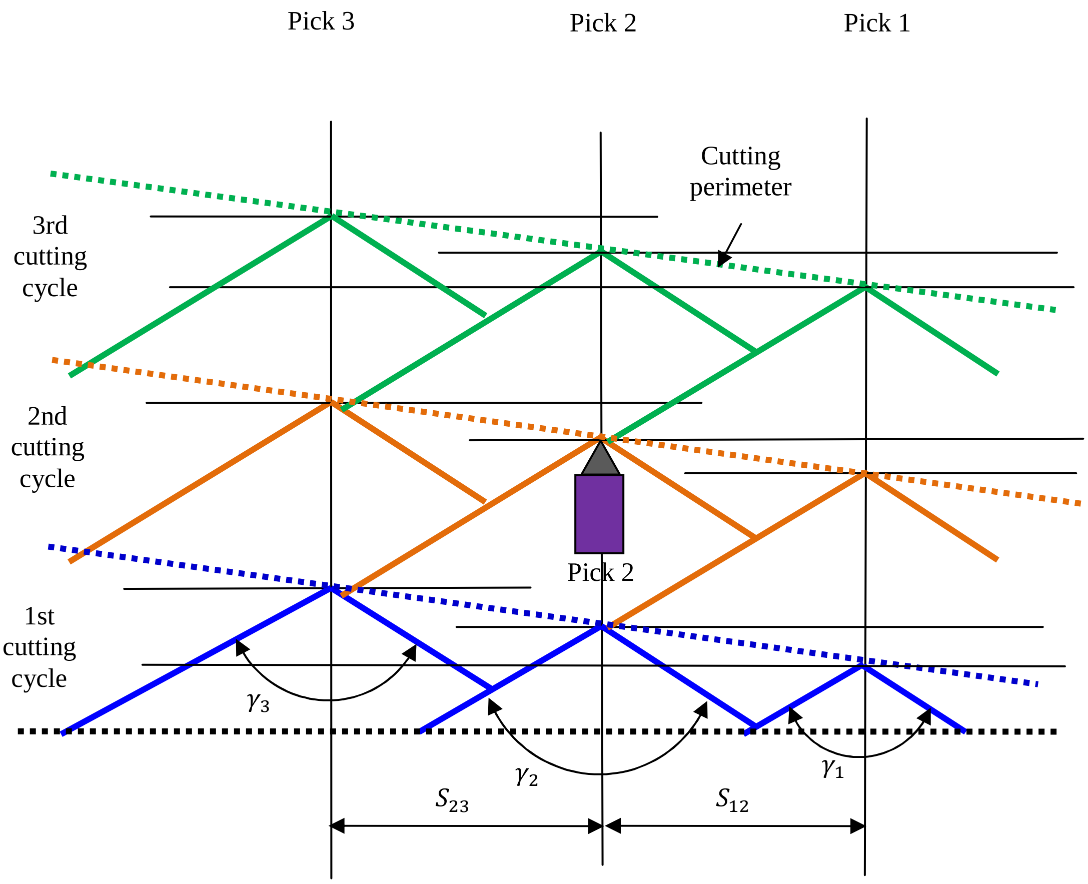


Figure 2. An example of effective rock breakout

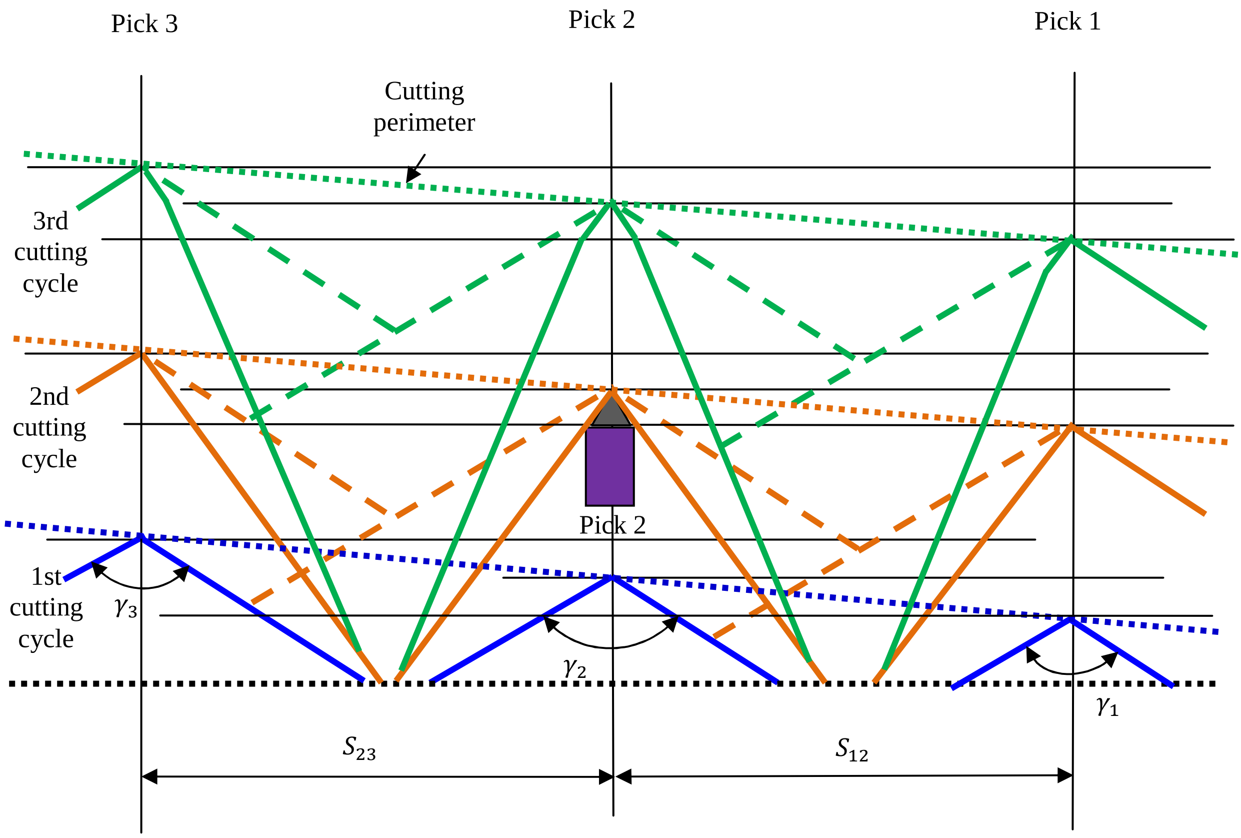


Figure 3. An example of ineffective rock breakout

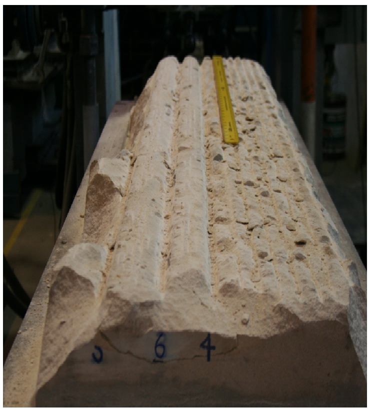
In Figures 2 and 3, S_{12} and S_{23} are the line spacing between Picks 1 and 2 as well as between Picks 2 and 3 (mm) respectively, γ_1, γ_2 and γ_3 are the breakout angles of Picks 1, 2 and 3 (deg) respectively. All the parameters in Figure 3 are the same as those in Figure 2 except that line spacing between two adjacent picks is much larger than that in Figure 2.

From Figure 2, it can be seen that the whole rock before the cutting perimeter of the first cutting cycle has been effectively removed by the cuts in the second cutting cycle. Hence, the rock breaking of the cuts in the second cutting cycle is effective. On the other hand, from Figure 3, it can be found that if the rock could break out along the broken lines, then the cuts in all cutting cycles would also make effective rock breaking. However, because the spacing is too large, the cuts are actually not able to breakout so much rock. The breakout angle of each cut becomes much smaller, leading to the actual breakout lines as shown by the continuous lines. As a result, after the second cycle, some rock areas before the cutting perimeter of the first cutting cycle are still left, i.e., the cuts given by Picks 1 to 3 in the second cutting cycle all make ineffective rock breaking. Similarly, rock breaking of Picks 1 to 3 in the third cutting cycles is also ineffective.

