INTERNATIONAL JOURNAL OF
OCCUPATIONAL SAFETY AND ERGONOMICS 2000, SPECIAL ISSUE, 23–33

Measurement of the Response Time of an Electrosensitive Protective Device in the Process of Its Certification

Marek Dźwiarek

Department of Safety Engineering,
Central Institute for Labour Protection, Warsaw, Poland

In the process of testing an electrosensitive protective system, determining its response time is of crucial importance. A unique double penetration method of measuring electrosensitive protective device (ESPD) response time has been worked out in the Central Institute for Labour Protection. In the first step, low speed penetration enables the detection zone border to be localised. In the second step of measurement, the probe is injected at a high speed and response time is measured. Three different ways have been taken for validation of the method: theoretical analysis, calibration of the stand, and taking a series of measurements. The double penetration method enables ESPD response time measurement results to be obtained, the accuracy, repeatability, and reproducibility of which is satisfactory enough to be assessed objectively.

safety of machinery safety devices
electrosensitive protective devices response time safety assessment

1. MACHINERY SAFETY ASSESSMENT

From a purely functional point of view the more efficiently a machine performs its task of processing material, the better it is. Life, however, is not that simple and in order for a machine to be viable it must also be safe. Indeed safety must be regarded as a prime consideration. Machinery risk can be defined as the possible occurrence of a hazardous event that can cause injury to users, damage to their health, or both. Risks fall into several categories:

Correspondence and requests for reprints should be sent to Marek Dźwiarek, Central Institute for Labour Protection, ul. Czerniakowska 16, 00-701 Warszawa, Poland. E-mail: <madzw@ciop.pl>.

- mechanical (e.g., perforation, puncturing, severing, cutting, crushing, shock, etc.);
- electrical (e.g., electrocution);
- physical-chemical (e.g., contact with dangerous substances, burns, etc.).

It is the responsibility of the manufacturer, importer, or end supplier of the equipment to ensure that the equipment supplied is in conformity with the essential health and safety requirements (EHSRs). Rules concerning machinery safety vary in different countries. Progressive globalisation process, however, requires that legal regulations in different countries be harmonised in order to remove obstacles in goods flow. To ensure the harmonisation of health and safety requirements within the European Union and to remove barriers to trade, the European Communities' Machinery Directive (Directive 98/37/EC) lays down EHSRs relating to the safe design and construction of machinery, and its proper installation and maintenance. It gives a hierarchy of measures for eliminating risk:

1. Inherently Safe Design. Where possible the design itself will prevent any hazards from arising. Where this is not possible
2. Additional Protection Devices. For example, guards with interlocked access points, presence sensing devices such as light curtains, sensing mats, and so forth, should be used. Any residual risk that cannot be dealt with by the aforementioned methods must be contained by
3. Personal Protective Equipment, Training, or both. The machine supplier must specify what is appropriate.

The manufacturer's responsibility is to show that the applied means of risk reduction are appropriate and that they comply with the requirements. In order to ensure that appropriate safety measures have been taken and that the machine is safe enough (see Figure 1), the manufacturer subjects it to conformity assessment.

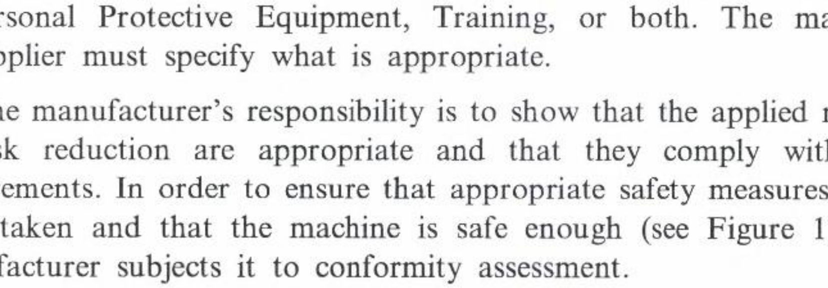

Figure 1. It is the supplier's responsibility to ensure that a machine is safe enough.

