MASTER

Bergbau-Forschung GmbH.

DE
43 Essen

Federal Republic of Germany

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**REPORT
TUNNEL PROFILER**

**State of Investigations on High-Pressure
Waterjet Assisted Road Profile Cutting Technology**

Essen, March 1981

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Table of Content

	<u>page</u>
Abstract	1
1. Introduction	2
2. Experimental Equipment	3
3. Water-Pressure Boost	5
4. Geological Conditions	5
5. Results of Trial Runs	6
6. Measuring Data Recording and Evaluation	9
7. Further Development	9
8. Notes	10

ABSTRACT

In order to widen the application range of mechanized tunnelling in the rock for application in hard-coal mining less clumsy heading systems need to be developed. For this purpose industrial-scale tests are run on the test rigs of Bergbau-Forschung as well as on one colliery. For these tests a road profile cutting machine equipped with various sensors and with a high-pressure waterjet assist in addition to the classic hard-metal tools, is used.

By systematic evaluation of test results new application possibilities for this combined heading system are found. Particular importance in this context is assigned to reduced cutting force and extension of the application range to cutting of hard rocks. Investigations also are made for finding out whether by high-pressure waterjets on their own interesting heading performances can be achieved. Furthermore the use of chemical additives and new nozzle designs with consideration of their cost-effectiveness is discussed.

The summary outlines technical and ergonomical advantages as well as further development.

Introduction

Since three years Bergbau-Forschung runs tests for application of high-pressure waterjets in road profile cutting for tunnelling in hard-coal mining (Fig. 1). The development work aims at function improvement of mechanical tools by means of high-pressure waterjets (Fig. 2) in order to enable less clumsy design of tunnelling machinery via reduction of the necessary high cutting forces for rock crushing, and in this way to widen the application range of this technology which thus could increase its share in tunnelling from approximately 20 % right now to 40 - 50 % in the years to come.

The tools used at present for rock crushing approach their performance limit set by high wear and by the possibility of energy transfer.

Therefore a new technique which implies more favorable rock cutting conditions is to be developed and operationally tested.

This new technology allows to cut a slot which follows the required road profile. A support element should fit into said slot so that subsequently the remaining rock mass within the profile can be removed by the classic techniques without deterioration of the strata around the road.

Research and development work is scheduled as follows:

1. Feasibility study of the technique on laboratory scale and in a sandstone quarry
2. Experimental operation of a full-scale test array underground

3. Planning, construction, and experimental operation of a prototype of the new tunnelling system for practice of the road profile cutting principle.

The first phase was meanwhile completed successfully.

At present underground tests are run on Rossenray colliery (Ruhr area). These tests are scheduled to be completed mid-1981.

Experimental Equipment

Profile Cutting with High-Pressure Waterjets and Hard-Metal Tools

The basic data on function principles of the combined hard-metal tool/high-pressure waterjet system established on laboratory scale served as the design basis for a road profile cutting machine (Fig. 3).

The experimental version consists essentially of the base-frame for housing the thrust unit which moves in the axis of heading advance. To this feed mechanism a cutting arm pivoting around a horizontal axis was fitted. Hydraulic rams are provided for both movements, i.e. the pivoting of the cutting arm and the feed in heading direction. The cutting arm pivots by 90° . Further 90° pivoting is possible by plugging the piston-rod end to another bearing provided in the cutting arm for this purpose so that a profile slot could be cut over 180° . In addition the length of the cutting arm could be adjusted by removable intermediate pieces so that for testing purposes three concentric segments could be cut.

A hydraulic power supply with adjustable pump was used for the hydraulics so that cutting speed was infinitely variable.

Cutting Tool

The cutting tool comprises three individual hard-metal bits which are equipped either with

- two leading nozzles
- two trailing nozzles
- four nozzles (two leading and two trailing ones)

(see Fig. 4).

According to the nozzle array, the forces acting on the tool can be varied dependently on the test parameters. These parameters are:

Cutting force - F_s

acting in cutting direction on the tool

Normal force - F_p

acting normally to the cutting direction (Fig. 5).

