

DESCRIPTION

**Method for measurement of the muzzle velocity of a
projectile or the like**

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Known measurement devices and methods use at least one coil pair, which is generally fitted after a muzzle brake of a weapon. The coils are in this case positioned at a defined distance from one another, with
10 the velocity V_0 being determined by the measured time which the projectile requires in order to travel over the distance defined by the coils.

One such device is known from CH 691 143 A5. In order
15 to measure the projectile velocity, two sensors are arranged on a mounting tube at a distance from one another adjacent to the muzzle of a weapon barrel of a high firing-rate gun. These sensors, which respond to a change in a magnetic flux, are connected to evaluation
20 electronics and have a coil pair comprising two coils and a closed magnetic circuit. The measured projectile velocity, or the fuze actuation time updated in this way, is then generally passed to the projectile as information before it emerges from the muzzle area.

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DE 697 09 291 T2 (EP 0 840 087 B1) discloses means for controlling the initial velocity of a projectile. In this case, a sensor means is provided which can measure a parameter related to the muzzle velocity. This is
30 done with the aid of the sensors which are fitted at least in or adjacent to the weapon barrel and can record a higher pressure in the weapon barrel, which occurs as a result of the propellant gases being heated adjacent to the weapon barrel. Strain gauges are
35 proposed as sensors, and are adapted such that they make contact with the weapon barrel. In this case, the strain on the weapon barrel is measured. The movement

and thus the velocity of the projectile are determined from the time difference between registration of the projectile passage through the two individual sensors.

5 DE 103 52 047 A1 proposes that at least two sensors, which are at a distance from one another, be integrated adjacent to or directly in the weapon barrel. As the projectile passes them, the sensors are subject to a strain as a result of the gas pressure adjacent to the
10 projectile base, which strain is converted to an electrical signal and is supplied, if necessary after amplification, to downstream signal processing. Quartz sensors in the form of longitudinal measurement dowels are preferably used as sensors, and are fitted either
15 in a mounting ring adjacent to or around the weapon barrel, or directly in the weapon barrel. The quartz sensors have the major advantage that they can convert even very small pressure changes into signals, are themselves physically highly robust and can be
20 integrated with an accurate fit, that is to say with a firm contact such that they cannot slide with respect to the weapon barrel. Mechanical loads on the weapon barrel therefore have no effects on the measurement result of the indirect pressure measurement.
25 Furthermore, the sensors are not directly subjected to the gas pressure and are installed in a fixed structure, in addition to the existing housing.

In contrast, DE 10 2005 024 179 A1 dispenses entirely
30 with direct measurement of the instantaneous muzzle velocity, since the actual muzzle velocity is determined by information relating to the instantaneous airspeed of the projectile, that is to say it is calculated back from this. The firing time for the
35 projectile is then corrected with the aid of a standard muzzle velocity preset firing time, on the basis of this instantaneous muzzle velocity, and is used as the current fuze actuation time. A microwave transmitter,

preferably in the GHz range, is used to transmit this information to the projectile, and transmits the instantaneous fuze setting, as determined for example by a fire control computer, to the munition or to a projectile.

A further method is to operate the barrel as a round waveguide and to measure the Doppler velocity of the projectile in the barrel, as disclosed in EP 0 023 365 A2. In this case, the frequency of the signal is above the cut-off frequency for the relevant waveguide mode. The electromagnetic wave which builds up in this case propagates in the barrel, and is reflected by the projectile. Furthermore, this results in a Doppler frequency shift which is dependent on the instantaneous velocity.

