International Journal of Occupational Safety and Ergonomics (*JOSE*) 2005, Vol. 11, No. 2, 191–202

Locking of Retractable Type Fall Arresters—Test Method and Stand

Krzysztof Baszczyński

Department of Personal Protective Equipment, Central Institute for Labour Protection – National Research Institute, Łódź, Poland

Retractable type fall arresters are very effective personal equipment protecting against falls from a height. These devices are used under different atmospheric conditions and in the presence of various types of industrial pollution. For this reason appropriate locking after conditioning simulating extreme conditions of a worksite is one of the essential characteristics of retractable type fall arresters. This article presents the requirements for locking of the devices. A previously used locking test method and its disadvantages are discussed. The article suggests an improved test method and test equipment. Measurement of the test mass acceleration is the most important improvement introduced into the test method. The article shows laboratory tests used to verify the method, which turned out to be a valuable source of information concerning the performance of retractable type fall arresters.

personal protective equipment against falls from a height   retractable type fall arresters
locking test method   measurement of acceleration signals

1. INTRODUCTION

Annual publications of statistical data concerning work-related accidents unequivocally indicate that working at heights is one of the most dangerous jobs in Poland. The practice of work conducted at a height and the organization of worksites under such conditions demonstrates that, in many cases, personal equipment protecting against falls is still the only method used to protect workers.

According to the requirements of European Standard No. EN 363:1992 [1] a system designed for fall arresting must consist of the following three components:

- an anchor device, which constitutes part of the worksite load-bearing structure or is directly connected to it,
- a component which connects a full body harnesses with an anchor device and arrests the worker's fall and minimizes its consequences,
- a full body harness which appropriately distributes the loads exerting their effect on the worker during fall arrest and ensures appropriate positioning of his body both during and after fall arrest.

Retractable type fall arresters [2, 3, 4, 5, 6] constitute one of the most effective types of equipment protecting against falls from a height presently used in Poland. Such equipment is designed mainly to protect people who have to move in the vertical direction, while carrying out some activities at the worksite. The principle of operation and, consequently, the construction of a retractable type fall arrester makes it possible for the user to move freely in the vertical direction, and, if he loses contact with the worksite surface, to arrest the fall and reduce the force acting through the full body harness on his body to a safe value.

Retractable type fall arresters are used under different atmospheric conditions [7] and in the presence of various types of industrial pollution. For

This publication has been prepared on the basis of the results of the first stage of the National Programme "Adaptation of Working Conditions in Poland to European Union Standards", partly suppored—within the scope of state services—in 2002–2004 by the Ministry of Economy and Labour. The Central Institute for Labour Protection – National Research Institute has been the Programme's main co-ordinator.

Correspondence and requests for offprints should be sent to Krzysztof Baszczyński, Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy, Zakład Ochron Osobistych, ul.Wierzbowa 48, 90-133 Łódź, Poland. E-mail: <krbas@ciop.lodz.pl>.

this reason, one of the essential characteristics of retractable type fall arresters specified by European Standard No. EN 360:1992 [2] is appropriate locking after conditioning simulating extreme conditions they can be exposed to at the worksite.

This paper concerns the problems associated with studies carried out in the Department of Personal Protective Equipment of the Central Institute for Labour Protection – National Research Institute (CIOP-PIB) in the field of locking of retractable type fall arresters. It characterizes the test methods used to date, discusses detected shortcomings and presents an improved methodology together with a description of a test stand.

2. RETRACTABLE TYPE FALL ARRESTER TEST METHOD USED TO DATE

The test specified in section 5.7 of European Standard No. EN 364: 1992 [8] is the essential test assessing the performance of retractable type fall arresters during fall arrest. In this test, a 100-kg test mass, free-falling from the height of 0.6 m, is used as a dynamic load for the retractable type fall arrester. As a result of the test, the maximum force acting on the rigid anchor point of the retractable type fall arrester and the total displacement of the test mass are determined. Such a test is not preceded by any special conditioning. In actual work situations, retractable type fall arresters must function correctly at worksites exposed to various environmental conditions, including both atmospheric conditions and pollution with dust or oil. For this reason, European Standard No. EN 360:1992 [2] also requires checking whether equipment can be used safely under specific environmental conditions. The idea of this test is to establish whether a retractable type fall arrester, and its interlocking mechanism presented in Figure 1, function correctly after conditioning simulating low temperature, high temperature, exposure to water, dust and oil.

