

DESCRIPTION

5 **Device and method for performing thermal compensation of a weapon barrel**

The invention relates to a gun barrel of a weapon, for example a revolver gun, for use in land-based or sea-based anti-aircraft systems. In particular, this
10 invention relates to a gun barrel which is mounted in a barrel cradle and a barrel support, wherein the barrel cradle is continued into a barrel support for the purposes of stabilization, guidance and damping of vibrations, said barrel support bearing or supporting
15 the barrel at a plurality of locations.

A gun generally comprises a lower mount, a turret and a barrel cradle with barrel support in which the barrel is mounted (EP 1 154 219 A). When solar radiation
20 occurs, the upper side of the barrel cradle is subjected to a relatively large increase in temperature, while the lower side, which is not subjected to the solar radiation, experiences only a relatively small increase in temperature. The resulting
25 thermal difference leads to different thermal expansion between the upper and the lower sides of the barrel cradle, with the result that a barrel with a certain length l is deflected downwards out of the original barrel axis by a certain angle δ at its free end. This
30 deflection depends to a great extent on the ambient influences and weather influences and in turn significantly affects the probability of the weapon hitting its target.

35 Such thermal differences can also occur laterally, for example if the weapon experiences solar radiation primarily from the side at sunrise or sundown or else due to wind which cools the side of the gun facing the

wind to a greater extent than the side facing away from the wind. During actual use, such effects will occur in combination.

5 Whenever the gun is fired, the barrel is stressed by the gases of the explosion and at the same time frictional heat is generated by the mechanical friction between the barrel and the projectile. This leads to an increase in temperature of the barrel. This is the
10 case, in particular, if the weapon is used in rapid fire. The heat is then concentrated at the breech end of the weapon and on the upper side of the barrel - to where the heat is transferred by convection. This firing-induced temperature gradient also leads to
15 deflection of the free end of the barrel out of the desired position.

Simple passive solutions according to the teaching of DE 30 05 117 employ a protective sheath which is fitted
20 directly onto the barrel, wherein the protective sheath according to the further teaching of DE 199 04 417 is not embodied in a radially symmetrical form in order to counteract asymmetrical heating.

25 DE 1918 422 discloses a thermal protection sheath composed of a metal sheath which surrounds the gun barrel at a small distance, wherein the quiescent layer of air between the gun barrel and the metal sheath functions as thermal insulation. These solutions are
30 static and cannot react to changing ambient conditions.

According to the teaching of WO 97/47 939 and US 4,753,154, double-walled gun sheaths conduct a working fluid along between the two sheath faces in
35 order to improve the conduction of heat out of the shot. These systems also operate in an unregulated and purely passive fashion.

Active heating elements, applied directly to the weapon barrel, are disclosed by DE 32 19 124 and GB 2,328,498. The heating strips parallel to the barrel axis over compensate external temperature effects by heating the barrel to a temperature which is approximately 10°C above the average ambient temperature. The deflection of the barrel from the normal position is determined, for example, by means of optical methods. This method is therefore very costly in terms of energy and at the same time very slow-acting, and the optical methods are susceptible to mechanical system stressing when the weapon is fired.

According to DE 44 33 627, the firing-induced rise in temperature is measured by a thermo-element which is introduced into the wall of the charge space by means of a blind bore. On the one hand, the mechanical stability is adversely affected by the bore and on the other hand a temperature gradient cannot be recorded over the length of the barrel.

Japanese abstract JP 7-91891 discloses active measurement of the sagging of the barrel by means of optical systems and at the same time discloses that the bending of the barrel is compensated by means of a hydraulic cylinder acting at both ends of the weapon barrel. This method is very costly. Furthermore, compensation can occur only in the plane which is formed by the barrel axis and the central axis of the hydraulic cylinder. For this reason, general compensation is not possible in the azimuth and elevation.

The object of the invention is to make available a device and a method by means of which simple and very cost-effective compensation of thermally induced bending of a barrel is possible even during the firing of the weapon.

The object is achieved by means of the features of patent claim 1 with respect to the device and by means of the features of patent claim 6 with respect to the method. Advantageous refinements are disclosed in the
5 dependent claims.

The weapon barrel is known to be inclined downward in the case of solar radiation. This deformation is caused by temperature differences between the upper and lower
10 side of the barrel support and the cradle. The effect of the barrel support and the effect of the cradle can basically be calculated as separate problems; however, they should be superimposed in order to determine the total inclination of the barrel.

