Analysis of the Effectiveness of Thermal Shroud on the Thermal Deformation of a Gun Barrel

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PRESENTED BY
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INTRODUCTION

The general

- Accuracy is well known as one of the main performance of a tank gun.
- Factors to affect the accuracy
  - gun, fire control system, ammunition, gunner, etc.
- In the case of gun, the centerline profile of the bore affects the in-bore movement, and exit state of the projectile, and finally its flight path to target.
- Factors to vary the centerline of the bore
  - sagging from the weight of a gun barrel itself
  - machining error (straightness, wall thickness)
  - deformation by internal or external heat source
INTRODUCTION

- Thermal deformation principles of gun barrel
  - Heat flux from solar radiation, wind, rain
  - Heat flux from the bore in firing
  - Uneven heating or cooling of gun barrel
  - Cross sectional temp. difference of gun barrel
  - Thermal deformation of gun barrel
  - The degradation of accuracy of gun system

- This presentation does not include the analysis related to heat flux from the bore in firing.
INTRODUCTION

- **Requirement of thermal shroud design**
  - To minimize the deformation of gun barrel by heat
  - To have light-weight structure

- **Purpose & Scope of the research**
  - To evaluate the effectiveness of thermal shroud
  - To study the effect of design parameters
ANALYSIS

Outline

Flow Field Analysis (FLUENT)
- to predict the heat transfer coef. at the outer wall of thermal shroud
- to calculate the temp. of a gun barrel, thermal shroud and air gap in between the two

Data Mapping Scheme: transferring CFD results to stress analysis

Thermal Stress Analysis (ABAQUS)
- to calculate the deformation of a gun barrel and the gun muzzle movement
ANALYSIS

- Prediction of the heat transfer coeff. at the outer wall of thermal shroud
  - wind velocity: 0.5 m/s, heat input: constant
  - Calculation Eq.: \[ h = \frac{Q}{T_{\text{wall}} - T_\infty} \]
ANALYSIS

□ Material properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Thermal shroud</th>
<th>Gun barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2,540</td>
<td>7,850</td>
</tr>
<tr>
<td>Conductivity (W/m·K)</td>
<td>1.0344</td>
<td>44.5</td>
</tr>
<tr>
<td>Specific heat (J/kg·K)</td>
<td>795.5</td>
<td>475</td>
</tr>
</tbody>
</table>

□ Mesh model of gun barrel with thermal Shroud
## ANALYSIS

- **Geographic conditions for analysis**
  - Latitude 35° north, longitude 127° 30' east
  - Solar radiation energy in Summer (21, Aug.)

<table>
<thead>
<tr>
<th>Case</th>
<th>Hour</th>
<th>Solar radiation energy (W/m²)</th>
<th>Wind vel. (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>direct</td>
<td>diffuse</td>
</tr>
<tr>
<td>A</td>
<td>7 a.m.</td>
<td>427.6</td>
<td>52.2</td>
</tr>
<tr>
<td>B</td>
<td>9 a.m.</td>
<td>792.4</td>
<td>96.7</td>
</tr>
<tr>
<td>C</td>
<td>12 a.m.</td>
<td>883.4</td>
<td>120.1</td>
</tr>
<tr>
<td>D</td>
<td>3 p.m.</td>
<td>850.6</td>
<td>103.8</td>
</tr>
<tr>
<td>E</td>
<td>5 p.m.</td>
<td>695.5</td>
<td>84.9</td>
</tr>
<tr>
<td>F</td>
<td>12 a.m.</td>
<td>883.4</td>
<td>120.1</td>
</tr>
</tbody>
</table>

- Orientation of a gun barrel to south
- Unless stated, analysis conditions refer to Case C
ANALYSIS

- Development of a coupled scheme for data mapping
  - Need to transfer the temperature results of fluid flow analysis to the thermal stress model
  - To solve the mapping problem according to different mesh system each other
  - Applied the point clouds concept

Donor point (grid for FLUENT)

Point cloud (grid for ABAQUS)
A cross sectional wall temp. of gun barrel

Wall temp. without thermal shroud (Max. T: 52 °C, ΔT : 12 °C)

