Applied Acoustics 88 (2015) 137–145

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Prediction of sound field from recoilless rifles in terms of source decomposition

Byunghak Kong [a], Kyuho Lee [a], Seo-Ryong Park [a], Seokjong Jang [a], Soogab Lee [b,*]

[a] Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul 151-742, Republic of Korea
[b] Center for Environmental Noise and Vibration Research, Engineering Research Institute, Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul 151-742, Republic of Korea

ARTICLE INFO

Article history:
Received 11 November 2013
Received in revised form 30 April 2014
Accepted 21 August 2014
Available online 16 September 2014

Keywords:
Hybrid prediction model
Recoilless rifle
Muzzle blast
Jet noise

ABSTRACT

In the present study, sound field from M40A1, a type of recoilless rifles, was measured using sound analyzers. Contrary to expectations based on the common characteristics of muzzle blast in previous studies, significantly different waveforms compared to those in other directions were observed in each acoustic pressure signal. In order to clarify how the surroundings affected the sound field, the temporal, spectral and directional characteristics were investigated using correlation functions and Fourier transforms. As a result, additional sources near the rear nozzle of the weapon were identified. Under the operating circumstances of recoilless weapons, blast and jet noise sources were found to be consistent with their acoustical characteristics. A hybrid model integrating the influences of blast and jet noise identified from source decomposition was derived according to the ISO standard 17201 and NASA empirical formulae. Since the predicted directivity pattern agrees moderately well with that measured in previous and present studies and the spectral distributions are in accordance with the measured ones, the hybrid model proposed in this study is considered to be appropriate for predicting the sound field from M40A1 recoilless rifle.

1. Introduction

Muzzle blast, a type of impulse sound, is a phenomenon associated with the rapid discharge of compressed air and propellant gas, which displace the ambient air and form blast waves at the front of the spherical volume of the gases [1]. These shock fronts contribute to huge variations in the local acoustic pressure within a very short time during propagation. This is a major characteristic that describes the acoustical similarity of muzzle blast and is called impulsiveness, which is revealed by the presence of several acoustical features such as short duration time, nonlinearity near the source, and broadband noise [2].

Most studies of muzzle blast [3–15] are based on this similarity of the impulsiveness. Weber [3,4] developed a blast source model to describe the strength and spectrum of the blast noise for an explosion in air depending on the radius of a spherical volume of compressed gas, and the International Organization for Standardization (ISO) [5,6] has recommended procedures to estimate the source data with respect to the energy, direction, and frequency contents using the Weber radius and provides guidance for calculating the sound propagation from shooting ranges. In addition, Fansler et al. [7,8] proposed a scaling law to predict the blast wave overpressure levels from an arbitrary gun muzzle according to dimensionless parameters such as the scaling length, Mach disc location, and blow-down parameter in a perspective on damage risk to the human body. Likewise, an optical measurement of the muzzle flow field by Schmidt and Shear [9], numerical simulations using a remarkable source model by Bin et al. [10] and Jiang [11–14], and a theoretical approach by Erdos and Del Guidice [15] also investigated its physical mechanism and characteristics based on these similarities.

In this study, the characteristics of shooting range from M40A1 recoilless rifle were investigated by acoustic pressure signals based on the principle of these similarities [16]. Typically, the recoil force is induced as a reaction to the propelling force that accelerates the projectile when a weapon is firing, and it has an impact on an operator. However, M40A1 becomes recoilless by cancellation of the recoil force, so this force rarely affects the user. Hence, there might be significant changes in the acoustic features that can enable "recoil" and "recoilless" rifles to be distinguished by means of the similarities in impulsiveness.

* Corresponding author. Address: #311-105 Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea. Tel.: +82 2 880 7384.
E-mail address: solee@snu.ac.kr (S. Lee).

http://dx.doi.org/10.1016/j.apacoust.2014.08.012
0003-682X/

Accordingly, the sound field was measured to investigate the similarities and dissimilarities of M40A1, and a prediction model that can include the effects of the dissimilarities is proposed. This article first presents an ISO standard procedure, which is one of prediction methods for shooting range based on the similarity, and introduces the measurement conditions in Section 2. Subsequently, the acoustic properties of muzzle blast from M40A1 are examined using measured signals, and the remarkable differences from recoil weapons are analyzed in Section 3. Then, a hybrid prediction model is suggested, and its accuracy and validity are examined in Section 4.

2. Methodologies

2.1. ISO 17201

Parts 2 and 3 of the international standard series ISO 17201 cover the prediction of source data and propagation of shooting noise, and they ultimately specify methods for the calculation of the sound exposure level (SEL) at a certain receiver point from muzzle blast. These procedures are briefly described in Fig. 1.