This has the disadvantage that two sensors must be located at a defined distance from one another. This design lengthens the measurement device adjacent to the muzzle of the weapon barrel. This can lead to instability of the entire weapon, or can cause problems when using sub-calibre ammunition. The discarding sabot which is released on emerging from the weapon barrel can damage the measurement device. Furthermore, the sensors must be mounted directly in the weapon barrel, or on it. In many cases, the weapon barrel supplier and the muzzle velocity measurement device supplier are not the same. This means that the sensors can be fitted adjacent to or in the barrel only subject to relatively difficult conditions, if at all. A muzzle velocity measurement device should operate independently of the weapon barrel that is used, without any intervention in the weapon barrel itself. A further disadvantage is that the measurements of the airspeed and the programming of the firing time outside the weapon barrel by means of a microwave transmitter requires a certain amount of interference immunity for the

information transmission between the transmitter and the projectile. Natural interference, as well as deliberate interference caused by jammers, can impede the measurement of the airspeed and the programming subsequent to this, or make it completely impossible. 5 Furthermore, the transmitter emission can be detected by external "electronic war factors" methods, with the gun location being found. The enemy therefore knows the location of the gun and can initiate countermeasures to 10 attack the gun. The keyword nowadays is "see but do not be seen". If the gun's location is given away by emissions, this gun is at major risk from efficient weapon systems. Furthermore, the measurement of the Doppler frequency shift is subject to specific 15 requirements for the oscillator stability. Vibration resulting from the firing of a shot can change the instantaneous transmitter frequency, and increase the complexity for accurate measurement of the frequency shift. Furthermore, the weapon barrel acts as an open 20 round waveguide, and can act as an antenna. This means that an external monitoring device can detect the emissions, and can determine the location of the gun.

The invention is based on the object of specifying a 25 means of measuring the muzzle velocity, which likewise does not involve any contact, but no longer has the last-mentioned defects.

The object is achieved by the feature of Patent 30 Claim 1. Advantageous embodiments are specified in the dependent claims.

The invention is based on the idea of likewise using the weapon barrel or the firing barrel, and/or parts of 35 the muzzle brake as a waveguide (a waveguide is achieved with a barrel having characteristic cross-sectional shape which has a very highly electrically conductive wall). Rectangular and round waveguides, in

particular, are in widespread use, but are operated below the cut-off frequency of the relevant waveguide mode. (For the principles relating to this, see <http://people.ee.ethz.ch/~kkrohne/AMIV/Wellenleiter.pdf> pages 24 to 33 or else <http://prp0.prp.physik.tu-darmstadt.de/~ejakobi/Mikrowel.pdf>, which are hereby referred to). No electromagnetic wave can propagate in the waveguide operated in this way, and there is therefore no energy transport along the waveguide. The electromagnetic field decreases exponentially in the direction of the waveguide, with this being a solution of the Maxwell equations, rather than being based on resistive attenuation.

In this case, the electromagnetic field must satisfy the constraint for a round waveguide, and the constraint for the projectile. In this case, it should be noted that the round waveguide need not necessarily have an exactly circular cross section. In fact, a profile can also be incorporated in the wall of the waveguide in order to achieve the desired transverse electromagnetic field distribution. This is shown in Figure 3, which illustrates how a rib structure in the muzzle brake ensures mode selection. When all of the constraints are satisfied, this results in a signal strength at the location $z = 0$ (when $Z_K = 0$) which is now governed by the position $z = z_P$ of the projectile in the waveguide. The offset Z_K between the transmission coupler (3.1) and the reception coupler (3.2) can be used for better mode selections, if necessary. However, in general Z_K should be equal to 0, and this applies only to that reception coupler which is closest to the transmission coupler (3.1). The situation illustrated in Figure 3 shows an arrangement comprising a transmission coupler (3.1) and a reception coupler (3.2). However, it is also possible to fit a plurality of reception couplers (4.2) in series, as shown in Figure 4, very close to one another and thus

in a compact form in the direction of the barrel end,
and in front of the transmission coupler (4.1), in
order to increase the measurement accuracy. The muzzle
brake is in this case not artificially lengthened, thus
5 avoiding the disadvantage of a long muzzle velocity
measurement device.

The measurement apparatus is formed by the gun barrel
or by some other firing apparatus in the form of a
10 barrel, the projectile, the muzzle area of the barrel,
for example a muzzle brake, and at least one
oscillator, a transmission coupler and, as a minimum, a
reception coupler or a plurality of reception couplers,
with the number being dependent on the desired
15 measurement accuracy of the measurement apparatus.

This simple measurement apparatus has the advantage
that the muzzle area and the muzzle brake need not be
artificially lengthened. The measurement apparatus is
20 integrated directly in the muzzle brake. Furthermore,
it can be used independently of the type of ammunition
(full-calibre or sub-calibre). The measurement
apparatus is compact, since the barrel and the muzzle
area, in particular the muzzle brake which is generally
25 used adjacent to the gun barrel, are part of the
measurement equipment. The accuracy of the measurement
itself is independent of the oscillator frequency, so
that the oscillator that is used need not be highly
frequency-stable, as in the case of the known Doppler
30 frequency measurements. All that is necessary is that a
lower frequency and an upper frequency should,
respectively, not be undershot or overshot. The simple
measurement is also a result of the fact that the
envelope is detected, rather than the frequency. The
35 measurement apparatus can be operated in the single
mode.

The invention will be explained in more detail using

one exemplary embodiment and with reference to the drawing, in which:

5 Figure 1 shows the principle of a measurement apparatus for measurement of the muzzle velocity of a projectile;

10 Figure 2 shows a schematic illustration of the limited, round waveguide as shown in Figure 1;

15 Figure 3 shows an illustration of the measurement section, integrated in the muzzle brake, and equipped with a rib structure for mode selection; and

 Figure 4 shows an illustration from Figure 3, with a plurality of couplers.

20 Figures 1 and 2 show the basic design of a measurement apparatus 100 for the measurement method. The measurement apparatus 100 comprises a gun barrel 1, in this case with a muzzle brake 3, and an oscillator 4 which is electrically connected via a signal supply 5
25 to a transmission coupler 6, in order to excite it. A reception coupler 7 is used for signal reception and is connected via a cable 8 for the received signal to a receiving unit 9, comprising a detector 9.1 and signal processing 9.2. The two couplers 6, 7 are integrated in
30 the muzzle brake 3, and form a coupler pair.

 The oscillator 4 in this case excites a waveguide mode (TE; TM) via the transmission coupler 6. In this exemplary embodiment, a frequency is chosen which is
35 below the cut-off frequency of the relevant waveguide mode. The desired waveguide mode is excited by mechanical and electromagnetic mode selection. The system comprising the barrel 1 (Figure 2 waveguide 1')

and the projectile 2 (Figure 2 cylinder 2') results in the signal strength at the location $z = 0$ which is dependent on the position $z = z_p$ of the projectile 2. The reception coupler 7, in this case a pick-up sensor,
5 receives this signal, which is passed to the receiving unit 9.

As already stated, the measurement apparatus 100 is operated in a selected waveguide mode below the cut-off
10 frequency of this waveguide mode in the waveguide or in a piece of waveguide which is integrated in the muzzle brake. Not only the fundamental mode, but also higher waveguide modes are possible. A distinction is drawn between transverse electrical (TE) and transverse
15 magnetic (TM) modes. Both modes can also be used in this case.

The fundamental principle of the measurement method will be analysed in somewhat more detail with reference
20 to Figure 2. If the round waveguide 1' is bounded by the cylindrical pin 2', then the electromagnetic field must on the one hand satisfy the constraints adjacent to the waveguide walls, and on the other hand must satisfy the constraints adjacent to the cylinder base.
25 Ideally, the walls and the cylinder base should be conductive. This means that the tangential component of the electrical field strength adjacent to these surfaces is " $E = 0 \text{ V/m}$ " (zero), and that the normal component of the magnetic induction adjacent to these
30 surfaces is " $B = 0 \text{ T}$ " (zero). This can be achieved by the introduction of two field components: the original electromagnetic field, which satisfies only the constraints adjacent to the walls, and an additional component, which has the same transverse distribution
35 as the original field and therefore also satisfies the constraints adjacent to the walls. The original field component is excited at the location $z = 0$. The frequency is below the cut-off frequency for the

selected waveguide mode. In order to satisfy the constraints adjacent to the cylinder base $z = z_p$ a second field component is generated, with cancellation by superimposition of the tangential component of the electrical field strength and the normal component of the magnetic induction of the original field. The superimposition of the two components results at the location $z = 0$ in a signal strength which is dependent on the position of the cylinder base at the location $z = z_p$.

