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Design and Development of Automatic Temperature Measurement Device Based on Can Bus Technology

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Abstract: An automatic online temperature measurement device on the Modular Artillery Charge System (MACS) is designed and developed, based on Controller Area Network (CAN) bus technology in this study. For measuring automatically the temperature of the modular charge, a non-contact measurement method is proposed. The primary idea of this method is to obtain the real-time value of the modular charge temperature through solving the unsteady heat transfer equations describing the variation in the modular charge temperature. As a part of the online temperature measurement device, an Initial Charge Temperature Sensor (ICTS) is also developed according to the similarity principle. This device can accurately measure the temperature field and real-time average temperature of the modular charge for all charge zones placed in a combat vehicle and simultaneously transfer the temperature information to the gunner task terminal computer through CAN bus interface for trajectory calculation and firing data correction, ensuring the weapon system meets the requirements of digitalization and informatization.

Key words: Automatic temperature measurement device, CAN bus technology, similarity theory, non-contact measurement method

INTRDUCTION

At present, a kind of Modular Artillery Charge System (MACS) is required primarily for larger caliber weapon systems (for example, for 155 mm howitzers, etc.,). The MACS provides propelling charges with combustible cartridge cases for 155 mm artillery. The charges are compatible with new and existing howitzer systems and offer enhanced precision with a reduction in weight and volume. Meanwhile, the MACS offers maximum flexibility in tactical logistics to warfighters. The build-a-charge system eliminates the need to dispose of unused cartridges and the charge system fires cleanly, without leaving residue in the cannon breech. Besides the excellent controllability and strong survivability, advanced howitzer systems are required to carry out firing for effect under no Fire For Adjustment (FFA) in order to realize the coverage of first burst group to target. An important condition to meet these requirements is accurate firing data setting. The charge temperature of the MACS is one of the main tactical and technical indices and particularly, is a critical firing datum affecting the muzzle velocity and firing accuracy of advanced howitzer systems (Ikram *et al*., 2007; Jiang *et al*., 2010; Zhou *et al*., 2007a). The influence coefficients of charge temperature on the muzzle velocity and range are, respectively $\partial_{v0}/\partial T$= 0.07-0.10% and $\partial X/\partial T$ = 0.12-0.22%, where is muzzle velocity and X is range (Peng and Zhou, 2009; Zhou *et al*., 2007b). This means that, for a howitzer of muzzle velocity with 1000 m sec^{-1}, the tolerance of the muzzle velocity and range are, respectively 0.7-1 m sec^{-1} and 45-85 m resulting from a discrepancy of charge temperature with 1°C for a different type of projectile. Actually, for existing howitzer systems, the measurement tolerance of the charge temperature is generally 3-5°C using the traditional measuring method (Liu *et al*., 2001; Lu *et al*., 2009). Obviously, this measurement tolerance will result in a severe range deviation and has a serious effect on the first round hit ratio (Guo, 2004). Therefore, improving the measurement accuracy of the charge temperature is an important means in which the firing accuracy, the coverage of the first burst group to target, the operational capacity and the survivability of modern artillery are increased. The MACS composed of several identical propellant charge modules is configured into howitzers. The variations of temperature in the vehicle are wide and unbalanced because of heat emission of motor and heat radiation of vehicle hood. The temperature change of modular charge placed in the turret always lagged behind that of environment temperature. However,

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there are still no effective methods measuring accurately and rapidly the modular charge temperature which changes with the environment temperature in the vehicle.

An automatic online temperature measurement device is developed for the MACS used to larger caliber weapon systems in this study. Using the measurement device, the temperature of modular charges placed in the turret of howitzer systems can be successively obtained. The measurement device is composed of a PC104 microprocessor, special calculation software and two sets of the special temperature sensors. The special calculation software, developed on the basis of the unsteady heat transfer equations, can determine the current values of the charge temperature according to the initial charge temperature and environment temperature from two sets of the special temperature sensors and charge character parameters such as the density, heat capacity and thermal conductivity. Two sets of the special temperature sensors are both mounted on the ammunition rack in the turret and used to measure the initial charge temperature and environment temperature in the turret respectively. When the device powers on and begins to work, one set of sensors are used to measure the current values of the charge temperature as the initial values of the charge temperature field and another set are used to measure successively the environment temperature in the turret as the boundary condition of the unsteady heat transfer equations on the charge temperature field. The temperature field and current average value of modular charges are real-time calculated through the special calculation software installed on the device.