The methods of conditioning defined in European Standard No. EN 364: 1992 [8] are presented in Table 1.

The locking test according to European Standard No. EN 364:1992 [8] involves checking whether the conditioned device arrests the fall of the test mass and remains locked until it is released. The testing methodology is characterized in very general terms, with only the following requirements specified:

- the device should be tested after conditioning,
- the tested device should be suspended in the unlocked state from its upper end point,
- the tested device should be set in motion by the test mass falling with the velocity not exceeding 2.5 m/s,
- the mass of the test mass should be 5 kg or more (increased in 1-kg increments), appropriately to the requirements of the tested device.

To date, the methodology has been carried out in the CIOP-PIB according to the following test protocol:

- after conditioning, the retractable type fall arrester was suspended in the structural anchor point of a rigid construction meeting the

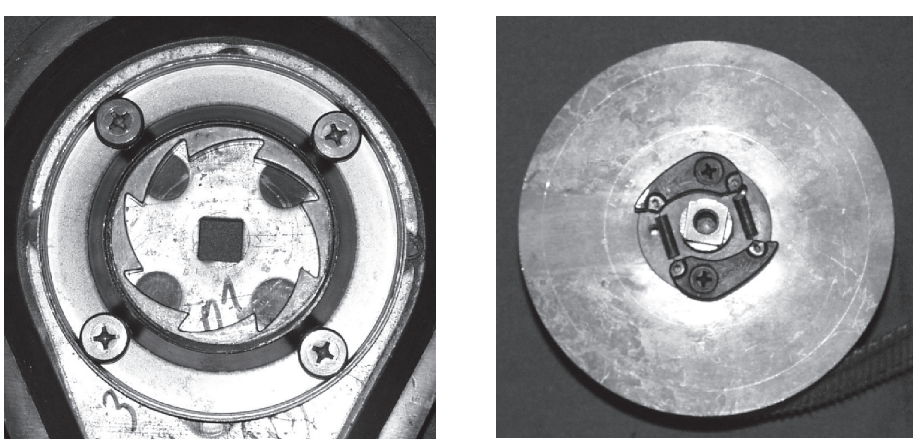

Figure 1. An example of an interlocking mechanism of a retractable type fall arrester.

TABLE 1. A Method of Conditioning of Retractable Type Fall Arresters Before Locking Test (according to EN 364:1992 [8])

Kind of Conditioning	Methods	Duration	Δt_c
Conditioning to cold	Device placed at a temperature of (–30 ± 2) °C	2 hrs	≤90 s
Conditioning to heat	Device placed at a temperature of (+50 ± 2) °C and relative humidity of (85 ± 5)%	2 hrs	
Conditioning to wet	Device placed at a water spray delivered at a rate of 70 L/hr (temperature 10–30 °C)	3 hrs	
Conditioning to oil	Retractable lanyard immersed in commercial grade diesel oil at a temperature of (+20 ± 2) °C	30 min	Not defined
	Dripping of a retractable lanyard	24 hrs	
Conditioning to dust	Device placed in the box with dry cement agitated by blasts of air		
	Parameters of the method:		
	• period of blast	2 s	
	• interval between blasts	5 min	
	• interval between sequences of movements of device	1 hrs	
	• total time of conditioning	5 hrs	
	• period of dust settlement (at the end of conditioning)	15 min	

Notes. Δt_c—time between the end of conditioning and test start.

requirements of European Standard No. EN 364: 1992 [8],

- the test mass of appropriate mass was fixed to the connector at the end of the retractable lanyard of the device and blocked in a quick release device,
- the quick release device was released and the fall of the test mass was observed,
- after the fall of the test mass was arrested, the length of the retractable lanyard outside the casing of the device was measured,
- it was assessed whether the retractable lanyard length did not exceed 0.318 m. This value results from a simple calculation of the terminal velocity of the test mass in free fall (assuming that before the activation of the interlocking mechanism it moves with 1-g acceleration). If the measured retractable lanyard length was shorter than 0.318 m, it meant that the interlocking mechanism was activated at the test mass fall velocity lower than 2.5 m/s.

The practice of laboratory testing of retractable type fall arresters as well as the theoretical analysis of related phenomena pointed to the existence of the following important disadvantages of the presented method:

- the assumption concerning the fall of the test mass with 1-g acceleration before activation of the interlocking mechanism may not be true. This related to the function of a spring which causes automatic tensioning of the retractable lanyard of the device, which, depending on the tension force, appropriately decelerates the fall of the test mass,
- in the case of a stepwise action of the interlocking mechanism (causing characteristic jerks of the test mass), measurement of retractable lanyard length outside the device does not make it possible to draw conclusions concerning the velocity of the test mass at the moment of fall arrest.