If the time profile of the signal strength at the location $z = 0$ is now analysed, then it is possible to deduce the muzzle velocity V_0 .

As can be seen from Figure 3, the desired waveguide mode can be excited by mechanical design measures, in this case by way of example by a rib structure adjacent to the waveguide wall. Furthermore, the mode selection is assisted by the type of excitation by the transmission coupler 10.1. Figure 3 shows the waveguide as part of the muzzle brake. The offset Z_K between the transmission coupler 10.1 and the reception coupler 10.2 can be used for better mode selection, if necessary. However, in general Z_K should be equal to zero, and this applies only to the reception coupler which is closest to the transmission coupler 10.1.

Figure 4 shows how the measurement accuracy is improved by a plurality of reception couplers 11.2. It should be noted that the reception coupler 11.2 which is furthest away from the barrel end is at the same distance from the barrel end as the transmission coupler 11.1. This means that no reception couplers 11.2 can be positioned after the transmission coupler 11.1.

The defects of the methods mentioned above according to the prior art are overcome by the following

characteristics of the measurement device proposed here:

- 5 • the couplers (transmission couplers and reception couplers) can be positioned very close to one another and can thus be integrated in the muzzle brake (3). There is no need to lengthen the muzzle brake. Furthermore, the couplers can also be installed in the barrel, if this is possible.
- 10 • The measurement device is integrated in the muzzle brake (Figure 3) only when it cannot be integrated in the weapon barrel. The measurement device is therefore independent of the barrel, and therefore
- 15 also of the barrel supplier.
- The measurement takes place within the muzzle brake or barrel, thus achieving better resistance to interference.
- 20 • The waveguide is operated below the cut-off frequency, and the length of the waveguide also minimizes the external emissions.
- 25 • The oscillator is not subject to any stringent stability requirements, since there is no need to measure a Doppler frequency.

PATENT CLAIMS

1. Method for measurement of the muzzle velocity of a projectile (2) or the like adjacent to a weapon or firing barrel (1) or adjacent to the muzzle brake (3), with the barrel (1) or the muzzle brake (3) being used as a waveguide, characterized in that the waveguide is operated below the cut-off frequency of the relevant waveguide mode (TE; TM).
2. Method according to Claim 1, characterized in that the instantaneous projectile velocity $V(t)$ can be measured and stored continuously.
3. Method according to Claim 1 or 2, characterized in that the projectile velocity profile in the waveguide is determined over the time (t).
4. Method according to one of Claims 1 to 3, characterized in that a prediction of the velocity (V_0) can be made while the projectile (2) is moving in the waveguide and before the projectile (2) leaves the waveguide.
5. Method according to one of Claims 1 to 4, characterized in that the evaluation time is chosen to be that time at which the projectile is precisely at that point of the reception coupler where the signal to be measured tends to zero or has some other characteristic response, such that the velocity (V_0) can then be measured.
6. Measurement apparatus (100) for carrying out the method according to one of Claims 1 to 5, having
 - a weapon or firing barrel (1),
 - a muzzle brake or the like (3),
 - a signal generator (4), which
 - is electrically connected via a signal supply

- (5) to at least one transmission coupler (6, 10.1, 11.1) for excitation of the weapon or firing barrel (1), and
- 5 - a receiving line (8) for passing on the measured signals at at least one reception coupler (7, 10.2, 11.2) to an evaluation device (9).
- 10 7. Measurement apparatus according to Claim 6, characterized in that the signal generator (4) generates a carrier in the continuous-wave mode (CW mode).
- 15 8. Measurement apparatus according to Claim 6, characterized in that the signal generator (4) generates a modulated signal.
- 20 9. Measurement apparatus according to one of Claims 6 to 8, characterized in that the signal generator (4) is an oscillator.