THE REFLECTION OF UHF ELECTROMAGNETIC ENERGY FROM ROCKS

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In the development of rock-cutting instruments for drilling and heading machines to give high productivity of breakage of hard rocks by the combined action of uhf electromagnetic and mechanical energy, a fundamental problem is the efficiency of utilization of the electromagnetic energy. This is because the efficiency of transmission of the uhf electromagnetic energy governs not only the economics of the rock-cutting process as a whole, but also its rate, because the latter depends directly on the power fed to the rock. Furthermore, reflected uhf electromagnetic waves present a serious hazard to the operating personnel.

Investigations of the irradiation of various rocks by decimeter waves have revealed that only part of the energy enters the rock and is absorbed so as to heat it. The reflected part of the energy is scattered into the surrounding space. The power $P_r$ entering the rock is related to the emitted power $P$ as follows [1]:

$$P_r = P (1 - \Gamma_p),$$

where $\Gamma_p$ is the coefficient of reflection with respect to power.

According to the conception of Brillouin [2], a system of electromagnetic waves propagated through a guide (except for a coaxial or strip line) consists of a superposition of plane waves, but cannot be regarded as plane as a whole. Therefore it is necessary to check whether it is possible to calculate the coefficient of reflection for a wave guide system loaded at the end by a rock in terms of the wave impedances.

To clarify the position, we performed some special investigations on reflection from the end of a rectangular wave guide loaded by various rocks. The results of the measurements and calculations are listed in Table 1, from which we see that the coefficient of reflection calculated from the wave impedances of the waveguide and rock is 15-20% lower than the experimental value. These results show that the wave impedances of the emitter and rock give only a rough value of the coefficient of reflection.

Experiments revealed that in the irradiation of rocks up to 85% of the uhf power supplied can be reflected. To increase the efficiency of utilization of the electromagnetic energy it is necessary to take special measures to match the wave impedances of the emitter and rock.

One of the simplest and easiest methods of matching is to position the emitting unit of the rock-breaking instrument at a certain distance from the irradiated surface, corresponding to maximum matching. This distance depends on the wavelength, the dielectric and magnetic parameters of the rocks, the geometry of the emitter, etc. It can be determined only experimentally.

Figure 1 is a plot of the coefficient of reflection vs the position of the emitter relative to the rock. We irradiated ferruginous quartzites with various percentage contents of iron minerals. The emitter was a rectangular waveguide 90 $\times$ 6 mm in cross section; the wavelength was 12.6 cm.

The coefficient of reflection depends very markedly on the position of the emitter relative to the rock (it varies by an order of magnitude) (see Fig. 1). This shows that finding the optimum distance is a very effective
TABLE 1. Experimental and Theoretical Coefficients of Reflection for Various Rocks

<table>
<thead>
<tr>
<th>Rock</th>
<th>Dielectric constant</th>
<th>Field frequency</th>
<th>Cross section of waveguide</th>
<th>Coeff. of reflection</th>
<th>Coeff. of reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>experimental</td>
<td>theoretical</td>
</tr>
<tr>
<td>Granite</td>
<td>10</td>
<td>10</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.70, 0.69, 0.64</td>
<td>0.59, 0.57, 0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.35</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.87, 0.85, 0.70</td>
<td>0.77, 0.74, 0.60</td>
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<tr>
<td>Ferruginous quartzite</td>
<td>7</td>
<td>10</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.61, 0.62, 0.58</td>
<td>0.54, 0.51, 0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.35</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.75, 0.69, 0.64</td>
<td>0.64, 0.57, 0.56</td>
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<td></td>
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<tr>
<td>Sandstone</td>
<td>4.5</td>
<td>10</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.55, 0.53, 0.48</td>
<td>0.44, 0.43, 0.40</td>
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<td></td>
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<td>8.35</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.64, 0.51, 0.52</td>
<td>0.52, 0.42, 0.41</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marble</td>
<td>13.6</td>
<td>10</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.76, 0.75, 0.72</td>
<td>0.64, 0.62, 0.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.35</td>
<td>18×6, 23×10, 28.5×12.6</td>
<td>0.82, 0.80, 0.74</td>
<td>0.71, 0.67, 0.61</td>
</tr>
</tbody>
</table>

Fig. 1. Coefficient of reflection vs distance between rock and emitter. 1) 10% Fe₂O₃ content; 2) 20; 3) 30; 4) 45% Fe₂O₃ content.

Fig. 2. Reflection coefficient vs temperature of rock. 1) 10% Fe₂O₃ content; 2) 20; 3) 30; 4) 45% Fe₂O₃ content.

means of matching. For the rocks in question at the given frequency, the distance corresponding to maximum matching lies between 12 and 20 mm. The coefficient of reflection is a periodic function of the distance between the rock and the emitter. Its second minimum is observed when the distance lies between 80 and 100 mm. However, it is not advisable to match the emitter at the second or subsequent minima, because as the distance increases there is a sharp fall in the electromagnetic field intensity gradient, leading to a fall in the rate of heating of the rock.

An emitter which has been matched by selecting the optimum distance can become mismatched during the operation of the uhf electrothermomechanical instrument. One possible cause of this is a temperature change in the irradiated surface. This has been verified experimentally.