Certain types of equipment are subject to special measures. This equipment is listed in Annex IV of the Directive (Directive 98/37/EC) and includes dangerous machinery such as some woodworking machines, presses, injection moulding machines, underground equipment, vehicle servicing lifts, and so forth. Annex IV also includes certain safety components such as light curtains (Grigulewitsch & Reinert, 1989) and two-hand control units (Dei-Svaldi, Kneppert, & Vautrin, 1995).

Machine testing is a very important stage in conformity assessment. The testing usually comprises a range of different parameters and properties of the tested device. In many cases the scope of the testing is defined precisely in type C standards. Yet, it often happens that it is carried out on the basis of the requirements of the Machinery Directive (Directive 98/37/EC). Such testing is extremely complicated and it requires the use of specialist equipment and special testing methods. In the European Union there are a number of notified bodies, which carry out such testing. Testing of this kind is also performed in testing laboratories in other countries. In the case of conformity testing, its accuracy, repeatability, and reproducibility are of crucial importance. Requirements concerning the competence of testing laboratories are specified in standard EN 45001 (European Committee for Standardization, 1989) as well as in the ISO/IEC25 guide (International Organization for Standardization, 1997). Testing methods developed according to the requirements of these documents will permit comparability of the results obtained in various laboratories.

Developing methods of testing machine and safety devices parameters is a special research task. For many years the Central Institute for Labour Protection has conducted research aimed at developing testing methods and test stands that ensure indispensable accuracy, repeatability, and reproducibility so that an objective assessment of the properties of the devices tested is possible. The efforts were concentrated in particular on testing the equipment listed in Annex IV of the Machinery Directive (Directive 98/37/EC). Developing the following testing methods was especially complicated:

- measurement of runup and rundown times of rotating machine elements;
- rigidity test for pressure pads of single spindle vertical moulding machines;
- kickback test of an antikickback device;
- kickback test on a standard test rig (see Figure 2);
- electrosensitive protective systems parameters;

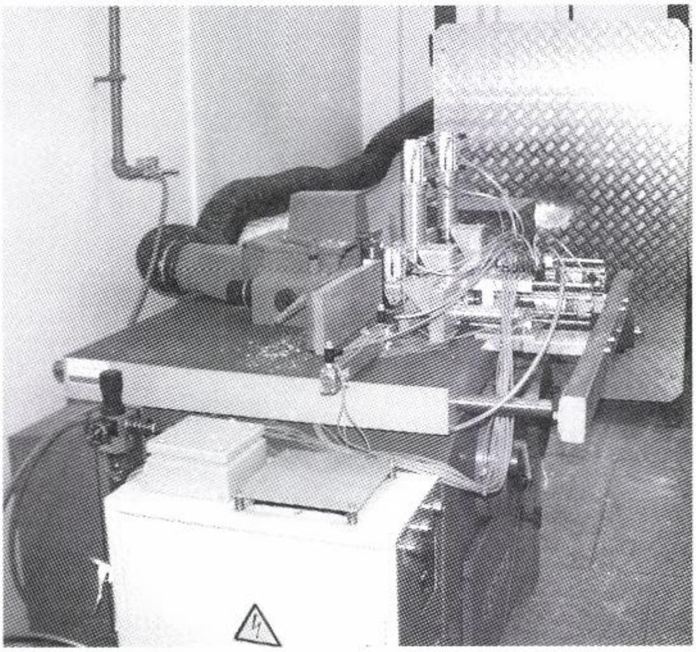

Figure 2. Standard test rig.