Wall temp. with thermal shroud (Max. T: 46 °C, ΔT : 3 °C)
ANALYSIS

- Temp. and flow characteristics of air layer by thermal shroud
  
  Temp. distribution of air layer  
  (ΔT : approx. 60 °C)

  Vel. distribution of air layer  
  (Max. Vel. : 3.5 cm/s)
ANALYSIS

□ Longitudinal wall temp. of thermal shroud and gun barrel

Max. T : 98.0 °C
Min. T : 23.4 °C

Max. T : 48.7 °C
Min. T : 43.5 °C
ANALYSIS

- Longitudinal temp. distribution and thermal deformation of gun barrel with thermal shroud

Max. elongation: 1.27mm

Temp. (°C) distribution

Thermal deformation (m)
ANALYSIS

- Comparison of the movement of gun muzzle with or without thermal shroud

The effectiveness of the thermal shroud is proved by analysis.
DESIGN PARAMETERS STUDY

- Materials of thermal shroud

<table>
<thead>
<tr>
<th>Properties</th>
<th>FRP</th>
<th>Al</th>
<th>Titanium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2,540</td>
<td>2,719</td>
<td>4,850</td>
</tr>
<tr>
<td>Conductivity (W/m-k)</td>
<td>1.0344</td>
<td>202.4</td>
<td>7.44</td>
</tr>
<tr>
<td>Specific heat (J/kg-k)</td>
<td>795.5</td>
<td>871</td>
<td>554.25</td>
</tr>
</tbody>
</table>

- Wall thickness of thermal shroud
  - 5mm
  - 10mm

- Radial gap between thermal shroud and gun barrel
  - 1.0L
  - 1.5L
Comparison of the movement of gun muzzle relating to materials

- FRP
- Al
- Ti

Origin

- 7 am
- 9 am
- 5 pm
- 3 pm
- 12 am

It is shown that the material does not almost influence the effectiveness of thermal shroud.

- Aluminum has the shortest time in thermal equilibrium.
Comparison of the movement of gun muzzle relating to wall thicknesses

It is shown that the wall thickness does not influence the effectiveness so much.
**DESIGN PARAMETERS STUDY**

- Comparison of the movement of gun muzzle relating to radial gaps

It is shown that a gap is a major parameter in designing the thermal shroud.
Design Parameters Study

- Consideration of radial gap's effects
  - Velocity vector (at 9 a.m.)

It is shown that the gap increment makes the flow velocity of air layer faster, and the wall temp. of gun barrel in more equilibrium.
Consideration of radial gap’s effects (cont.)

Wall temp. distribution of gun barrel (at 9 a.m.)

It is shown that the wall temp. difference of gun barrel becomes on the decrease.
Consideration of radial gap’s effect (cont.)

- Validation examination by various gap sizes

Finally, as the gap increases more, the deformation of a gun barrel decreases.
TEST RESULTS

- Validation of analysis by non-firing test
  - test scene and apparatus

- Target range: 20m
TEST RESULTS

- Validation of analysis by non-firing test (cont.)
  - Comparison of the results by non-firing test with the calculation results according to test ambient conditions

- All values are at a distance of 20m from gun muzzle.
TEST RESULTS

□ Real firing test results
✓ Target range : 1km

Max. $\Delta T$ at the outer of gun barrel : 2.0° C

With thermal shroud

Max. $\Delta T$ at the outer of gun barrel : 10.5° C

Without thermal shroud
DISCUSSION AND CONCLUSIONS

- An attempt was made to evaluate the effectiveness of thermal shroud, and to study the effect of design parameters by analysis.
  - A coupled scheme that transfers the results of fluid flow analysis to the thermal stress analysis has been developed.
  - The effectiveness of the thermal shroud has been verified.
  - The gap between the thermal shroud and gun barrel is a major parameter in designing.
  - The thermal deformation of a gun barrel decreases, as the gap increases.

- This analysis is thought to be good, comparing calculation results with test results.

- The results of this study will be helpful to design the thermal shroud.
END OF PRESENTATION

QUESTION?

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