Research of the axial strong magnetic field applied at the initial period of inertial stretching stage of the shaped charge jet

Ma Bin\textsuperscript{a,b}, Huang Zhengxiang\textsuperscript{a,s}, Zhongwei Guan\textsuperscript{b}, Zu Xudong, Jia Xin\textsuperscript{a}, Xiao Qiangqiang\textsuperscript{a}

\textsuperscript{a} School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, PR China
\textsuperscript{b} School of Engineering, University of Liverpool, Liverpool L69 3QG, UK

\section*{A R T I C L E I N F O}

Keywords:
Shaped charge jet
Magnetic field
Penetration
X-ray

\section*{A B S T R A C T}

The stability of shaped charge jets (SCJs) is an important factor affecting their penetration ability, and it will be worse in case of the large standoff under the natural condition. The external magnetic field can improve the stability of SCJs, and increase their depth of penetration (DOP). This paper evaluates the effect of an axial magnetic field on a SCJ through DOP experiment and X-ray experiment, and the field is loaded at initial period of the inertial stretching stage during experiments. A standoff of 650 mm (11.61CD) is employed in the experiments. The initial energy is provided by capacitors, and the initial voltages at both ends of them are 20.18 kV in the experiments. The experimental results show that the external magnetic field loaded at initial period of the inertial stretching stage of the SCJ can increase its stability, the penetration capability is increased by 72.8%. The radiograph indicates that the stability of the SCJ influenced by the strong magnetic field is better than the natural conditions. The DOP experimental results are consistent with the X-ray experimental results.

1. Introduction

It is well-known that the shaped-charge jet has a high tip speed and a low tail speed, causing it to stretch to great lengths at large standoff distance [1]. However, since the penetration ability of the jet is proportional to its length [2], the stability of a shaped charge jet is an important factor affecting its penetration capability. However, after a certain length of time, the jet becomes unstable and breaks up into many pieces approximately equal in size. once broken, performance of the jet is significantly degraded under the natural condition. In order to improve the penetration ability of the jet at large standoff distance, previous methods of increasing stability mainly focused on improving the physical-mechanical properties of SCJ materials and the machining process; the shape and size of liners has also been optimized. However, the penetration ability of a SCJ at a large standoff is still unsatisfactory. Littlefield [2], Fedorov et al. [3–5] and Ma et al. [6–9] showed electromagnetic action can enhance the penetration ability of a shaped charge jet.

Littlefield [2] theoretically analyzed the stability of rapidly stretching, perfectly plastic jets when subjected to axial magnetic fields, the results indicated that imposed axial magnetic fields appear to be effective in stabilizing plastic, elongating jets. The successful use of electromagnetic fields to stabilize uniformly elongating plastic jets is sensitive to a number of parameters, and the most important of these parameters is the magnetic Reynolds number. In addition, he studied several kinds electromagnetic action affecting the stability of a SCJ based on related governing equation and perturbation theory [10–16]. Fedorov et al. [6,8,9] showed that jet stretching with a diffusion magnetic field was accompanied by magnetic field compression inside the jet, resulting in the appearance of radial stretching electromagnetic forces; in this study, the increase (10%) in DOP was observed when the magnetic field induction is changed from 1 Tesla to 10 Tesla. The authors then introduced and analyzed several kinds of electromagnetic actions controlling the jet at different stages of shaped charge firing and considered the salient deformation features of metal cumulative jets in a longitudinal low-frequency magnetic field on the basis of a model of a uniformly stretching cylindrical incompressible rigid-plastic conducting rod. Ma et al. [6–9] analyzed the coupling process between external magnetic field and a shaped charge jet, as well as the inhibiting effect of the electromagnetic force on rotation motion of the shaped charge jet. Both numerical simulation and experimental results all verified the correctness of this research. Fig. 1 in Literature [6] shows the coupling between an SCJ and external magnetic field.

In this paper, X-ray and DOP experiments were conducted to research strong magnetic field coupling with the SCJ. DOP experiments were conducted to evaluate the effect of the strong magnetic field loaded at initial period of the inertial stretching stage of the SCJ on its penetration ability. Furthermore, for two cases of the natural conditions...
and presence of the strong magnetic field, we extract the radiographs at the same time to compare their salient features.

2. Experiments

2.1. Analysis of timing sequence

Previous work analyzed the effect of external magnetic field loaded at later inertial stretching stage through DOP test method [6]. The experimental results indicated that the coupling action of the magnetic field can effectively inhibit the rotation of the jet particles after breakup. Under the effect of the field, the jet particles after breakup can still remain aligned with the SCJ initial axis and have high penetration capability. Therefore, the external magnetic field loaded at the later inertial stretching stage can improve the stability of the jet effectively, and the penetration ability of the jet coupled with the magnetic field was increased dramatically.

Present work is to research the coupling mechanism between the SCJ and the external magnetic field loaded at initial period of the inertial stretching stage, and X-ray and DOP test methods are used in this work.

If the standoff is sufficient long, all kinds of instabilities of shaped charge jets could occur easily. In this work, a standoff of 650 mm is selected, because it is far more than the optimum standoff, the performance of the shaped charge seriously decline, and the shaped charge jet could undergo formation, elongation, breakup, rotation and drift under this standoff. In addition, the experimental results could be compared with the results in literature [6]. Fig. 1 shows the timing diagram of SCJ coupled with the magnetic field loaded at initial period of the inertial stretching stage. Walters et al. [17] indicated that the initial jet length of a conical liner is determined based on the slant length of the cone. Combining parameters of Ø56mm shaped charge and the solenoid structure, the distance between the bottom of the liner and the entrance of the solenoid in the experiments is set to 60 mm, as is shown in Fig. 1, which could guarantee that the external magnetic field is loaded timely when the SCJ is at initial period of the inertial stretching stage.

Based on the dynamic characteristics of the SCJ (The time of the shaped charge detonated is set to zero-time), we can obtain the duration of elements inside the solenoid, as is shown in Table 1.

Table 1
Duration of elements with different velocities entering and leaving the solenoid.

<table>
<thead>
<tr>
<th>Standoff/mm</th>
<th>V/mm μs⁻¹</th>
<th>T₁</th>
<th>T₂</th>
<th>ΔT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>22.9</td>
<td>46.7</td>
<td>23.8</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>23.6</td>
<td>48.6</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>26.6</td>
<td>56.6</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>31.0</td>
<td>68.5</td>
<td>37.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>38.4</td>
<td>88.4</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>53.2</td>
<td>128.2</td>
<td>75.0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>97.6</td>
<td>247.6</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

2.2. DOP experiments

To investigate the effect of the strong magnetic field loaded at initial period of the inertial stretching stage on the penetration ability of the SCJ, the DOP experiments are carried out. The relative position of experimental setup is designed based on above analysis of the timing sequence, which is shown in Fig. 2. The system timing sequence is controlled through controlling the initiation interval between the shaped charge and the explosive used for closing the time-delay switch.

The Ø56 mm shaped charge and the solenoid used in the experiments have been used in previous researches, their characteristics are introduced in literature [6], and the related electric parameters of the strong magnet is shown in Table 2.

During the experiments, we use the capacitors as energy source. In addition, the time-delay switch controls the closing time of the circuit, and it will be closed when the voltage of capacitors reaches the experimental setting value. Based on the experimental set time delay, the jet passes through the solenoid and interacts with this field during
دریافت فوری
متن کامل مقاله
امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات