CALIBRATION, PRECISION AND SYSTEMATIC ERRORS OF CERN-LSG's

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SUMMARY

Precision, detection of systematic errors largely depend on the calibration of the LSD. Since the beginning of its operation a special effort has been put at CERN on this crucial point\(^1\). The overall procedure for calibration remains basically the same but many features have been changed and some modifications have improved the stability and ensured an excellent control.

The treatment of the pulse on hit of a calibration cross, which almost completely directs the quality of the results, is not easy near the centre where these pulses are different from measurement pulses. Different solutions have been adopted to eliminate this difficulty.

It seems very useful to systematically check the calibration by applying the outcoming parameters to the digitizings from artificial lines. In addition, some precaution has to be taken in the calibration program. One describes these points and presents results on beam-track measurements. A more detailed analysis of the LSD performance on bubble chamber film is discussed in the report "Some considerations of space reconstruction precision" of this conference.

1. CALIBRATION CONDITIONS

The LSD has two different co-ordinate systems, one is cartesian, the other is polar. Thus the measurement information is mixed and to handle it, one must know the relation between the two systems.

1.1 Calibration procedure

Calibration is performed to give:

- the relation between the (R,θ) and (XY) co-ordinate systems;
- the inaccuracy inherent to each system.

It consists of:

- the measurement of a pattern of 177, 20° angle crosses 7 mm spaced and pointing towards the centre\(^*\).
- the fit of the classical relation between polar and cartesian systems depending on the characteristic parameters of the LSD.

\(^*\) The X-Y position of the crosses on the glass plate has been measured with a very high accuracy (1μ). The transformation to the X-Y LSD system is performed by measuring five crosses during calibration. The RMS residual of this fit is about 3μ and represents essentially the operator setting error.
It provides:
- The parameters \((R_c, R_o, \theta_0, \Theta_o, \Theta_o)\) for processing the data in the filter program;
- Fit residuals interpreted as giving the inaccuracy of the two systems (local non-linear distortion) and used to correct each digitizing by a linear interpolation.

1.2 **Treatment of calibration pulses**

The theoretical width of a pulse at its base is given by:

\[
W(\alpha) = \frac{1}{2} \tan \alpha + d + a \cos \alpha
\]

\(a\) track width, \(d\) slit length
\(\alpha\) slit-track angle, \(d\) slit width

The theoretical ratio of pulse heights at zero angle and \(\alpha\) angle is: \((\alpha/\alpha)\sin \alpha\). So, for a slit 1000 x 50\(\mu\)m, the calibration pulse is about four times broader and four times smaller than a radial track pulse. As a consequence the noise is twice more important (fig. 1).

On LSDI, the width of a pulse is taken at one digital step from the top. If the noise amplitude reaches one digital step, the width transmitted may be wrong. On fig.1 one sees how difficult it is to determine the right width of a calibration pulse near the centre, where the pulse is broad. As a result, one experimentally finds an artificial pulse displacement in the centre region. The calibration fit (rotation, translation and magnification) cannot take this effect into account. It then appears as extra-components added to the normal XY fit residuals and the application of the calibration parameters to the digitizing of an artificial straight line, leads to a distortion in the opposite direction.

Currently, the machine is tuned in order to correctly digitize a real track; calibration is performed in the same hardware conditions.

To correct the noise negative effects we preferred to study its origin. Two types of solutions have been chosen for each LSD.

**LSDI:**

We simply took a smaller and broader slit 600 x 80\(\mu\)m, whose effect is to give a quasi-triangular calibration pulse. The top of this pulse is then rather well defined even in the presence of noise.