15 The invention is therefore based on the idea of using temperature sensors and therefore a system to correlate temperature. The system is technically capable here of determining the temperature differences between the
20 upper and lower sides of the barrel support (of the sensors located opposite one another) as well as between the right-hand and left-hand sides of the barrel support (of the sensors located opposite one another). The calculation of the inclination of the
25 barrel is carried out by means of the temperature differences. The compensation of the inclination of the barrel is then carried out by means of the inclination value, wherein the compensation is carried out by changing the orientation of the barrel in the azimuth
30 and/or elevation. At the same time, monitoring of the temperature sensors and of the data box can be integrated.

35 The temperature compensation function is used as an additional parameter in the weapon control and, in particular, in the calculation of the azimuth and elevation of the weapon. Temperature-induced deflection of the barrel can therefore be compensated directly by the servo-motors of the weapon. The method according to

the invention is therefore very fast; it regulates with the customary speed of up to several 10° per second.

At the same time, the method can be used during firing
5 of the weapon. It is not necessary to adjust the weapon from a ready-to-fire state into a non-ready-to-fire maintenance state in order to perform the compensation of the barrel. This increases the period of use of the weapon.

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Only very few technical modifications have to be performed for the device according to the invention. Essentially, the installation of known temperature sensors and their connection to the data box is
15 sufficient on the hardware side. The device is therefore very cost-effective.

The compensation of the barrel does not induce any new bending torques or stresses in the barrel. This
20 increases the service life of the weapon.

The failure of individual sensors can be compensated by means of a mathematical model, since a continuous temperature distribution can be assumed in the barrel
25 cradle and barrel support (plausibility check). However, the evaluation algorithm contains various fallback levels for the event of a plurality of sensors failing. The system is therefore particularly stable with respect to the loss of individual sensor data
30 items.

In a development of the invention, the time profile of the temperature correlation function is recorded and is stored for later maintenance work in such a way that it
35 can be read out in the gun computer. As a result, the thermal loading of the gun can be logged subsequently or faults in the calculation algorithm can be discovered.

In accordance with the customary military temperature ranges, the sensors and the data box are configured for a functionally capable method of operation, usually from -46°C to $+120^{\circ}\text{C}$. In this temperature range, the measurements are carried out with sufficiently high resolution and accuracy. The resolution and accuracy are obtained from the mathematical model used; a resolution of 0.1°C and accuracy of 0.2°C have proven adequate in practice.

The present idea is therefore characterized by:

- a very simple measuring method with conventional temperature sensors; the system is cost-effective and stable
- redundancies in the sensors with a high degree of fail safety of the system with respect to the failure of individual measuring sensors
- very fast compensation of the barrel deformation by means of gun drives
- use during firing of the weapon possible, even in the case of rapid fire
- compensation of azimuth errors as well as of elevation errors owing to thermally induced barrel deformation
- no mechanical adverse effect on the barrel or bearing of the barrel due to measuring means.

The invention is to be explained in more detail with reference to an exemplary embodiment with a drawing, in which:

fig. 1 shows a gun turret according to the prior art,

fig. 2 shows the gun turret with the device according to the invention in the barrel cradle and the barrel support,

5 fig. 3 shows a simplified illustration of the arrangement of the sensors from fig. 2, and

fig. 4 shows a block diagram illustration of the method.

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Fig. 1 shows a conventional revolver gun 10 with a gun turret 1, a lower base 2, a barrel cradle 3 and a barrel support 4 as a prolongation of the barrel cradle 3. The barrel support 4 is composed essentially of a tube frame (not illustrated in more detail) and can, like the entire gun 10, be lined with a protective sheath (not illustrated in more detail).

According to fig. 2, such a gun 10 is provided with a plurality of temperature sensors p1-pn, preferably a number of 16, in the region of the barrel cradle 3 and the barrel support 4. By means of the 16 sensors (p1-p16), the temperature is measured at the barrel support 4 (twelve sensors) and at the cradle walls 3 (four sensors). Plug boxes 5 combine the signals of the temperature sensors p1-p16 from the barrel support 4 and cradle 3 and transmit them by data connections 6 to the data box 7, where the analog signals of the temperature sensors are digitized. The data box 7 subsequently transmits the data to the GCU 9 (DVS) via the Ethernet link 8. The GCU then compensates the deformation by means of an offset with respect to the horizon (adaptation of the inclination value). The data box 7 comprises an analog/digital converter and a server with Ethernet.

