LIMITS OF MEASUREMENT RANGE OF PULSE DETECTORS FOR IONIZING RADIATION

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Abstract: An analyzes of acceptable measurement range of pulse detector for ionizing radiation, having in mind necessary accuracy of the measurement and the probability of the results is given. In addition to the analyses the possible solutions for enlarging the already determined range are elaborated. On the bases on the experiments the determined measurement range for simple measurement circuits with fixed measure time is tested. The obtained results show that measurement range, which guarantee the given standard deviation in fact is narrower than the declared range given in the production data catalogues. Although the concrete calculations are given for the subminiature GM counters the results are acceptable in a semi conductor pulse detectors.

1. INTRODUCTION

The pulse detectors for ionizing radiation, having numerous facilities, acceptable dimensions and dissipation, are regularly used in portable measurement instrumentation made for measuring dose rate or dose. Since GM and semiconductor detectors, have strongly nonlinear characteristic, the real usable measuring effect is much narrower than the declared range given in the production data catalogues. First of all, this is because of the inevitable condition for measurement accuracy in the whole usable range and the reliable results. The low measuring range limit is caused by the result reliability (small number of occurrences-bad statistics). It means that the measuring range low limit should be determined, having in mind the maximum allowed measurement time, which directly influences the measurement accuracy. From the other side, the upper range limit is caused by the GM sensor dead time, or from the pile up effect when semiconductor detectors are used, and from the acceptable non linearity.

2. DETERMINATION OF MEASUREMENT RANGE ACCEPTABLE LIMITS

The character of the radiation field interaction with the sensor is statistical, causing to consider the result as statistical variable. The mean value of the counting speed in fact, is a mathematical expectancy. For a specific pulse detector, the efficiency is known from the typical counting/exposition curve. An example of such typical curve for the pulse detector ZP 1310 is presented on Fig. 1 [1], where the detector efficiency is given in: counts/s/mGy/h. The analyses and the tests support are made just for this type of detectors, where the low range for the lowest dose rate corresponds to a small number of output pulses, which means that this is a typical case of low efficiency sensors.

So, the counting detector's speed will be:

$$f = E \cdot D' \qquad (1)$$

where:

f is mean counting speed value,

D' is dose rate

E is detector efficiency,

The registrated pulse number f_r with such a detector in fixed measuring interval ΔT will be:

$$f_r = E \cdot D' \cdot \Delta T \tag{2}$$

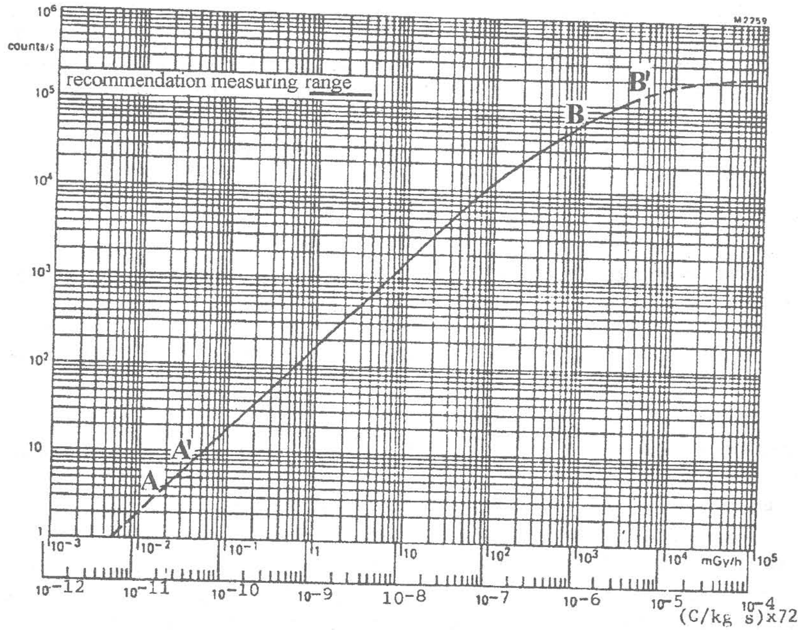

Fig. 1. Typical curve counting/exposition for ZP 1310
A'B'-measuring range limits (catalogue recommendation)
AB acceptable limits

When measuring is performed in the low limit range, with a small number of events, for the variable f_r, Poisson's distribution is best approximation. Having in mind the fact that Poisson's curves maximum is near the mean value of the expected counting, it is practically justified to use symmetrical Gauss distributions, assuming that the distance interval from the mean value is not relatively big in relation to the mean value. According to this, the probability for P^* will be:

$$P^* = P\left(\bar{f} - \Delta < f < \bar{f} + \Delta\right) = P\left(-\frac{\Delta}{s} < f_{st} < \frac{\Delta}{s}\right) \tag{3}$$

where f_{st} is standardized value, given with the equation (4), and s is standard deviation.