Profile Cutting by High-Pressure Waterjets Only

In parallel to the above-described joint development work of Bochumer Eisenhütte and Bergbau-Forschung, an alternative experimental equipment is developed in cooperation with the US Department of Energy. This equipment comprises a guide frame which corresponds, as to its shape, to the road cross section. To this frame the tool holder is fitted (Fig. 6).

Cutting Tool

The road profile slot is cut exclusively by six high-pressure nozzles arranged at different angles thus enabling to cut a 80 mm wide slot (Fig. 7).

In addition it is tried to cut the road profile slot by two rotating nozzle heads equipped with two nozzles each

The cutting of road cross section profiles by high-pressure waterjets only implies almost no reaction forces. This means considerable advantages with respect to lighter weight of the experimental equipment.

Water-Pressure Boost

The high water pressure is generated by means of so-called pressure boosters (Fig. 9) mounted to a trailer frame behind the experimental equipment and connected to the cutting arm by high-pressure mains of 6.3 mm inside diameter and 14 mm outside diameter. These crucial components were placed at our disposal by the US Department of Energy and modernized present state of technology by the supplier of these components (Messrs. Flow Industries, Inc. Seattle, USA).

The individual functional units comprise essentially the pressure booster as such which is run with a hydraulic pump. The installed power of such a unit is of 250 kW and its maximum delivery is of 30 l/min at 3000 to 4000 bar. These pressure boosters are reversible-pump systems (Fig. 10) and, up to present, unmatched with respect to capacity and efficiency; their operational reliability could be brought to a high standard in the course of the test runs so that even particularly critical parts as e.g. high-pressure seals no stand for several hours. These features are, in addition, likely to be further improved.

Geological Conditions

Prior to the heading trials the suitability of the rocks on site was tested by core drillings (Fig. 11).

The compression strength of the sandstone on site, the so-called Ruhr Quarzit, was determined to be of approximately 100 N/mm^2 , its tensile strength of approx. 8 N/mm^2 , and its abrasive-mineral content of 65 %. Thus the rock can be regarded as a very typical sandstone as found

on tunnelling sites underground. However, this kind of rock is not very favorable to high-pressure waterjet cutting due to the silicatic binding matter which it contains.

Results of Trial Runs

Hard-Metal Tools Combined with High-Pressure Waterjets

The design of the experimental equipment enables a wide variation range of the most relevant heading parameters (Fig. 12). For proving the feasibility of the working principle, i.e. contour cutting by high-pressure water nozzle and hard-metal tools, the following test schedule was established:

- Measurement of cutting force and normal force at
  - various high-pressure water nozzle arrays relative to the hard-metal tool
  - various water pressures
  - various speeds
  - various cutting webs
  - small and large nozzle diameters

In addition all surrounding parameters, e.g.:

- possible cutting exactitude with respect to the contour of the cut and the resulting cross section
- space requirement of the nozzle/tool array
- longevity of the hard-metal tools, the high-pressure water nozzles, and all components of the high-pressure water system

had to be recorded.

Fig. 13 is to show first of all that an exactly defined slope can be cut into solid sandstone by high-pressure waterjets and hard-metal cutting tools.

Fig. 14 is representative for a whole series of diagrams resulting from various investigations.

Fig. 14 shows the cutting force components (cutting force, normal force) versus cutting web. The tool configuration comprises two (leading) nozzles aiming the rock immediately ahead of the cutting edge and two (trailing) nozzles aiming the rock immediately behind the cutting edge of the tool. This configuration yielded the best test results. The cutting force could be reduced by approximately 70 % and the normal force by approximately 50 %. With higher cutting speeds this positive effect decreases, however, in those cutting speed ranges which are of interest for hard coal mining a marked reduction of the cutting force components is possible.

In the course of the investigations carried out on combined hard-metal tool/waterjet array a best-suited water pressure could be determined. This value reads 1500 bar.

With water pressures below 1000 bar the high-pressure water tools do not cut yet any rock chips from the heading face. With pressures up to this value only the pulverized rock was flushed from the cut and additional rock matter was removed from above the plane a - a. Thus the unremoved rock mass ahead of the tool forms, relative to the plane a - a an acute-angled (ϵ) slope (Fig. 15).

