INVESTIGATION OF ICE AND ROCK DRILLING BY MELTING

by

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ABSTRACT

Considerable experience of the Leningrad Mining Institute in deep borehole drilling by melting in Antarctica and in Arctic Ocean islands as well as successfull experiments in rock drilling by melting confirm the possibility that this new method of borehole drilling provides certain important advantages. Many technological processes are followed by melting of solid bodies in contact with surface heated up to a temperature which is higher than the melting point. The melt which forms flows from the heated surface or melting sample under the action of an impressed force. This method (combined with the others) is used in mining when sinking shafts, for quick ground consolidation of quicksands. The essence of this method is in installing a heater into the thickness of the quick grounds to be traversed. When current passes through the electrodes of the heater, electrons come into collision with atoms of the conducter lattices and so electric energy is transformed into heat energy. The conducter (heater) is heated to a high temperature and melts the surrounding quickground. The idea of openings (holes) sunk by melting provides for 3 most important advantages :

- using of drills with hoist electrical cable, which eliminates the necessity of drill pipes and of labour-consuming and prolonged descent-hoist operations ;

- supporting (when drilling) of hazardous or fissured rocks because through solidification of the hole walls by the melt which is over the penetrator, which eliminates the necessity of a casing, of expensive work on shaft lining or of plugging ;

- more effective and wider application of the methods of logging and well geophysics due to the absence of the action of steel casing screening.

Considerable experience in the field of drilling by melting in Antarctica and in Arctic Ocean island as well as successful experiments in rock drilling by melting /I/ carried out by the Leningrad Mining Institute confirm both the principal probability of this new method of probe drilling and the real possibility of the practical achievement of the above mentioned advantages. This is proved by the common tendency towards energy concentration increase in the face by traditional methods of machine drilling /I/ and by the presence and availability of new alloys and composite materials possessing rather high thermal stability and other necessary properties. Moreover, the results obtained in theoretical works /I,2/ prove that the main but practically the only difficulty of the realization this method is ensuring of penetrator long-term operation at the temperature level of 1200 - 1600° C.

Rock drilling by melting, i.e. borehole formation, is the result of rock melting up to viscous-plastic state due to the contact heat transmission and to melt pressing out over the penetrator with glassy smooth walls. Formation is the result of complex heat exchange and hydrodynamic processes. Complete and exact mathematical description of these processes and their interrelation is too difficult. The difficulties prevented design engineers from being grounded in the procedures of penetrator construction and rock drilling by melting. Ice drilling-melting analitical expressions /I/, based on a number of simplifying assumptions, made it possible to obtain calculated dependences for the determination of all construction and technological parameters with quite satisfactory exactitude. Experience of thermal drills with cable development and their successfull introduction in real field conditions confirmed above mentioned dependence /I,2/. However, their direct application for technical and technological calculations, related with rock drilling by melting can't be successful because of important differences in ice and rock properties, temperature level, materials for tool elements and character of processes.

The aim is to find an approximate analitical solution to the problem of rock drilling by finding the dependence of melting velocity on the main construction and technological parameters. Describing this complex process through calculation and analysis will aid the development of optimal penetrator construction and effective drilling technology.

To take into account the influence of thermophysical properties, natural temperature and rock state, construction dimensions, thermal capacity and the properties of the penetrator material as well as the state, properties and movement regime of melting rock surrouding the penetrator, flow rate, properties and the temperature of washing which cools the penetrator, it is necessary to find the solution of a task set in the case of drilling by melting process. The established process of heat exchange when drilling by melting comes very quickly and it is the most typical for interrelation analysis of the determining factors. This process can be simply described mathematically based on the theory of moving heat sources /I/ according to which the temperature field in rock mass is a constant one (quasi-stationary) in the coordinate system moving with the penetration.

A simple variant of drilling without core sampling (continuous face) is given below.

The penetrator shape is a body in rotation of "chain line" around its vertical axis. For simplicity it must be a one-dimensional problem supposing a uniform heat distribution from the working surface of the penetrator to the surrounding mass. In a given case such simplicity is quite permissible as the drilling-melting process is a dynamic one and in the course of this process a quasi-stationary temperature field in a rock mass surrounding the penetrator is formed. Heat disturbance depth is insignificant because of the small thermal conductivity of rock and because it is constant in a system of moving coordinates related with the penetrator. It is quite comparable both in axial and in radial direction. Furthermore, heat which is dissipated in the surrounding rock mass during drilling by the melting process constitues a small portion of the heat being absorbed for rock melting and subsequent melt overheat. Therefore, a possible inaccuracy in estimation of a given portion of heat can be neglected.