In order to clarify these points, a series of preliminary laboratory tests were carried out. First, the values of forces exerted by retractable type fall arresters on the test mass during its fall (before activation of the interlocking mechanism) were determined. For this purpose, nine types of devices were investigated using a Zwick (Germany) ZS-100 testing machine. The results of these investigations, expressed as averaged values of three tests, are presented in a graphic form in Figure 2.

This graph demonstrates unequivocally that:

- the tension force F_z of the retractable lanyard fell within the 2–67 N range,
- the tension force F_z increased with the increase of retractable lanyard length L pulled out of the device casing,
- F_z was also dependent on the specific design of the device.

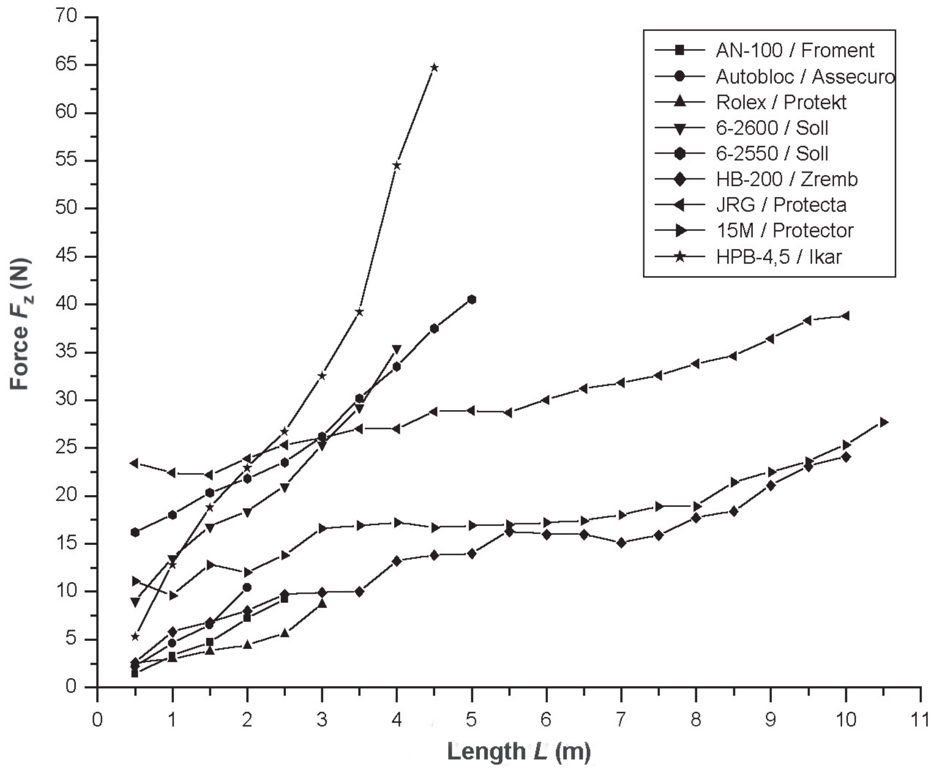

Figure 2. Dependence between the force F_z acting on the end of retractable lanyard and the length L of the retractable lanyard segment removed from the device.

This means that the values of the tension force can be compared with the values of the gravity force acting on the test mass. Thus, it is confirmed that for most designs of devices the assumption of free fall of the test mass (before activation of the interlocking mechanism) does not reflect the actual fall conditions.

The next stage of preliminary testing involved the assessment of a retractable type fall arrester whose interlocking mechanism was supposed to function in a stepwise manner. The tests utilized a test mass of 10.0 kg and equipment (characterized in detail in the next section of the paper) measuring the acceleration of the test mass along the vertical axis passing through its gravity centre. Observations made during the test demonstrated that the device arrested the fall of the test mass and remained locked after fall arrest until the moment of manual unlocking (removal of the test mass). The curve of test mass acceleration and the curve of its velocity obtained by numerical integration using Pias version 3.11 software [9] is presented in Figure 3.

After test mass fall arrest, the length of the retractable lanyard pulled out of the device casing was measured using a measuring tape, obtaining a result of 0.537 m. In view of the testing method used to date and its assessments criteria (the length of the pulled-out retractable lanyard not exceeding 0.318 m) the result was unacceptable.

