ACCURATE VELOCITY MEASUREMENT

AIM

The aim of this application note is to guide the user through the steps required to achieve high precision velocity measurement using the Projectile Velocity Measuring System (PVMS) type 858 system. The principles of measurement are essentially straightforward: detect the crossing times of the projectile on each vertical optical screen and then calculate the velocity from the known separation divided by the time difference.

From this short description it is already apparent that in order to achieve high precision we need to measure the crossing times to great accuracy; we need to know the separation between the sky screen cradles accurately and we need to ensure that the optical screens are indeed vertical. In addition, it is assumed that the projectile flight path is horizontal and it is essential to ensure that there is little elevation present.

The electronic detectors measure the crossing times to the very high precision of 0.1 microseconds, so the accuracy of the system is then governed by the accuracy with which we can perform the set-up. In the next two sections, we discuss how best to set up the system so that it meets its specification of 0.1% accuracy in the measurement of velocity. There are two phases to the set-up: first choose an sky screen separation appropriate to the projectile velocity and the firing height above the optics in the cradles. Both of these factors affect the final accuracy achievable. Choosing the separation is simply a question of looking up its value in a table or getting it from one of the menus in the software. Once the choice has been made we then have to actually position and align the cradles; we will discuss these first and then return to the question of selecting the separation - usually two metres or more.

POSITIONING THE CRADLES

The sky screen cradles should be placed under the projectile flight path at the required separation, and oriented so that the cradles are parallel to each other. The following diagrams illustrate the aimed for set up and show what is to be avoided.

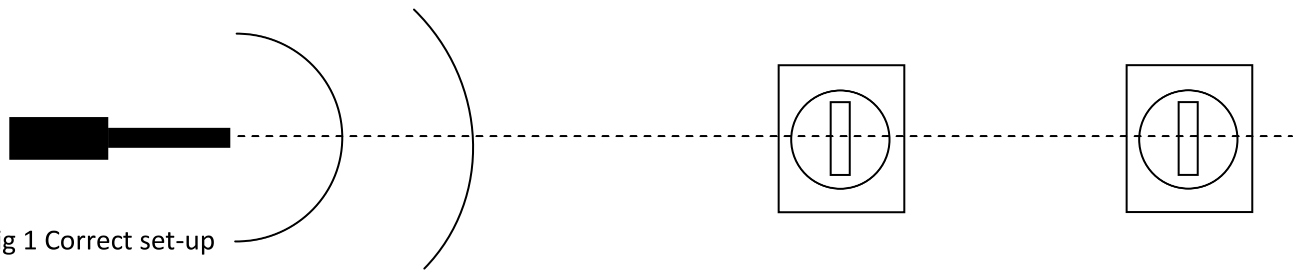

Fig 1 Correct set-up

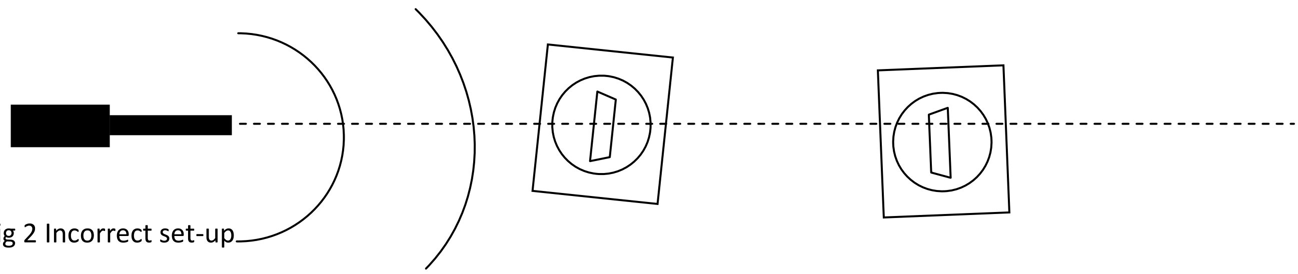

Fig 2 Incorrect set-up

Fig. 1 shows the correctly set up system: the cradles are parallel to each other and lie directly under the projectile flight path.

Fig. 2 shows an incorrectly set up system with the major types of error:

The cradles are twisted relative to each other

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ISO 9001 SCS cert. No. 980010
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The angle of twist will affect the crossing times of the projectile through each optical screen. It is possible to see this relative twist for quite a large range of cradle spacing from 1m to 10m. Move to a position where you can line up the two lens hoods by eye. Now look carefully at the flanges on the sides of the cradles. Any asymmetry here indicates that the cradles are misaligned. One or both may need to be rotated into the proper position.