The penetrator with an electric resistance type heaterin its central part and with a system of forced cooling of main elements is considered as a body of uniformly distributed heat source. Any heater of this type has a limited specific volume heating capacity determined by its construction, properties of materials, period of operation. An active thermal capacity of penetrator is N. When drilling by melting process heat is consumed for overheat of surrounding melt Q_1, latent melting heat Q_2 and heating of surrounding rock mass from its natural temperature to the melting point Q_3. Thus :

$$N = Q_1 + Q_2 + Q_3. \qquad (I)$$

As the thickness of melt layer under working surface of penetrator is small, temperature distribution through its thickness can be considered approximately rectilinear and melt overheat temperature is taken as an arithmetic mean between the temperature of penetrator surface and rock melting temperature (transition between solid-liquid states).

Three equations with three unknown quantities were obtained by analysis taking into account accepted assumptions :

- drilling by melting velocity ;
- penetrator surface temperature ;
- average thickness of melt layer.

As a result of joint solution of these equations, an analytical expression for the dependence of drilling velocity on the main technological and constructive parameters in the form of transcendental equation :

$$\frac{N_a - \rho_\pi \left[\Phi F_z + (T_{arp} - T_\pi) C_\pi F \right] v}{C_p \rho_p F_z v} =$$

$$= \frac{\rho_\pi v}{4 \lambda_p} \left[\Phi \frac{F_z}{F} + (T_{arp} - T_\pi) C_\pi \right] \times \qquad (2)$$

$$\sqrt[3]{\frac{\lambda v \rho_p b \left[(R^2 + 2b^2) \operatorname{sh} R/b - 2bR \operatorname{ch} R/b \right]}{2 \left[2p - b g \rho_p (\operatorname{ch} R/b - 1) \right]}} ,$$

N_a - penetrator active power, W ;
v - mechanical velocity of drilling by melting, m/sec ;

F - penetrator surface area, m^2 ;
F_z - hole (face) cross-section, m^2 ;
R - radius of penetrator upper end face, m ;

Φ - specific heat of rock melting, J/kg ;

ρ_π, ρ_p - rock, melt density, kg/m^3 ;

C_π, C_p - specific mass heat capacity of rock, melt, J/(kg.°C) ;

f - chain line parameter ;

λ_p - melt thermal conductivity index, W/(m.°C) ;

λ - hydraulic resistance index (when melt moves) ;

p - specific axial load, Pf ;

g - acceleration due to gravity, m/sec^2.

The equation obtained for drilling by melting velocity relates all the determining factors of the process : penetrator constructive parameters, its active thermal capacity, axial load on the face as well as thermophysical properties of rock drilled and its melt.

Authenticity of complex and multifactor process of drilling by melting depends mainly on the determination and accuracy of the initial parameters and on the objectivity of experimental results registered. If penetrator construction parameters and drilling process technological parameters (active thermal capacity and axial load) are known beforehand and results of the process (drilling by melting velocity) can be fixed exactly in the experiment, authentic determination of rock thermophysical properties and all the more its melt offer serious difficulties as their properties change greatly. The above mentioned determination is an independent scientific problem. Therefore, rock (namely basalt) physical and thermophysical properties were taken from actual data obtained in the experiment carried out by laboratory in University of California, Los Alamos (U.S.A.) /2/.

Application of high temperature energy generator in the face will permit drilling without the use of drill pipe string, substituting hoist electrical cable : this will provide not only minimum losses through energy transfer from the surface, but also a possibility of full automation of drilling by the melting process.

The practical use of the new prospective method of drilling by rock melting is already possible and advisible when drilling in snow and firn and ice deposits, in loose rocks cemented by ice, on geotherms, in salt deposits, plugging by easily melted materials, for earth fall and pit edge consolidation, for pipe line in urban facilities etc. It can provide a real economic benefit.

LITERATURE

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