The arrangement of the sensors in the barrel cradle and barrel support as well as the connection of the components is described below. Starting from fig. 3,

four planes are defined substantially perpendicularly with respect to the barrel axis, wherein one plane E4 is preferably located in the barrel cradle, and three planes E1-E3 are preferably located in the barrel support. The planes bear in each case temperature sensors (for example PT 100) which are basically known from the prior art and which are preferably arranged in the region of the corners of the planes. The first plane E1 in the vicinity of the barrel mouth bears the four sensors p1-p4, the next plane in the direction of the barrel cradle E2 bears the sensors p5-p8 etc. The sensors are connected to the data box 7 via data lines 6. The data box 7 digitizes the analog signals of the temperature sensors and transmits the temperature data to the GCU 9 via a data link 8. By using this arrangement it is possible to measure the temperature distribution at the barrel cradle 3 and the barrel support 4.

The values of the temperature measuring sensors p1-p16 are digitized and transmitted to the data processing device (GCU 9). At the same time, said values are compared with the respective error values of the barrel 11. For the temperature-induced barrel deflection, a mathematical model is created which uses optimization parameters to form the relationship between the temperature values of the measuring sensors p1-p16 and the overall barrel deflection.

The sequence of the method according to the invention is illustrated in a summarized fashion in fig. 4. For a person skilled in the art, the general algorithm presented in said figure makes it clearly apparent, without further effort, how the compensation of the azimuth error or a mixed form of these two should be set up, with the result that it is possible to refrain from making an explicit statement here. The invention relates in the same way to the compensation of the azimuth error. The numerical weighting parameters a, b,

g are either input in advance into the system (GCU) or determined when the gun 10 is being measured and installed, and transferred into the mathematical model.

- 5 The temperature values are made into polynomials in order to obtain a view of the length for the mapping of the barrel error. The GCU 9 receives temperature values T with, in each case, an index for the respective sensor from the data box 7. As a result, average
10 temperature differences in elevation of each sensor plane E1 to E4 of the barrel support and of the cradle are determined. In parallel with this it is determined whether and how many of the sensors are functionally capable and are supplying plausible values.

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The temperature differences in the planes E1 to E4 are obtained from

$$T_{E1_Diff_El} = \frac{(T_{E1_top_right} + T_{E1_top_left})}{N_{E1_number_correct_upper_sensors}} - \frac{(T_{E1_bottom_right} + T_{E1_bottom_left})}{N_{E1_number_correct_bottom_sensors}} [^{\circ}C]$$

20

to

$$T_{E4_Diff_El} = \frac{(T_{E4_top_right} + T_{E4_top_left})}{N_{E4_number_correct_top_sensors}} - \frac{(T_{E4_bottom_right} + T_{E4_bottom_left})}{N_{E4_number_correct_bottom_sensors}} [^{\circ}C]$$

- 25 The barrel inclination V for each sensor plane is obtained by applying the following correlation, wherein the a and the b are numerical adaptation parameters. The following are obtained:

30 from

$$V_{E1_barrel_P_El} = a_{R_El} \cdot T_{E1_Diff_El} + b_{R_El} [rad]$$

to

$$V_{E3_barrel_P_El} = a_{R_El} \cdot T_{E3_Diff_El} + b_{R_El} [\text{rad}]$$

and

$$V_{E4_barrel_P_El} = a_{W_El} \cdot T_{E4_diff_El} + b_{W_El} [\text{rad}]$$

The determined overall barrel inclination is subsequently weighted for each sensor plane E1-E4. As a result, the plausibility monitoring is simplified in order to ensure the modularity for the calculation of the overall barrel inclination (if a sensor plane is missing). The following are obtained:

$$V_{barrel_R_P_El} = V_{E1_barrel_P_El} \cdot g_{1_El} + V_{E2_barrel_P_El} \cdot g_{2_El} + V_{E3_barrel_P_El} \cdot g_{3_El} [\text{rad}]$$

and

$$V_{barrel_W_P_El} = V_{E4_barrel_P_El} \cdot g_{4_El} [\text{rad}]$$

with the weighting parameters g which are to be adapted numerically.