On the other hand, when analyzing the test mass velocity curve presented in Figure 3 it can be observed that the velocity did not exceed 2.5 m/s throughout the process of fall arrest. Taking into consideration the latter result, as well as the observations presented previously, it can be stated that the device was functioning correctly.

Summing up the presented considerations and the results of preliminary laboratory tests, it can be stated that the previous method of testing the locking used for retractable type fall arresters demonstrates an important disadvantage: an adequate assessment of equipment with some specific characteristics is not possible.

3. ESSENTIAL ASSUMPTIONS FOR THE NEW TEST METHOD

The main idea of the new test method was to make it possible to assess the phenomena defined in

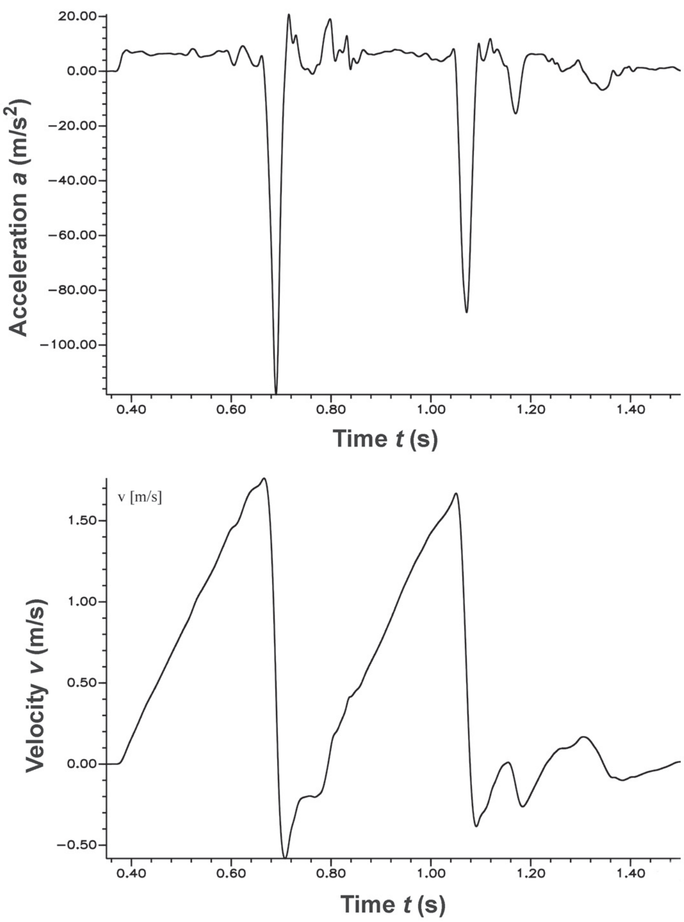

Figure 3. The acceleration *a* and the velocity *v* of the test mass *m* = 10.0 kg during its fall arrested by a retractable type fall arrester.

European Standard No. EN 360:1992 [2], that is, to assess whether the conditioned device is locked by the fall of the test mass and remains locked until it is released, with a precise measurement of the velocity of the test mass at the moment of the activation of the interlocking mechanism of the fall arrester.

The new method was defined by formulating the following assumptions:

- it should be consistent with the general provisions contained in European Standard No. EN 364:1992 [8],
- the retractable type fall arrester should be suspended in a test stand according to the manufacturer's requirements specified in the instructions for use,
- the pull-out velocity of the retractable lanyard at which the device is locked should be assessed on the basis of the velocity of the test mass,
- the velocity of the test mass should be obtained by numerical calculation based on the measured and recorded time signal of the acceleration of the test mass,
- the signal of the acceleration of the test mass should be recorded during the time interval including suspension before the fall, the fall and the state after fall arrest,
- prior to the test, the test mass should be positioned under the retractable type fall arrester on the vertical axis passing through the anchor point of the test stand,
- the test mass should be released without initial velocity,
- the design of the test mass should make incremental increase of its mass possible.

4. TEST STAND

In order to implement the new test method according to the assumptions, a test stand was designed. It is presented in Figure 4.