DESIGN OF AUTOMATIC MEASUREMENT DEVICE ON MACS

As well-known, each individual module consists of the combustible cartridge case, flash tube and propellant grains. Under the field condition, the modular charge is always in the thermal non-equilibrium status due to the change of the environment temperature. The temperature field of the modular charge is the unbalanced temperature field and varies with the environment temperature and time. From the view of operational use on the actual battlefield, the modular charge temperature is not allowed to be measured by holing or other contact measurement methods. Therefore, a non-contact measurement method is proposed in this study. The primary idea of this method is to obtain the real-time value of the modular charge temperature through solving the unsteady heat transfer equations. For the characteristic of non-contact measurement of the charge temperature on the actual battlefield, a design program of an online measurement device is proposed as shown in Fig. 1. The online measurement device consists of a PC104 microprocessor, special calculation software and two sets of the special temperature sensors. The main function of the special calculation software is to calculate the numerical solution of the unsteady heat transfer equations. Two sets of the special temperature sensors are used to obtain respectively the initial condition and boundary condition, i.e., the initial charge temperature and environment temperature in the turret, for the unsteady heat transfer equations.

Mathematical model used in the special calculation software: The heat transfer process of modular charges can be described by the unsteady heat conduction model of a two-dimensional axisymmetric cylinder. Because the individual module consists of the combustible cartridge case, flash tube and propellant grains, the differential equation should be written as follows:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}(\lambda \frac{\partial T}{\partial x}) + \frac{1}{r}\frac{\partial}{\partial r}(\lambda r \frac{\partial T}{\partial r}) \quad (1)$$

where, T is the modular charge temperature. ρ, c and λ are the density, specific heat and thermal conductivity of materials respectively.

In order to solve Eq. 1, the initial condition and boundary condition need to be given. The temperature of the modular charge when put on the ammunition rack in the turret is the initial charge temperature, so that:

$$T(x, r, t)|_{t=0} = T_0 \quad (2)$$

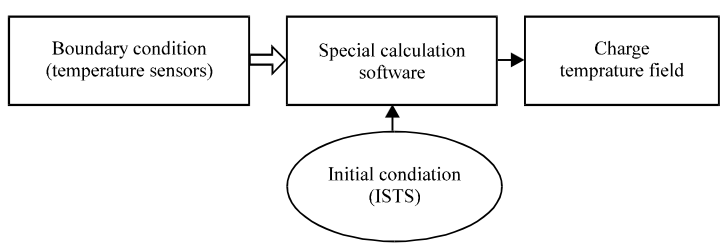

Fig. 1: Design program of an automatic online measurement device on MACS

The initial charge temperature T_0 may be obtained by the special temperature sensors called initial charge temperature sensors. Consider the heat transfer between the surface of the modular charge and the air in the turret as natural convection. The boundary conditions, at the outer surface of the combustible cartridge case and the center of the charge are, respectively:

$$-\lambda\frac{\partial T}{\partial n} = h(T_s - T_\infty) \tag{3}$$

$$\frac{\partial T}{\partial r} = 0 \tag{4}$$

In Eq. 3, n is the outer normal direction of the charge surface. h is the convection heat-transfer coefficient. T_s and T_4 are the surface temperature of the combustible cartridge case and the environment temperature in the turret. The environment temperature T_4 may be obtained by the special temperature sensors mounted on the ammunition rack in the turret.

Since the unsteady two-dimension axisymmetric heat exchange problem mentioned above is difficult to find an analytical solution, numerical methods are adopted and the discretization method is used here. We apply the control volume method to discretize the above heat exchange equations (Tao, 2001; Zhou and Wang, 1990). In order to establish the finite difference expression of the temperatures, integrate Eq. 1 at the interval [t, t+Δt] for any nodal point within the domain, then it can be discretized as:

$$\left[\lambda_{i-1,j} + \lambda_{i+1,j} + \lambda_{i,j-1}\frac{r_{i,j-1}}{r_{i,j}} + \lambda_{i,j+1}\frac{r_{i,j+1}}{r_{i,j}} + (\rho c)_{i,j}\frac{\Delta x^2}{\Delta t}\right]T_{i,j}$$
$$-\lambda_{i-1,j}T_{i-1,j} - \lambda_{i+1,j}T_{i+1,j} - \lambda_{i,j-1}\frac{r_{i,j-1}}{r_{i,j}}T_{i,j-1} - \lambda_{i,j+1}\frac{r_{i,j+1}}{r_{i,j}}T_{i,j+1} = (\rho c)_{i,j}\frac{\Delta x^2}{\Delta t}T^0_{i,j} \tag{5}$$

In this relation the superscript 0 designate the current time increment.