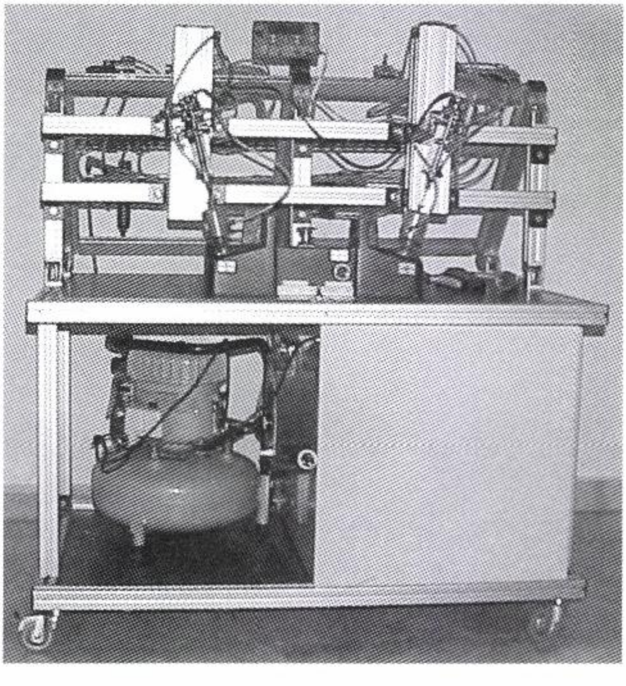

Figure 3. Stand for testing a two-hand control system.

- two-hand control systems parameters (see Figure 3);
- safety related control system category according to EN 954-1:1996 (European Committee for Standardization, 1996), and so forth.

In the process of testing an electrosensitive protective system, determining its response time is of crucial importance. A unique double penetration method for the ESPD response time measurement has been worked out in the Central Institute for Labour Protection (Dźwiarek, 1997, 1998).

2. DESCRIPTION OF THE METHOD

A great step towards safety at work improvement was made when electrosensitive protective devices (ESPDs) were applied to protecting press and robot-assisted manufacturing system operators. The way the device is mounted is of crucial importance. The parameters enabling a proper ESPD mounting with respect to the controlled dangerous zone, ensuring the safe distance to be kept, are as follows: response time, sensitivity, and dimensions of the detection zone.

The experimental procedure of response time measurement is realised in two steps; therefore, a test piece penetrates the detection zone twice. In the first step, low speed (v_m) penetration enables the detection zone border to be localised (see Figure 4).

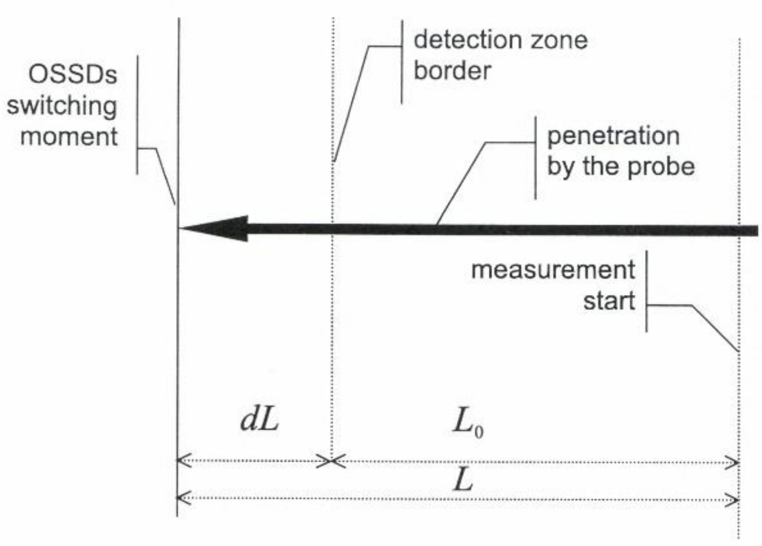

Figure 4. Penetration at low speed v_m. *Notes.* OSSDs—output signals switching devices.

