In-situ Measurements of Cutter Forces on Boring Machine at Åspö Hard Rock Laboratory
Part II. Characteristics of Cutter Forces and Examination of Cracks Generated

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Summary

By means of spectral analysis, the measured normal forces, tangential forces, and side forces acting on two button cutters on the boring machine in Åspö Hard Rock Laboratory were analysed and the basic characteristics of the cutter forces were determined. After the measurements of the cutter forces, some rock core samples were taken from the bottom and the wall of the test borehole. These samples were cut, polished, and examined by means of a Scanning Electron Microscope (SEM). The lengths of the major cracks in the rock samples were measured, and a relation between the length of the median cracks and the relevant cutter forces was investigated.

Keywords: In-situ measurement, cutter forces, tunnel boring machine (TBM), cracking zone, nuclear waste repository.

1. Introduction

In-situ cutter force measurements have been carried out by Hopkins & Foden (1979) and Samuel and Seow (1984) on disc cutters mounted on tunnel boring machines (TBM), and by Zhang et al. (2003) on the button cutters of a boring machine. In addition, Samuel and Seow (1984) have described the characteristics of the measured cutter forces. However, the previous studies on the characteristics of cutter forces have only dealt with disc cutters rather than button cutters. Furthermore, no investigations of the cracks induced by cutter forces in field rock have been performed so far.

This paper continues the research reported by Zhang et al. (2003). On the basis of the measured cutter forces, the authors performed the following studies:
1) The basic characteristics of the button cutter forces were investigated.
2) The lengths of the cracks induced in the rock were measured.
3) The relation between the cutter forces and the length of the cracks was explored.

The aims of this paper can be summarised as follows:
1) to determine the relation between the normal force and the length of the median cracks on the basis of the in-situ measured results, and to compare this relation with the relevant results based on previous laboratory studies (Kou, 1995);
2) to investigate the effects of the boring machine parameters on rock boring and on crack formation; and
3) to comment on the design of the boring machine with reference to the field measurements.

2. Characteristics of Cutter Forces

The research by Zhang et al. (2003) only shows the cutter forces measured during 8 seconds of boring with the machine. This is not long enough to find the basic characteristics of the force signals. Therefore, it is necessary to perform spectral analysis of the force signals by means of fast Fourier transforms. Here we used the MATLAB program to perform the spectral analysis. Figure 1 shows the results of the spectral analysis for both the front cutter and the gauge cutter during the first 7 minutes of boring in casing 10. From Fig. 1 one can determine the maximum and mean normal force (or tangential force or side force) of both the front cutter and the gauge cutter during the first 7 minutes of boring. The results indicate that the maximum and mean normal forces on the front cutter are 684 and 120 kN, respectively. Note that in casing 10 the total thrust is 1568 kN and the average normal force of each cutter is approximately 80 kN. However, the maximum and mean normal forces on the gauge cutter in the same period are 104 and −1.2 kN, respectively. It is clear that the maximum normal force of the front cutter is much larger than that of the gauge cutter. The tangential force and side force of both cutters show similar results. The main reasons for these results have been discussed by Zhang et al. (2003).

From Fig. 1 we can draw the following conclusions:
- For the front cutter, the main energy components lie in the range 0–5 Hz.
- For the gauge cutter, the main energy components lie in the range 0–10 Hz, because a high level of power appears at the frequency \( f \approx 9 \) Hz. In addition, corresponding to \( f \approx 9 \) Hz, a relatively high level of power occurs in the power spectra plot for the side force of the front cutter, see Fig. 1b. This shows that the side force of the front cutter is related to all the three directional cutter forces on the gauge cutter.
- According to Fig. 1a–c, as \( f \approx 0.15 \) Hz, the second highest levels of power relevant to the \( F_N, F_T, \) and \( F_L \) of the front cutter occur. The \( F_N, F_T, \) and \( F_L \) corresponding to \( f \approx 0.15 \) Hz should be the two highest peak values in Fig. 11a, 11b, and 11c in Zhang et al. (2003), respectively. This is because these peak forces appear in the period \( T = 5–7 \) seconds. Under such peak cutter forces, the