**LSD2:**

We kept a slit 1000 x 40\(\mu\)m, more efficient for filtering and ionization measurements. An integrator is added behind the AGC. It gives a pulse whose height is proportional to the original pulse area and hence independent of the slit-track angle. The width is given at the base of the pulse.
1.3 Processing of the spirals in the calibration program

The calibration program SCALP\textsuperscript{2)} is basically the same for all the SPIRAL READER users. We have only changed the procedure of treatment of the consecutive spirals in order to make sure that the starting values of the parameters in the linearized fit are good. This becomes necessary if one considers that the $R_0$ parameter, very influent in the central region, is the only parameter which could normally change when the periscope reference head is replaced. To illustrate the importance of the starting value of $R_0$, (fig.2b) shows a reconstructed straight line obtained by using a calibration for which the operator positioning was, on purpose, bad and the input $R_0$, 150 R counts far from the correct value. One sees a clear central distortion of the order of 8$\mu$. The fig.2a shows the same line, from the same calibration but with the correct $R_0$ value. The origin of the distortion comes from the fact that the translation $R-R_0$ made in the program displaces the central digitizing, non radially, if the centre of the spiral does not coincide with the centre of the calibration pattern. As a consequence the central crosses are artificially displaced and distortion appears in this region.

To prevent such an effect, we use the first spiral to fit good input parameters. These parameters are then applied to the three spirals which are averaged. Fig.2c shows the straight line corresponding of the bad positioning and the wrong $R_0$ value. The iteration procedure has eliminated the effect described.

1.4 Calibration results

The quality and stability of the calibration results are nearly the same for both LSD's. Table 1 gives the main figures. One sees that:

- The RMS scatter of all the useful digitizings on the crosses is 2$\mu$;
- The resulting statistical precision on the cross center is less than 1$\mu$ (0.7$\mu$ in the radial direction, 0.25$\mu$ in the tangential direction);

In spite of this very good precision, it remains systematic effects. Fit residuals are as large as 30-40$\mu$. Their RMS values are of the order of 10$\mu$ ($R$ direction) and $5\mu$ ($\Theta$ direction). One takes these effects into account by correcting each digitizing using a linear interpolation between residuals. It is worthwile to note that we did not try to find a mapping function from $R-\Theta$ to X-Y system for practical reasons. An analytical function takes some time to be correctly adjusted and its validity period is short (few months) due to the necessary changes on the hardware (mirror on the cone, for instance). Besides this, the standard analysis of the map of residuals is very useful to detect hardware effects such as bad centering of the $\Theta$-encoder, slit excentricity, local optical distortions, etc.

For three successive spirals, the RMS error on regularly spaced co-ordinates are of the order of $3\mu$ and $2\mu$ in the $R$ and $R-\Theta$ directions respectively. The statistical error on the cross centre being so small, these values correspond almost entirely to the operator setting error. One randomizes these errors by frequent calibrations over one experiment.
1.5 **Calibration in time**

It is rather difficult to compare different calibrations at long time intervals, because of the normal changing conditions of the hardware such as the periscope reference head, already mentioned. We presently calibrate every two days. The resulting parameters are used for the corresponding production.

For a period of fifteen days the RMS error for one spiral is 6.6μ and 2.5μ in the R and Rs directions respectively. Subtracting the time independent error established above (3μ, 2μ) one sees that the precision for such a period is 5.8μ and 1.5μ (R, Rs). The major error is radial which is not very consequent, so one could conclude that the reproducibility is very good.

Over longer periods the variation of the parameters Ro, Rc, θo, xo, Yo is checked and any abnormal evolution is immediately reported to the engineers.

2. **CALIBRATION AND PRECISION CHECKS ON ARTIFICIAL PATTERNS**

The example given above shows the importance of verifying the quality of a calibration, on artificial straight line. This allows to detect any hardware trouble and check of the information coming from broad calibration pulses.

2.1 **Measurement of a square grid**

A square grid made of 30μ lines spaced by 5 mm is measured. One fits a straight line through the digitizings of the whole line and through 5 mm segments. The outcome results are the followings:

- For a zero slit-line angle, the RMS error on a single digitizing is 1μ and does not depend on R;
- The overall RMS scatter for the radial line is 1.5μ, very close to what we would expect from the statistical fluctuation (1μ) and the cross detection error (.25μ). A slight systematic shift of the order of 1μ is visible just in the central region. This effect comes from the difficulty of correctly analysing the calibration pulses in this region. The consequence of an effect of this type on tracks, is analyzed in section 3.