In a further embodiment, the inherent inertia of the system is additionally taken into account. Said inertia occurs as a result of the fact that the measuring sensors p1-p16 can indicate changes in temperature significantly more quickly than this gradient can be compensated in the barrel 11 and barrel support 4 and barrel cradle 3. In order to take into account the measuring delay, what is referred to as a D component is added to the control process. Said D component is composed of the first numerical derivative of the previously mentioned P components of the barrel support 4 and of the cradle 3.

$$\frac{\Delta V_{barrel_R_P_El}}{\Delta t} = \frac{(V_{barrel_R_P_El}(t_n) - V_{barrel_R_P_El}(t_{n-1}))}{t_n - t_{n-1}} \quad [\text{rad/min}]$$

and

$$\frac{\Delta V_{barrel_W_P_El}}{\Delta t} = \frac{(V_{barrel_W_P_El}(t_n) - V_{barrel_W_P_El}(t_{n-1}))}{t_n - t_{n-1}} \quad [\text{rad/min}]$$

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This is multiplied by the D parameters

$$V_{barrel_R_D_El} = \frac{\Delta V_{barrel_R_P_El}}{\Delta t} \cdot D_{R_El} \quad [\text{rad}]$$

10

and

$$V_{barrel_W_D_El} = \frac{\Delta V_{barrel_W_P_El}}{\Delta t} \cdot D_{W_El} \quad [\text{rad}]$$

15 wherein the D parameters are in turn numerical fit parameters. The overall barrel inclination is determined from the sum of the P components and D components of the barrel support and of the cradle.

$$V_{barrel_El} = V_{barrel_R_P_El} + V_{barrel_W_P_El} + V_{barrel_R_D_El} + V_{barrel_W_D_El} \quad [\text{rad}]$$

PATENT CLAIMS

1. A device for performing thermal compensation of a weapon barrel (11) of a gun (10) having at least one weapon barrel (11) which is mounted in a barrel cradle (3), and in a barrel support (4) as a prolongation of the barrel cradle (3), **characterized** in that a plurality of temperature sensors (p1-p16) are integrated into the barrel cradle (3) and the barrel support (4) and are connected via data lines (6) to a data box (7), and the data box (7) is connected to a data processing device (9), wherein the data processing device (9) calculates a barrel inclination by means of temperature differences, and in order to perform thermal compensation the data processing device (9) can act on actuators in order to change the orientation of the weapon barrel (11).
2. The device as claimed in claim 1, **characterized** in that preferably 16 temperature sensors (p1-p16) are integrated, wherein variations in the number are possible.
3. The device as claimed in claim 1 or 2, **characterized** in that preferably four planes (E1-E4) are defined substantially perpendicularly with respect to the barrel axis, wherein one plane (E4) is preferably located in the barrel cradle (3), and three planes (E1-E3) are preferably located in the barrel support (4).
4. The device as claimed in claim 3, **characterized** in that the temperature sensors (p1-p16) are preferably arranged in the region of the corners of the planes (E1-E4).

5. The device as claimed in one of claims 1 to 4, **characterized** in that the barrel support (4) is frame-like.
- 5 6. The device as claimed in one of claims 1 to 5, **characterized** in that the actuators are servo-motors of the gun itself, with which servo-motors the weapon barrel (1) can be oriented in its azimuth and/or elevation.
- 10 7. A method for performing thermal compensation of a weapon barrel (11) of a gun (10) having at least one weapon barrel (11) which is mounted in a barrel cradle (3), and in a barrel support (4) as a prolongation of the barrel cradle (3), having the steps:
- 15 • measuring the temperature by means of temperature sensors (p1-p16) on the barrel cradle (3) and the barrel support (4),
- 20 • determining the temperature difference between the upper and lower sides and between the right-hand and left-hand sides of the barrel cradle (3) as well as the barrel support (4),
- 25 • calculating the barrel inclination by means of the determined temperature differences, and
- compensating the barrel inclination by changing the orientation of the weapon barrel (11).
- 30 8. The method as claimed in claim 7, **characterized** in that temperature differences of each sensor plane (E1 to E4) of the barrel support (4) and of the barrel cradle (3) are determined in elevation and/or azimuth.
- 35 9. The method as claimed in claim 7 or 8, **characterized** in that the temperature-induced barrel deflection is compensated directly by actuators, such as servo-motors of the actual gun of the weapon.

10. The method as claimed in one of claims 7 to 9,
characterized in that failure of individual
temperature sensors (p1-p16) is compensated by
5 means of a mathematical model.
11. The method as claimed in claim 10, **characterized**
in that the evaluation algorithm contains various
fallback levels for the event of a plurality of
10 temperature sensors (p1-p16) failing.
12. The method as claimed in one of claims 7 to 11,
characterized in that the inherent inertia of the
system is also taken into account.
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13. The method as claimed in one of claims 7 to 12,
characterized in that time profiles of the
temperature correlation function are recorded.
- 20 14. The method as claimed in claim 13, **characterized**
in that the time profile/profiles is/are also
stored for later maintenance work in such a way
that they can be read out in the gun computer.