Finite Elements in Analysis and Design 124 (2017) 22–32

Contents lists available at ScienceDirect

Finite Elements in Analysis and Design

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

A mesh generation method for worn gun barrel and its application in projectile-barrel interaction analysis

Chuanjun Ding, Ning Liu*, Xiangyan Zhang

School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, Jiangsu, China

ARTICLE INFO

Keywords:
Gun barrel
Parametric modeling
Finite element analysis
Wear
Thermo-mechanical model

ABSTRACT

Although wear mechanism of gun barrel and projectile-barrel interaction have been comprehensively studied in the past three decades, attention has seldom been paid to the interaction between worn barrel and projectile. In the present work, a new parametric geometric modeling method for gun barrel and a new finite element meshing strategy for the worn barrel are proposed which involve the joint use of Python code and ABAQUS software. A transient coupled thermo-mechanical finite element (FE) model is developed to compute the plastic deformation of rotating band and the performance of interior ballistics. Additionally, material thermal properties of the rotating band are considered and user subroutine VUAMP and VFRICTION are implemented within the FE model in order to take account of the propelling force caused by propellant gas and the effect of changing friction stress, respectively. The FE results obtained in simulation verify the ability of the proposed meshing strategy to improve analysis accuracy with respect to the interaction between the worn barrel and the projectile.

1. Introduction

The projectile-barrel interaction process consists of the engraving process of the rotating band and the following in-bore motion of the projectile during a firing cycle [1]. Their relationship before launch is shown in Fig. 1 through the use of a 12.7 mm gun. With the increase of firing cycles, barrel wear occurs as an increase in bore diameter at both land and groove positions, which is mainly due to the complicated thermo-chemical and mechanical environment in interior ballistics (IB) process. Normally, this type of material removal initiates from the commencement of rifling and spread down the gun barrel towards the muzzle. Depending on the degree of wear, leakage of high-pressure gas between the projectile and the worn barrel will gradually reduce the IB pressure, muzzle velocity as well as flight stability of projectile. Therefore, investigation of projectile-barrel interaction when gun barrel is worn is warranted.

Various experimental and numerical methods have been proposed to study the wear process of barrel in the past three decades. Lawton [2] performed theoretical and experimental studies on thermo-chemical wear mechanism about the gun barrel and derived a relation between wear, bore temperature and propellant erosivity which can be used to estimate the wear rate of gun barrel. Rosset et al. [3] conducted firing tests of a small caliber experimental gun barrel made of cobalt-base alloy and their results suggested that cobalt-base alloy barrel is an excellent candidate for gun liner. In order to calculate the convection heat transfer coefficient of barrel, Değirmenci et al. [4] demonstrated a thermo-chemical approach which was validated by experimental firing tests. The thermal erosion of 40 mm gun tube was investigated by Chung et al. [5] by adopting the exponential form of wear rate equations as a function of heat input. Huang et al. [6] established the finite element models for the 37-mm ceramic chamber and conducted thermal stress and ballistic dynamic stress analyses, their results showed that ceramic has good heat resistance and mechanical strength. Sopok et al. [7,8] described the thermal-chemical-mechanical gun bore erosion models for an advanced artillery system. They concluded the erosion condemnation of gun tube by the provisional diametric origin erosion limit criteria of 2.54 mm which results from the formation of macro-pits on the bore surface.

Lots of researchers have analyzed the behavior of projectile-barrel interaction. Montgomery [9–11] found that there are two distinctly different wear mechanisms of the rotating band. Specifically, when a molten film is formed on the surface of the band, slipping becomes lubricated and friction is determined by hydrodynamic considerations alone. The impact of M855 projectile loading rate and charge weight on engraving process was studied experimentally by South et al. [12]. Their experiments improve the recognition of the complicated process between engraving and launch. Wu et al. [13] investigated quasi-static and dynamic engraving performance of two short rifled gun barrels and

* Corresponding author.
E-mail address: ln101@163.com (N. Liu).

http://dx.doi.org/10.1016/j.finel.2016.10.003
Received 22 February 2016; Received in revised form 9 October 2016; Accepted 12 October 2016
0168-874X/ © 2016 Elsevier B.V. All rights reserved.

Fig. 1. Presentation model of projectile and barrel.

projectiles with the rotating band made of copper, Al-bronze and nylon. Their data suggested that strain rate and temperature have significant effects on the deformation behavior of the rotating band during engraving process. The analysis of detailed stress situation of a guided projectile during engraving process by Xue et al. [14] revealed that the launch reliability of guided projectile is sensitive to the width of rotating band. A study of the microscopic mechanism of plastic deformation of rotating band based on metal material theory, by Yin et al. [15,16], showed that due to severe friction, fibrous tissue heats up quickly and recrystalizes after engraving process. Esen [17] studied the non-linear vibration of the barrel of anti-aircraft gun, which is induced by the interaction with a high speed projectile. In their interaction model, the accelerating projectile is treated as a moving mass. In order to observe the effect of different charge, shell and firing conditions on the barrel, Andrews et al. [18] measured the stress of a 155 mm gun barrel during firing. The results show that highest strains will be experienced in new barrels and even with moderate wear the band strain from all charges will decrease. Garner et al. [19] inspected 5.56 mm aging barrels which involving application of in-bore automated laser profilometry device, and demonstrated that the laser profilometry scan outputs can be coupled with the exterior geometry of the barrel, so that a custom barrel model can be created. However, they did not elaborate about the procedure in their paper.