The difference Eq. 5 is formulated by computing the space derivations in terms of the temperatures at the future time increment. Such an arrangement is a backward-difference formulation because the time derivative moves backward from the times for heat conduction into the node. It can be seen that this backward-difference formulation does not permit the explicit calculation of the temperatures $T_{i,j}$ at the next time increment in terms of the temperatures $T^0_{i,j}$ at the current time increment. Rather, a whole set of equations must be written for the entire nodal system and solved simultaneously to determine the future temperatures $T_{i,j}$. Thus backward-difference methods produce an implicit formulation for the future temperatures in the transient analysis. Comparing with the explicit formulation, the implicit formulation can not directly solve the future nodal temperatures; however, no restriction of the stability requirement is imposed on the solution of the equations that are obtained from the implicit formulation. This means that larger time increments can be selected to speed the calculation. The obvious disadvantage of the implicit method is the larger number of calculations for each time step. For problems involving a larger number of nodes, however, the implicit method may result in less total computer time expended for the final solution because very small time increments may be imposed in the explicit method from stability requirements. Much larger increments in Δt can be employed with the implicit method to speed the solution.

Initial charge temperature sensor: The initial charge temperature sensor (ICTS) is developed according to the similarity principle. To ensure that the heat-transfer process of ICTS is the same as that of the actual charge, it is required that the model should have characters of geometric similarity and physical similarity with the prototype. From the similarity principle and dimensional analysis, it is known that the Fourier and Biot numbers of the model should be equal to those of the prototype, i.e:

$$Fo_m = Fo_p \tag{6}$$

$$Bi_m = Bi_p \tag{7}$$

where, the subscript m and p are designated as the model and prototype respectively. If γ_i = (i = γ, t, ρ, c, R, h) is introduced to represent the ratios of homonymous physical quantity between the model and prototype, the ratio coefficient groups should satisfy the following relations:

$$\frac{\gamma_\lambda\gamma_t}{\gamma_\rho\gamma_c\gamma_R^2} = 1 \tag{8}$$

$$\frac{\gamma_h\gamma_R}{\gamma_\lambda} = 1 \tag{9}$$

Since the model and prototype are in the same environment and the temperature change of the model is required in synchronism with that of the prototype, $\gamma_h = 1$ and $\gamma_t = 1$. From Eq. 8 and 9, we obtain:

$$\gamma_\rho\gamma_c\gamma_R = 1 \text{and } \gamma_\lambda = \gamma_R \tag{10}$$

According to the design requirements, the characteristic dimension of the model is 1/5 of the prototype, i.e., $\gamma_R = 1/5$. Thus, the result of Eq. 10 is:

$$\gamma_p \gamma_c = 5 \text{ and } \gamma_\lambda = 0.2 \quad (11)$$

Provided the selected or artificial materials of the model satisfy the Eq. 11, it can be ensured that the heat-transfer process of the model is the same as that of the prototype. Figure 2 is the actual photograph of the ICTS developed according to the similarity principle.

DEVELOPMENT OF NON-CONTACT ONLINE MODULAR CHARGE TEMPERATURE MEASUREMENT DEVICE

On the basis of the studies of propellant heat-transfer characteristics and unsteady heat transfer model describing the modular charge temperature change, a non-contact automatic online temperature measurement device is developed for the MACS configured into larger caliber weapon systems. It can accurately measure the temperature field and real-time average temperature of the modular charge for all charge zones placed in a combat vehicle. Figure 3 is the photograph of the non-contact automatic online modular charge temperature measurement device. When this device powers on and begins to work, one set of sensors is used to measure the current values of the modular charge temperature as the initial values of the charge temperature field and another set is used to measure successively the environment temperature in the turret as the boundary condition of the unsteady heat transfer equations on the charge temperature field. The temperature field and current average value of the modular charge are real-time calculated through the special calculation software installed on the device. The temperature information obtained from the measurement device may be transferred to the gunner task terminal computer through a CAN bus interface for trajectory calculation and firing data correction.