A signal of the measurement start activates the probe position measurement. After the response time t_r passes from the moment of detection zone border crossing, output signals switching devices (OSSDs) switch. At this moment the number on the actuator rod position counter, representing the distance the probe has travelled since the beginning of the measurement, is registered. We can write

$$dL = v_m \times t_r \tag{1}$$

In the second step of the measurement, the probe is injected at a high speed v_d. When the position becomes equal to the defined value l, time counting starts. After output relays of the equipment under test (EUT) change, time t_p is registered (see Figure 5). We have

$$t_r = \frac{t_p}{1 - \frac{v_m}{v_d}} + \frac{l - L}{v_d - v_m} \tag{2}$$

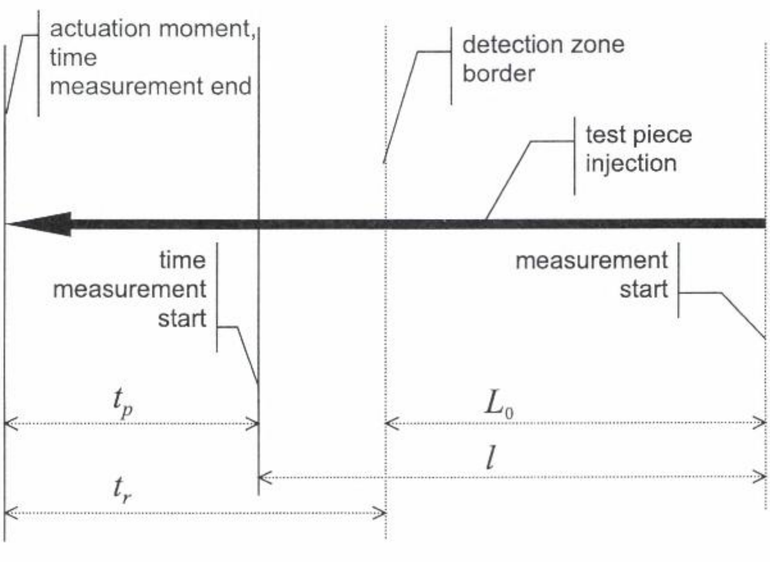

Figure 5. Penetration at high speed $v_d > v_m$.

Therefore, on the basis of the measured value t_p and known values of speeds v_d and v_m, we can determine the response time. In practice, measurements of both time t_p and displacements L, l, and dL with sufficient accuracy pose no difficulties. The problem of speed measurement is rather complicated, however. Measurement accuracy is also affected by the fact that two different response times may appear in the two steps of the measurement mentioned before. In practice, the following conditions are usually satisfied:

$$l = L \qquad v_m \ll v_d \qquad v_m \times t_r \approx 0 \tag{3}$$

Therefore, both these problems can be solved and we can rewrite Equation 2 in the form

$$t_r = t_p \tag{4}$$

3. EXPERIMENTAL STAND

The experimental procedure is realised on a special experimental stand SBUO1 shown in Figure 6. The quick-release valve controls the air outflow from the penetrating actuator and enables the speed to range