Said acute angle results in higher normal force because the tool, while cutting, tends to "climb up" said slope.

With higher water pressure (>1000 bar) more ^{rock} particles from the bottom underneath the plane a - a are cut off.

This break-off ahead of ^{the} tool results in hollow spaces being formed underneath the cutting edge. Since the propagation of these hollow spaces extends almost over the total cutting width, only low normal forces act on the tool while passing these "undermined" zones.

Simultaneously new application possibilities were found when cutting hard rock by high-pressure waterjet-assisted hard metal tools. Rocks exhibiting compressive strengths $> 80 \text{ N/mm}^2$ could be headed into.

At present experimental operation of the road profile cutting equipment is carried on with underground on Rossenray colliery (Fig. 16). These tests are supposed to confirm the applicability of road profile cutting technology in underground operations (Fig. 17). Here the tests are run essentially in softer rocks as well as in the transition zones rock/coal seam since there is a risk of unwanted mineral fall from stratified or fissured rock and consequently a risk of damage to the cutting arm.

The first trial series, however, gave promising results, and it is hoped to confirm by further investigations the positive effects of this new tool combination.

Road Profile Cutting by High-Pressure Waterjets Alone

Besides the use of combined hard-metal tools and high-pressure waterjet arrays it was tried to cut the road profile by waterjets only (Fig. 18).

Basically the feasibility of this cutting principle was confirmed by the trials run as yet. At the same time it was found that a cutting tool equipped with nozzles only still requires considerable development work.

While the waterjets, due to their high impact performance, cut deep slots into the rock, rips remain between the

individual slots, and these rips damage the nozzles and the cutting arm.

In order to avoid problems of that kind, the nozzles which up to present were rigidly aimed were replaced by nozzles oscillating in a plane perpendicular to the cutting direction. Another performance improvement was obtained by using two rotating cutting heads each equipped with two nozzles.

Measuring Data Recording and Evaluation

For recording, processing, and evaluation of the data measured throughout the trials a computerized measuring system is used. This system is installed in a van and comprises essentially a process computer and various measuring and ancillary equipments for measuring forces, speeds, hydraulic pressures, etc. (Fig. 19). The polling of sensors and measuring-data stores is done automatically by various recording and evaluation programs.

Further Development

The trials run up to present on the one hand confirm the positive effects of high-pressure waterjets, on the other hand, however, energy requirements are still relatively high. For this reason further investigations aim at systema optimization of these new techniques.

A possibility for limiting the energy requirement may be found in improved nozzle geometry (Fig. 20).

The nozzles used up to present were not "made to measure," i. they are no optimized cutting nozzles. In cooperation with university institutes and nozzle manufacturers, development work is done.

In addition it was tried to improve the efficiency of high-pressure waterjets by additives. Since the generation of water pressures between 2 and 3 kbar and deliveries in the

range between 50 and 60 l/min still cause problems in industrial operation, it is tried to reduce the required water pressure and to obtain a better focussed jet by means of additives (Fig. 21).

Initial results confirmed that by additives to the high-pressure water a marked increase of cutting performance is possible in the investigated pressure ranges of up to 2,0 kbar. The technical and ergonomic advantages probably obtainable by use of high-pressure waterjets in road profile cutting systems may be summed up as follows (Fig. 22):

1. - High exactitude when cutting to profile
2. - Good conditions for support setting, no deterioration of rock structure
3. - Lightweight machinery
4. - No reaction/restoring forces
5. - Independent on rock and strata conditions
6. - Low tool wear
7. - Efficient dust control
8. - No sparking

These advantages enabled the design of an advanced heading system comprising today already the following steps: heading, loading, clearance, and support setting (Fig. 23) Subsequently full-scale technical investigations are to follow which are to support the design of a definite road-heading concept into which the profile cutting techniques will be integrated.

NB

This project is sponsored by the provincial ministry for economics and transport of Nordrhein-Westfalen.

The project is carried out in cooperation between Bergbau-Forschung GmbH, the US Department of Energy, and Bochumer Eisenhütte Heintzmann GmbH & Co.

The high-pressure water system is property of the US Department of Energy and was placed at the disposal of Bergbau-Forschung within the framework of a cooperation agreement.