One should mention that the square grid also provides other information, for instance:

- The reconstruction of the grid lines without using the calibrations residuals will reflect any hardware effect by looking at the distortions. Fig.3 gives the behaviour of the radial line for a given cone mirror.
- The study of the pulse height distributions as function of the angle θ and the radius R provides information for correcting ionization measurements. In the present situation, a calibration cycle consists of three spirals on the calibration grid and three spirals on the square grid. The same program treats, first the chicken path, then the square grid as a check of the calibration results. This procedure is not too heavy and very safe.
2.2 Measurement of a star pattern

A more detailed analysis of the characteristics of the pulses in the plane is achieved by measuring a star pattern with 36 arms, 35μ width, every 10°. It is used whenever important modifications are made, in order to make sure that for radial tracks the pulse height remains independent of R and θ. The statistical RMS deviation of 2μ on each leg confirms that the same precision is obtained in any direction.

3. TRACK MEASUREMENTS

Some tests are made regularly either to observe the effect of possible calibration distortions on tracks, or at the beginning of a bubble chamber run, to give an idea of the quality of the pictures.

3.1 Influence of calibration on tracks

Since the parameters (1/p, λ, φ) of beams are well defined from the run conditions, the measurement of primary tracks allows to observe the influence of the calibration. Fig.4a shows the beam momentum on an experiment Kp (1.760 GeV/c) as a function of the abscissa x of the interaction point in the chamber (x entry = -70 cm). This distribution is broader at the low x values. If one uses, in the filter program, a calibration which produces a central distortion of 4μ as in fig.2b one obtains a non uniform distribution (fig.4b). The systematic error introduced can be estimated by:

\[
\frac{Δp}{p} \sim \frac{R}{R} \sim \frac{ε}{f} \quad R \text{ (cm) radius of curvature} = \frac{P(GeV/c)\cos λ}{0.5 H(kG)}
\]

\[f \quad (cm) \quad \text{Sagitta} \quad f = \frac{L^2 \cos^2 λ}{8R}
\]

\[ε \quad (cm) \quad \text{error on sagitta}
\]

\[L \quad (cm) \quad \text{Track length}
\]

\[
\frac{Δp}{p} \sim \frac{8Rε}{L^2} (\cos λ \sim 1)
\]

For ε = 50μ (4μ on 2m HBC film) and L = 30 cm: Δp/p \sim 1.5 %. The errors on the angles λ, φ are:

\[Δφ \sim \frac{ε}{L \cos λ} \frac{3}{2} \quad Δλ \sim \frac{ε \cos \frac{1}{L}}{L} \frac{3}{2}
\]

They could reach 0.5 mr and have to be taken into account especially in the reconstruction of short, fast connecting tracks (ε decay).

3.2 Precision on beam tracks

One measures beam tracks and fits circle through the digitizings in the film plane. This test is made at the beginning of a run when geometrical titles are not available, in order to get information on the picture quality (bubble density, film optical conditions, possible track distortions).
For Exp. 42 (K⁻p 4.2 GeV/c) measurements have been made on beam tracks, in space 80 cm long. The estimated multiple scattering error is 2µ. The mean scatter of master points along the fitted circle was 3.5µ. The statistical error on the master points is less than 1µ so the remaining inaccuracy came either from calibration or possible chamber distortions present at the time of the run. Others more complete tests are made over short and long periods of measurements.

* * *

REFERENCES


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Table 1
$R = \text{constant}$

$\alpha = 0^\circ$
0.1 ms/cm
0.5 V/cm

$\alpha = 20^\circ$
0.1 ms/cm
0.1 V/cm

Fig. 1

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a - Straight line (3 spirals) - Calibration from bad pointing - Good $R_0$ starting value -

b - Calibration from bad pointing - Wrong $R_0$ starting value -

6 - Calibration from bad pointing - Wrong $R_0$ starting value - Iteration on 4th spiral -

Fig. 2
Typical deformation coming from the cone mirror.

Fig. 3

Beam momentum = F(x)

Good calibration

Bad calibration

Fig. 4