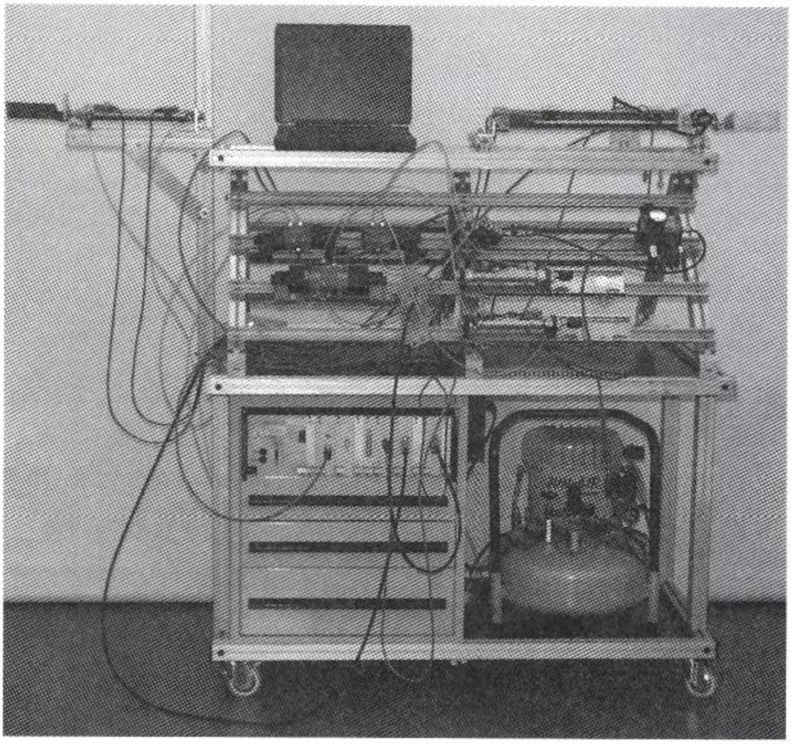

Figure 6. Experimental stand for testing of electrosensitive protective devices (ESPDs).

from 0.1 to 2500 mm/s. The actuator rod position is measured using an angle-to-impulse converter. The signal of the start of the measurement is generated by a limit switch. Its localisation on the actuator ensures the slightest possible influence of the slips upon measurement accuracy. Time measurement is realised by means of a synchronised generator. The speed of the actuator rod is measured in terms of measuring its translation in a predetermined time. A microprocessor controls the measurement. It should be noted that the stand has been built to ensure the required accuracy, repeatability and reproducibility of results, which are of special importance in this case.

4. MEASUREMENT ERROR ANALYSIS

Equation 2 presented the relation between the response time of the EUT and the time measured t_p, translations L and l, and penetration speeds v_m, v_d, respectively. We can, therefore, having known t_p, L, l, v_m, and v_d determine the response time measurement error.

$$\Delta t_r = \left|\frac{\delta t_r}{\delta t_p}\Delta t_p\right| + \left|\frac{\delta t_r}{\delta v_m}\Delta v_m\right| + \left|\frac{\delta t_r}{\delta v_d}\Delta v_d\right| + \left|\frac{\delta t_r}{\delta l}\Delta l\right| + \left|\frac{\delta t_r}{\delta L}\Delta L\right| \quad (5)$$

The smallest measurement errors appear when conditions (3) are satisfied and Equation 5 takes the form

$$\Delta t_r = \left|\Delta t_p\right| + \left|\frac{\Delta l}{v_d}\right| + \left|\frac{\Delta L}{v_d}\right| \quad (6)$$

Then, measurement of the penetration speed is not required. For the measurement error to be assessed we should determine errors Δl, ΔL, Δt_p first. On the basis of the theoretical analysis carried out all components of the measurement error given by the Equation 6 can be determined. Finally, we obtain

$$-0.8\,\text{ms} \leqslant \Delta t_r \leqslant 0.35\ \text{ms} \quad (7)$$

It is always very important to prove that the total measurement error is really enclosed within the assumed limits. To this end, a series of measurements was taken under conditions as close to real ones as possible. This was done using a special calibration device, which could simulate real ESPD operation enabling at the same time a correct setting of response time. For each measurement, preset response time was determined randomly (using a random-number generator of uniform distribution) taking the values from the interval 0–65 ms. As the measurement of the detection zone border position plays a very important role in the whole measurement process the experiments were performed for its four different positions. Table 1 presents the rates n of particular values of Δt error for successive measurement series for all 120 measurements.