$$f_{st} = \frac{f - \bar{f}}{s} \tag{4}$$

Having in mind that the accomplished assumption (not too big distance from the mean value $\bar{f}$) will be:

$$P^* = 2P\left(f_{st} < \frac{\Delta}{s}\right) \tag{5}$$

The portable dose rate devices, besides the general characteristics (measurement with a defined error in a determined measuring range), should satisfy many other not less important limitations, and keep the dimensions of the device to minimum. It is also actual but at the same time impossible need to obtain a high measuring accuracy with pulse detectors for portable instrumentation. In practice, for such device types it is acceptable that the measurement error should be 0.1 (10%), with statistic probability 0.95 (95%). In this case, the determination of the low measuring range limit turns to determination of the reliability range when the standard deviation $s(\sigma)$ can be well evaluated [2]. For such cases it is known that:

$$\sigma = \sqrt{\bar{f}} \tag{6}$$

Starting from the equation (5) for the specific analyzed detector and for $P = 0.95$, with the table values of the error function Φ(u) [3] it is obtained:

$$0{,}475 = P\left(f_{st} < \frac{\Delta}{s}\right) = \Phi\left(\frac{\Delta}{s}\right) \quad \text{or} \quad \frac{\Delta}{s} = 1{,}906 \tag{7}$$

To evaluate the standard deviation value, real data are acquiesced from an ionizing radiation source with the help of a device with detector which is a subject of this analyses [6]. The distance between the detector and the radiation source was chosen so that the lowest limit of the declared detector measurement range should be obtained.

The measurement interval is taken to be much bigger than the allowed measurement interval ΔT [2]. In such conditions, the obtained mean counting value is $\bar{f} = 4{,}36$ imp/s, and according to the relation (6) the standard deviation σ or $s = 2.088$ imp/s. Using these values in the equation (7), the limit approaching from left and right to the obtained mean value is $\Delta = 4.89$ imp/s. The left limit, practically is unrealizable because of the insensibility of the detector, the migration is only to right and in fact it is the low acceptable measurement range limit.

The upper measurement range limit, first of all is determined with the maximum counting, which depends on the detector dead time and the allowed measurement error. The maximum possible counting is approximately equal to the reciprocity dead time value τ [1]. This means that during the counting f (imp/s) the detector will count with losses $f \cdot \tau \cdot 100(\%)$. For the same counting error, as well as for the low limit of the measurement range from 10% it will be:

$$f_{max} < 1/10\ \tau \tag{8}$$

In this example, $\tau = 15$ µs, so it comes that $f_{max} < 7 \cdot 10^4$, which is also the lower limit from the declared of 10 imp/s.

Such determined measurement range limits of the typical curve counting/exposition on Fig.1 are marked with A and B.

In practice, obviously it is not possible to be satisfied with the width of the real usable detector range, especially because of the need that the measurement devices should react, from background to accident cases with high input radiation. The resolving of this question is possible although it is not simple.

3. WIDENING OF THE USABLE MEASUREMENT RANGE

The widening of the low limit is possible with widening of the measurement interval only for low dose rate, feasible with microprocessor based measurement device and implantation of appropriate algorithm. In such way the unallowable long measurement time for high expositions will be avoided. It is confirmed in practice (in the radiation protection field) that the measurement time for the portable measuring devices for dose rate, should not be greater than 8 s [4, 5].

The widening of the measurement range upper limit is possible with the reduction of the detector dead time or with correction of the counting losses.

The reduction of the dead time (for instance with GM detectors) is possible with appropriate optimization of the bias resistor, but only in determinate limits because it directly affects the declared detector life. This means that for substational widening of the sensor range, the solution for counting losses correction will be practically acceptable.

The reduction of the errors due to counting losses, is possible to be solved as follows:

1. With design of a device that adds additional pulses for compensation of the losses because of the detector dead time, to the pulse train representing the actual measured value.

2. With correction of counting losses based on empirical or theoretical relation between the obtained and the expected counting.

But, disregarding the chosen solution, it is important to mention that at such widening the measurement results are with doubtful accuracy. The accurate corrections depend on the accuracy showing the dead time. The exact dead time is different from the typical declared in the catalogues, because its typical value is influenced by some sources of uncertainty. First of all, it depends on the dose rate which means that it should be measured at maximum possible counting, and the correction should be done counting the dead time measured in the above mentioned circumstances, and not with its catalogue data.

4. CONCLUSION

- The low measurement range limit of pulse detectors, with a fixed allowed measurement intervals is narrower than the ones in catalogue data for the same amount as it is the mean counting value for the lowest recommendable dose rate.

- The upper measurement range limit is also rather smaller than the declared one. It depends on the detector dead time measured in real conditions with maximum possible counting, and not from the typical value declared in the catalogues.

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