RESULTS COMPARISON AND DISCUSSION

The temperature field of modular charges is simulated numerically by the implicit difference schemes deduced above. Because the module is composed of several different materials and the thickness of some material is very thin, such as the combustible cartridge case and flash tube with only 2-3 m m, choose $\Delta x = 0.1$ m m as the space step. From the structure of Eq. 5, it can be seen that the coefficient matrix of the set of equations contains a large number of zero elements. In fact, the coefficient matrix is a pentadiagonal matrix. For this kind of sparse matrix, iterative methods of solution are more efficient than direct methods such as Cramer method. The Gauss-Seidel iteration method is used for solution of these equations in this study. $\Delta t = 1$ sec can be chosen as the time step because of no restriction of the stability requirement for the implicit difference schemes. The initial temperature of the calculation is 18°C and the

Fig. 2: Actual photograph of ICTS

Fig. 3: Photograph of non-contact automatic charge temperature measurement device

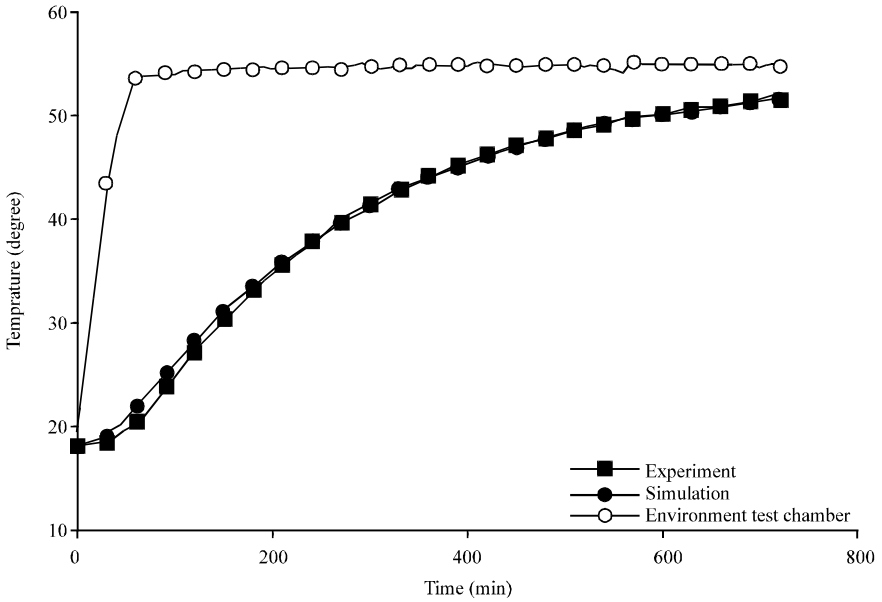

Fig. 4: Comparison between numerical simulation and experimental measurement

environmental temperature rises from 18-55°C, as same as the experimental condition, to compare with the experimental results. A comparison between simulation curves and experimental results is shown as Fig. 4. In the experimental configuration, test points are arranged along the axial and radial direction of the modular charge. Platinum resistance thermometers are mounted into the actual propellant grains located at the test spots. The history of propellant temperature change is measured and recorded by platinum resistance thermometers. From Fig. 4, it can be seen that calculation results are well matched with measured ones. This indicates that the used physical models and the developed application software are correct and might be applied to predict the real-time temperature of the modular charge. Therefore, only if the ammunition performance and change history of environment condition, including the thermal characteristic parameters of module materials, environment temperature and heat transfer conditions, are known, the distribution of the modular charge temperature field can be determined using the application software developed in this study. Furthermore, the first round hit ratio of larger caliber weapon systems can be improved due to an accurate knowledge of the charge temperature.

CONCLUSION

An automatic online temperature measurement device on the Modular Artillery Charge System (MACS) is designed and developed, based on Controller Area Network (CAN) bus technology. For measuring automatically the temperature of the modular charge, a non-contact measurement method is proposed. The primary idea of this method is to obtain the real-time value of the modular charge temperature through solving the unsteady heat transfer equations describing the variation in the modular charge temperature. Comparing calculated curves with experiment results indicates that the used physical model reflects the real-time change process of the charge temperature with the environment temperature. Thus, the developed device can accurately measure the temperature field and real-time average temperature of the modular charge for all charge zones placed in a combat vehicle and simultaneously transfer the temperature information to the gunner task terminal computer through a CAN bus interface for trajectory calculation and firing data correction, ensuring the weapon system meets the requirements of digitalization and informatization.

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