Linear rock cutting experiments in CSIRO's Rock Cutting Laboratory have validated the above theory. Some experimental results are shown in Figure 4. Technical details of the experiments will be published in due course. Figure 4-a shows three cutting lines (labelled 1, 2 and 3 respectively) which were made to simulate an initial rock cutting condition by three adjacent picks in a drum. Cut 3 was 10mm deeper than cuts 1 and 2. In Figure 4-b, cut 4 was cut 20mm deeper on the groove made by cut 1 and in Figure 4-c, cut 6 was cut 20mm deeper on the groove made by cut 3. It can be seen that the breakout angle of cut 4 was much smaller than that of cut 1 and the breakout angle of cut 6 was much smaller than that of cut 2. After cut 6, most original rock surface left by cuts 1 to 3 still remained, indicating that the rock breaking of either cut 4 or cut 6 was ineffective and groove-deepening has occurred.

a. cuts 1-3

b. cut 4



c. cuts 5-6

Figure 4. Ineffective rock breaking and groove-deepening

Ineffective rock breaking will not only reduce cutting efficiency, but also increase pick failure rate.

1. Narrowed breakout angle will cause rubbing between pick body and rock surface (Figure 5), resulting in severe pick body wear. As evidence, obvious rubbing marks have been observed inside the cutting groove and the pick body both after cut 4 (Figure 5).
2. Groove-deepening will exert larger frictional force on pick tips and cause them to wear and/or fracture. From Figure 5, it can be found that some white powder was left on the pick tips. This powder was produced because the tips ground the rock during the cutting process.
3. When ineffective rock breaking happens, the cuts in some cutting cycles or sequences cannot remove the rock they aim to remove. As a consequence, some cuts after these cycles or sequences have to remove more rock than they are designed to. This means much larger forces will be applied to the picks that make these cuts and may cause the cracking of their tips and/or the bending of their bodies.
4. Ineffective rock breaking will significantly increase the temperature between pick cutting elements and rock face because of the increased frictional force. It will also generate large sparks due to the rubbing of pick steel body against rock surface as shown in Figure 6. High temperature will often weaken the mechanical strength of cutting elements and pick bodies.

4 Discussions

Ineffective rock breaking is very harmful to pick reliability and thus should be avoided. Comparing Figure 2 with Figure 3, it can be seen that ineffective rock breaking also means that the picks in a drum cannot form effective cut interactions. When designing a drum, one has to take into account rock breaking property to ensure effective rock breaking for optimal pick usage and production efficiency.

In drum design, cutting patterns are often used to illustrate cutting actions [16] and optimize pick lacing arrangements. However, in the current practice, cutting patterns are often drawn based on an assumption that breakout angle is unchanged and breakout line can extend indefinitely. Figure 7 shows a part of a cutting pattern developed based on this assumption. Nevertheless, from Section 3, it is known that this assumption is not always valid. When some parameters such as advance speed, rotational speed and line spacing

Figure 5. Rubbing marks after cut 4

Figure 6. Large sparks generated from ineffective rock cutting

change, ineffective rock breaking could happen. In this case, breakout angles and breakout direction no longer remain the same. As a result, the cutting pattern based on the currently used assumption becomes invalid. For example, in Figure 7, the cutting lines made by picks 33 and 38 are very long. This may not reflect the reality. The actual cutting lines made by these two picks are very likely to be different from what are shown in Figure 7. If this is the case, failure assessment results of picks 33 and 38, and other related picks could also be different from what are estimated based on this pattern. Cutting pattern can be used to investigate cutting actions such as interactions between cuts only when it can reflect both effective rock breaking and ineffective rock breaking correctly.

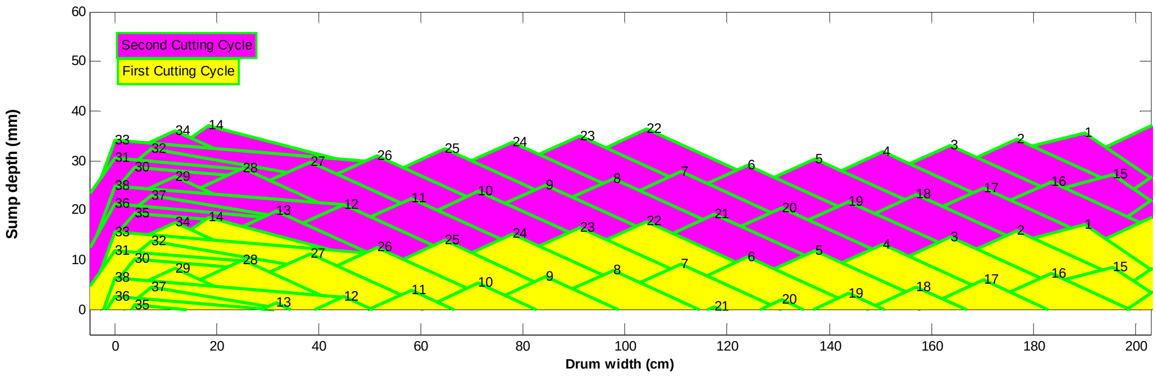


Figure 7. An example of cutting pattern

A lot of factors including pick geometry, cutting tip material, rock property, drum design and operational parameters can affect rock breaking effectiveness. In the current, the most effective approach to identifying ineffective rock breaking is still laboratory rock cutting tests. It is desirable to develop theoretical models for determining rock breaking pattern because rock cutting tests are costly and time-consuming.