The cradles are not aligned along the flight path

The angular deviation between the flight path and the line joining the cradles will adversely affect the crossing times. The flight path will need to be identified via some aiming mark. It is then necessary to ensure that the muzzle, the cradles, and the aiming mark all line up visually.

The first screen is too close to the muzzle
The muzzle blast can create microphonics noise in the equipment if the screen is too close to the muzzle. Also, the muzzle ejects debris, which is initially ahead of the projectile, and this can lead to false triggers in the system. As a rule of thumb, the distance from the first screen to the muzzle should be at least 3 metres for 556 and 5m for 12mm ammunition.

In the light of the above discussion, the main steps in positioning the cradles should be carried out in the following order:

A. Establish a visual aiming mark so that you can identify the flight path from muzzle to aiming mark.
B. Place the first screen at the correct distance from the muzzle along the flight path.
C. Place the second screen approximately at the recommended distance from the first screen.
D. Using the aiming mark, adjust the cradles to lie on the flight path. In some systems, you can use the supplied aiming telescope to aid this procedure.
E. By sighting along the cradles check that they are parallel.
F. Now approximately level each cradle using the attached spirit levels.

Any movement in the cradles may affect the positioning carried out in the previous step. It is better to cycle through D, E, and F rather than trying to perfect each on its own. You are now ready to set the separation between the cradles.

SETTING THE CRADLE SEPARATION

In some systems, you will be supplied with a 2m steel setting bar containing two holes. Slip the bar holes over the pegs on the side of the cradles. With two bars, you can also ensure that the cradles are parallel to each other when both bars are located in their pegs but without strain on any peg.

If you do not have setting bars, you will need to measure the distance between pegs from cradle to cradle and on *both* sides of the cradles. The difference in distances obtained should be less than a half millimetre – anything more than this indicates a relative twist in the cradles. You will need to record this information for input into the computer system.

If any position adjustments have been made you will need to ensure that you have not now moved either cradle off the flight path.

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VERTICAL ALIGNMENT OF THE CRADLES

All PVMS systems are supplied with a pair of crossed spirit levels either attached to the cradle or to the lens mount. Three adjustable feet are attached to the base of the cradle. Choose the left foot as the pivot and tighten its locknut softly. Now adjust the right-hand foot until the spirit level parallel to the line joining the left and right feet shows level. Once level has been achieved, adjust the back foot until the other spirit shows level. Repeat the cycle until both bubbles show level accurately centred between the marks. Once both levels are set, tighten the locknuts on each leg firmly, and re-check the level accuracy.

If there has been significant movement during this process it may be necessary to reset or re-measure the separation between the cradles. If so, the vertical alignment process will need to be repeated.

CHOOSING THE DETECTOR SEPARATION

The required detector separation depends on the projectile velocity and the height of firing above the detectors. The following is an approximation that can be used to find the find the minimum detector separation needed to achieve the precision in measurement of velocity:

$$S = \left(2V\delta t + 2H\delta\psi + \delta S\right)/v$$

In this expression:

δt Error in the measurement of the crossing time (nominally 0.1×10^{-6} second)
$\delta\psi$ Error in the vertical alignment (nominally 1 minute of arc = 0.000291 radians)
δS Error in the separation (nominally 1mm = 0.001 m)

v Relative error in the measurement of velocity (0.1% = 0.001)

V Nominal projectile velocity (m/s)
H Height of flight path above lens hood (m)

S Spacing (m) required to achieve the specified relative error v

Using the above nominal values, the formula specialises to

$$S = 0.582H + 0.0002V + 0.5$$

For a velocity of 1000 m/s and a projectile height of 2m, the required distance is

$$S = 1.164 + 0.2 + 0.5 = 1.864 \text{ (m)}$$

This means that a separation of 2 m will ensure that the 0.1% accuracy specification is indeed achievable.

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MEASUREMENT OF DELTA V

By setting up three detectors P_1, P_2, P_3 along the flight path, we can measure the velocities V_{12}, V_{23} across successive detector pairs, and then the retardation in the projectile can be measured. The retardation can be represented in terms of the rate of change of velocity with distance i.e. $R = \frac{dV}{dS}$, and this quantity can be measured by the ratio $R = \frac{V_{12} - V_{23}}{S_{mid}}$. Here S_{mid} is the distance between the *mid points* of each detector pair.

The absolute error in R is given by the formula:

$$\delta R \le \left(2\delta V + R\delta S_{mid}\right)/S_{mid}$$

Since the retardation R is usually small, the relative error $\delta R/R$ in retardation is likely to be huge, and it makes more sense to work directly with the absolute error in retardation as expressed above.

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