TABLE 1. Rates of Particular Values of the Measurement Errors

L	Δt (ms) –0.8	–0.7	–0.6	–0.5	–0.4	–0.3	–0.2	–0.1	0	0.1	0.2	0.3	Δt_{ave}	$\sigma(\Delta t)$
50	1	2	2	1	6	1	4	3	5	2	3	0	–.23	.28
100	1	2	2	2	0	2	4	3	4	4	4	2	–.14	.31
150	1	3	4	1	7	0	5	0	1	5	2	1	–.28	.32
200	0	2	6	2	4	1	3	5	2	2	2	1	–.27	.29
Global	3	9	14	6	17	4	15	11	12	13	12	4	–.23	.31

Notes. L—length determined in the first penetration, Δt—measurement error, Δt_{ave}—average value of error, σ—standard deviation.

We have

$$P(\Delta t < -0.8) < F_g(x_1) = 0.09$$
$$P(\Delta t > 0.3) < 1 - F_d(x_{30}) = 0.09 \qquad (8)$$

These results prove that the real values of the measurement error lie within the interval given by Equation 7.

5. CONCLUSIONS

The presented unique double penetration method for ESPD response time measurement has been worked out by the author in the Central Institute for Labour Protection to satisfy the needs of the certification of those devices. This method can also be applied in examining various protective device prototypes in the course of the design process.

The double penetration method allows to overcome many obstacles appearing in the course of ESPD response time measurement, for example, laborious and time consuming measurement process, limited possibilities of measurement process automatization, serious difficulties appearing when measuring under environmental stress conditions, and so forth. This method, therefore, reduces effects of the factors affecting the uncertainty of the measurement.

The measurement stand SBUO1 supplied with a computer control system on which the double penetration method was realised makes it possible for the repeatability and reproducibility of the measurement results to rise considerably and for the cost of measurements to be reduced. The stand structure allows taking measurements on a shaker and in a climatic or electromagnetic compatibility chamber. Three different ways were used to validate the method:

- theoretical analysis of the measurement accuracy,
- calibration of the stand using the traceability method that enables one to compare the obtained results with international standards,
- a series of measurements of a known response time and determination of the obtained accuracy.

The measurement schedule allows checking the measurements' accuracy as well as their repeatability and reproducibility as the theoretical and experimental results are in an excellent agreement. The measurement results proved that the total response time measurement error lay within $<-0.8\ \text{ms},\ 0.4\ \text{ms}>$ in the entire measuring range. Thus, the double penetration method enables ESPD response time measurement results to be obtained, the accuracy, repeatability and reproducibility of which is satisfactory enough to be assessed objectively.

REFERENCES

Dei-Svaldi, D., Kneppert, M., & Vautrin, J.P. (1995). *Presence sensing systems used as protective devices*. Vandoeuvre, France: Institut National de Recherche et de Sécurité.

Directive 98/37/EC of the European Parliament and of the Council of July 22, 1998 on the approximation of the laws of the Member States relating to machinery. *Official Journal of the European Communities*, Vol. 41, No. L 207, July 23, 1998, pp. 1–46.

Dźwiarek, M. (1997). A method for response time measurement of electrosensitive protective devices. *International Journal of Occupational Safety and Ergonomics, 2*(3), 234–242.

Dźwiarek, M. (1998). Measurement accuracy of the electrosensitive protective device response time when using the double penetration method. *International Journal of Occupational Safety and Ergonomics, 4*(3), 363–384.

European Committee for Standardization (CEN). (1989). *General criteria for the operation of testing laboratories* (Standard No. EN 45001:1989). Brussels, Belgium: Author.

European Committee for Standardization (CEN). (1996). *Safety of machinery—Safety-related parts of control systems. Part 1: General principles for design* (Standard No. EN 954-1:1996). Brussels, Belgium: Author.

Grigulewitsch, W., & Reinert, D. (1989). *Light barriers with test facility. Information and operating specification sheet on safety.* Sankt Augustin, Germany: Berufsgenossenschaftliches Institut für Arbeitssicherheit.

International Organization for Standardization and International Electrotechnical Commission. (1997). *General requirements for the technical competence of testing laboratories* (Guide ISO/IEC 25). Geneva, Switzerland: Author.