The above studies provide good references for the research of wear mechanism of gun barrel and the effects of interaction between projectile and weapons. Nevertheless, due to the complicated configuration of gun barrel and absence of appropriate modeling method, the exact 3D FE model of the worn barrel has seldom been developed, let alone the thorough analysis of IB performance. The difficulties lie in the following: (1) as a 3D spiral model, the length of rifling is much greater than its height, so it is not easy for an engineer to build 3D geometry of gun barrel. For example, the length-height ratio of rifling, which will be used in current analysis, is 908.0/0.35 with a twist angle 7.16°; (2) the value of wear along the axial direction of tube is uneven and sometimes it just a small portion of the height of rifling, which increases the difficulty in establishing the FE model of worn barrel.

In order to well understand the interaction between the worn barrel and projectile, a parametric geometric modeling method was developed in present study by means of Python code and ABAQUS/CAE software (if not specified, ABAQUS in this paper refers to ABAQUS/Explicit). Based on the developed geometric model of the barrel, a novel FE meshing strategy was formulated to construct the FE model of worn barrel. Combined with user subroutine, several transient thermo-mechanical FE analysis, with varying wear degrees of the barrel, were performed to validate the effectiveness of the proposed modeling methods. Additionally, a simple FE model without consideration of the thermal freedom was also presented for comparison. Finally, associated conclusions about the interaction of projectile-barrel were obtained.

2. Parametric modeling of gun barrel

It is evident that due to the complexity of geometry, generating accurate 3D barrel geometry with rifling and discretizing them into FE mesh is by no means trivial. Generally, engineers use geometry modeling software to construct 3D geometry of barrel. However, because of the compatibility between software, the geometry file of a barrel (with rifling) is often considered as lack of adequate accuracy in pre-processing software. Therefore, studies are seldom performed on the FE analysis considering full 3D interaction of projectile-barrel.

In spite of this, progresses made in spiral geometry modeling provide detailed insights into realizing the modeling of a barrel though parametric equations. For instance, Chen et al. [20] proposed a new parametric geometric model for spiral triangular strand using Pro/Engineer software, at the same time the full 3D finite element models of spiral triangular strand were developed with ANSYS software. In addition, by joint use of commercial software MATLAB and HyperMesh, Erdonmez et al. [21] created the desired 3D mesh of single and double helical wires of wire rope subjected to axial loads. Stanova et al. [22–24] carried out an exhaustive study into the geometry of wire rope and its mechanical behaviors, confirming the correctness of the derived parametric equations of helical wire strand. Also, an effective procedure to generate 3D FE models of complicated spiral strand cables which accurately capture the radial contact between individual wires, was devised by Judge et al. [25], such procedure can be used to construct spiral strands of any diameter and lay angles. Ma et al. [26] developed two methods for building a 3D geometry of a wire rope bent over a sheave in Pro/Engineer with MATLAB, their results reveal that two parametric modeling methods can be applied to any helical-strand wire rope.

So this section is aimed at building the 3D geometry of a barrel with rifling based on the above proposed parametric modeling methodology through the use of Python code and ABAQUS/CAE. The Python scripting interface is embedded in ABAQUS/CAE environment which provides a broad range of linear or nonlinear finite element analysis and meshing capacities. Based on the ABAQUS/CAE environment, Python code could be called not only to conveniently implement pre-processing and post-processing commands of ABAQUS/CAE, but also developed to deal with various sophisticated problems, such as topology optimization [27]. For detailed use procedure, the reader is referred to the user manual of ABAQUS [28].

2.1. Parametric equation of barrel cross section

A typical cross-section schematic of the barrel considered in this study is composed of rifling and tube, as shown in Fig. 2(a). With the origin at the central point O, a right hand Cartesian coordinate system is built in which the diameters in the position of groove, land and outer wall are, D_G, D_L and D, respectively. Here, the width and height of rifling are W_L and h. The Z axis is identical with the barrel axis or the motion direction of the projectile. Then the coordinates of control points (P_1-P_8), as shown in Fig. 2(b), could be derived by means of the following parametric equations [22].

$$X_{ic} = R_c \cos\left(\frac{2\pi i}{M} + \alpha_0\right) \tag{1-a}$$

$$Y_{ic} = R_c \sin\left(\frac{2\pi i}{M} + \alpha_0\right) \tag{1-b}$$

$$Z_i = \frac{2\pi R_b i}{M \tan(\theta)} \tag{1-c}$$

Where R_c and R_b are the radii of control points and outer wall. α_0 is the initial position angle, θ is helix angle of the rifling. The construction parameter M is a constant value that could be used to control the geometry accuracy of the barrel. In present study, M is set at 120 by

Download English Version:

https://daneshyari.com/en/article/4966223

Download Persian Version:

https://daneshyari.com/article/4966223

Daneshyari.com