5 Conclusions

In rock cutting, if the line spacing between picks on a drum is too large, cuts of picks cannot interact with each other effectively. As a result, ineffective rock breaking will happen. In this case, pick failure probability can significantly increase due to narrowed breakout angle and increased work loading. Ineffective rock breaking can cause various pick failure modes including pick body wear, pick body bending, pick tip wear and pick tip fracture. Consuming a large number of picks can be a big cost to the operators or owners. In addition, higher pick failure rate usually means lower machine availability and productivity. Therefore, ineffective rock breaking has to be avoided in production. To achieve this, the characteristics of rock cutting with given picks should be well examined and considered in the drum design and pick failure assessment. In the future, the authors will study how to automate cutting pattern design to reflect effective and ineffective rock breaking correctly.

Acknowledgement

The authors wish to thank Peter Clark and Craig Harbers of CSIRO Earth Science and Resource Engineering for their technical supports in the rock cutting tests.

References

[1] Sun Y. and Li X.S. Modeling the property variation of diamond composite and its impact on the reliability of cutting tools. *Advanced Materials Research*, 565:448–453, 2012.

[2] Sun Y., Li X.S. and Shao W. Influence of cutting parameters and interactions on the depth of cut in continuous mining operation. *Advanced Materials Research*, 538-541:1422–1428, 2012.

[3] Evans I. A theory of the cutting force for point-attack picks. *International Journal of Mining Engineering*, 2:63–71, 1984.

[4] Goktan R. and Gunnes N. A semi-empirical approach to cutting force prediction for point-attack picks. *The Journal of South African Institute of Mining and Metallurgy*, 105:257–263, 2005.

[5] Hurt K.G., Morris C.J. and MacAndrew K.M. The design and operation of boom tunnelling machine cutting heads. In *Proceedings of the 14th Canadian Rock Mechanics Symposium on Rock Breaking and Mechanical Excavation*, pages 54–58, Vancouver, British Columbia, 1982.

[6] Sun Y. and Li X.S. Influence of cut interactions on cutting force of a pick. *AASRI Procedia*, 3:694–699, 2012

[7] Liu S.Y., Du C.L. and Cui X.X. Research on the cutting force of a pick. *Mining Science and Technology*, 19:514–517, 2009.

[8] Su O. and Akcin N.A. Numerical simulation of rock cutting using the discrete element method. *International journal of Rock Mechanics & Mining Sciences*, 48(3):434–442, 2011.

[9] Sun Y. and Li X.S. Determination of Attack Angle and Tilt Angle of a Cutting Pick. *Advanced Materials Research*, 705:415–418, 2013

[10] Li X.S. and Sun Y. Development of Hard Rock Cutting Tool with Advanced Diamond Composites. *Advanced Materials Research*, 690-693:1831–1835, 2013.

[11] Boland J.N., Li X.S., Rassool R.P. and Hay D. Characteristics of Diamond Composites for Tooling. *Journal of the Australian Ceramic Society*, 46(1):1–10, 2010.

[12] Li X.S. and Boland J.N. The wear characteristics of superhard composite materials in abrasive cutting operation. *Wear*, 259:1128–1136, 2005.

[13] McNider T., Grygiel E. and Haynes J. Reducing frictional ignition and improving bit life through novel pick and drum design. In *Proceedings of the 3rd Mine Ventilation Symposium*, pages 119–125, University Park, Pennsylvania, USA, 1987.

[14] Li X.S., Boland J.N., and Guo H. A comparison of wear and cutting performance between diamond composite and tungsten carbide tools. *Industrial Diamond Review*, 68:51–54, 2008.

[15] Barber J.S. A laboratory investigation of rock cutting using large picks. *International journal of Rock Mechanics & Mining Sciences*, 1:519–534, 1964.

[16] Hurt K.G. and MacAndrew K.M. Designing roadheader cutting heads. *The Mining Engineer*, 9:167–170, 1981.