In order for the source data to be used as input variables for further calculation, the data must be frequency and angle dependent because the acoustic energy and spectrum of muzzle blast are highly directional. Thus, ISO 17201 Part 2 recommends a procedure that is consistent with this requirement. This method has two major steps: estimation of the acoustic energy and calculation of the spectrums including their directional characteristics. The former step, acoustic energy estimation, is based on a similarity principle that implies that a part of chemical energy generated from the explosion of the propellant is used to accelerate a projectile. In the first, the kinetic energy of the projectile is calculated from its mass and launch speed, and the chemical energy is estimated from the projectile energy by the recommended conversion factor. Then, the total acoustic energy of the muzzle blast is calculated from the conversion ratios between energy types. In the second, the directivity of the source is applied according to the type of weapon, e.g., rifle, pistol, and shotgun, as shown in Fig. 1, and finally, the angular source energy distribution is obtained as follows [5]:

$$S_q(\alpha) = \frac{p_W^2}{\rho_c} 4\pi R_W^2 \int_{\omega_1}^{\omega_2} \frac{1}{\pi} \left[\omega^2 + 9\frac{c^2}{R_W^2} \left(\frac{c^2}{R_W^2 \omega^2} + 1 \right) \right]^{-1} d\omega \tag{1}$$

In Part 3, the SEL at the reception point from one specific shot is calculated using a ray tracing model. In this step, the sound power level and directivity have to be replaced by the angular sound source distribution estimated in Part 2, and the propagation conditions such as geometric spreading, atmospheric absorption, and ground reflection are imposed. Therefore, the SEL, $L_E(f)$, can be obtained using the following equation [6]:

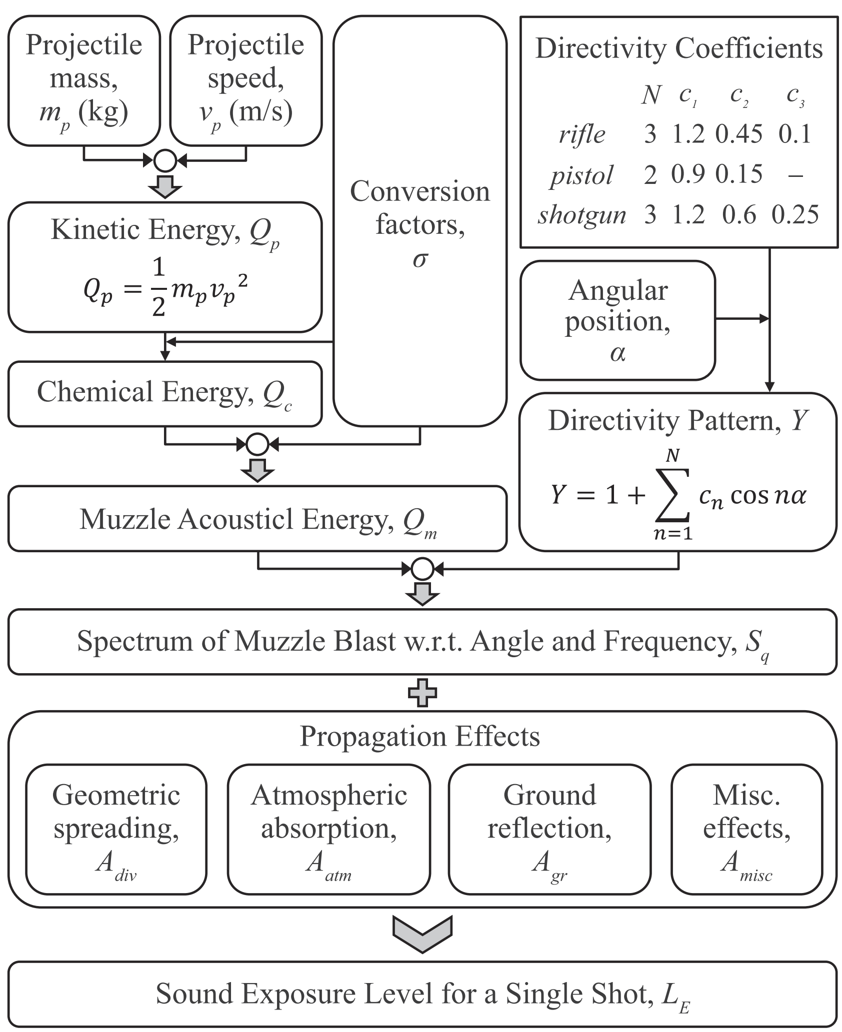

Fig. 1. ISO 17201: Flow chart of the estimation procedure for sound exposure level from the muzzle blast [5,6].