The basis for the stand is a rigid construction (3), which meets the requirements of European Standard No. EN 364:1992 [8]. On the rigid construction, a bracket (4) with an anchor point for the tested equipment is mounted. The bracket's (4) dimensions are designed so that its anchor point, which makes it possible to attach a retractable type fall arrester, is on the vertical axis passing through the jaws of the quick release device (2). Additionally, to make it possible to

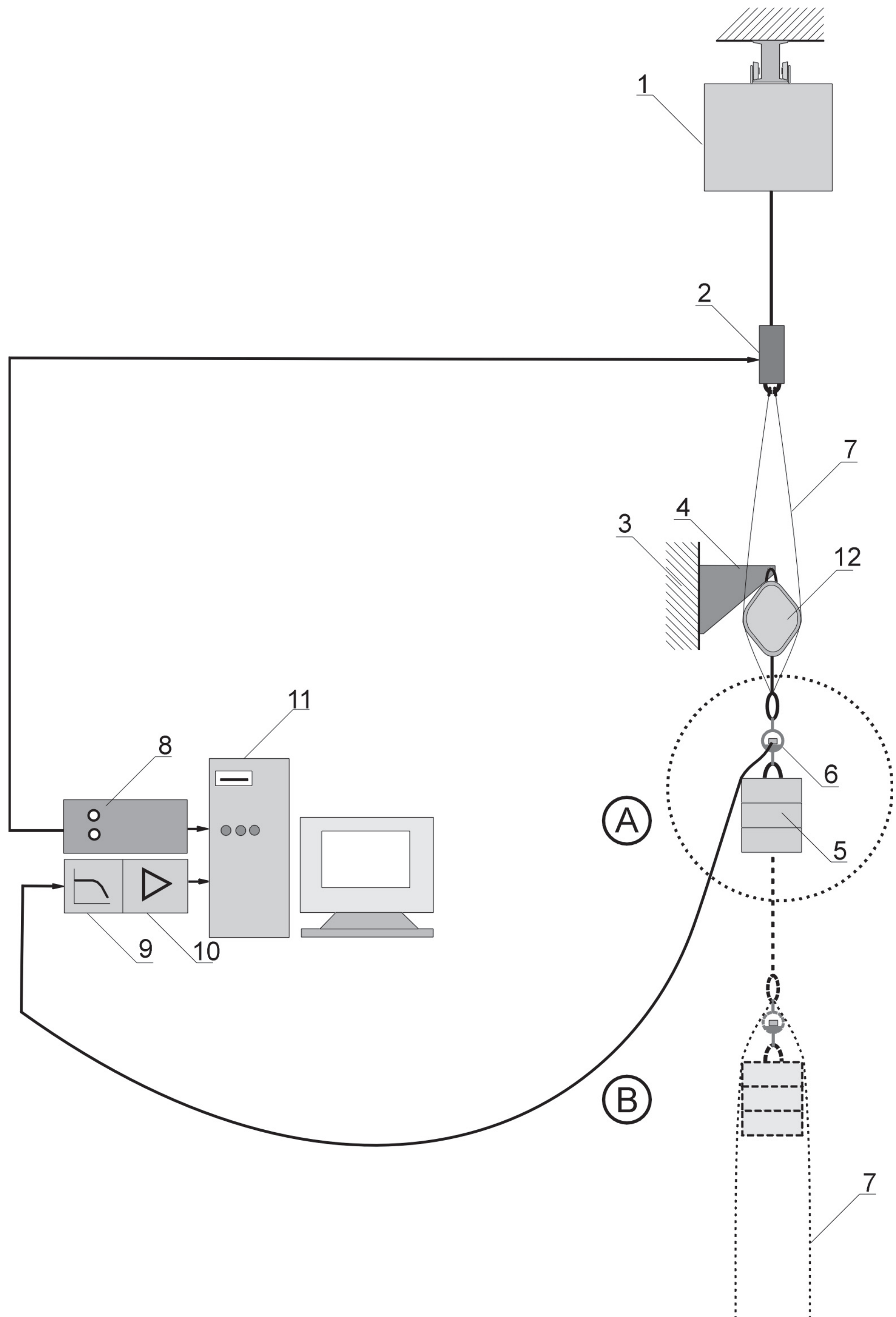

Figure 4. Retractable type fall arrester-test equipment and test method. *Notes*. A—state before fall, B—state after fall, 1—power winch for lifting and lowering test mass, 2—quick release device, 3—rigid construction, 4—bracket with anchor point, 5—test mass, 6—accelerometer type 7265A (Endevco, USA), 7—flexible connector, 8—controlling device for quick release device, 9, 10—low-pass filter with amplifier type 106 (Endevco, USA), 11—personal computer with measuring card type DAP-1200e (Datalog, Germany), 12—retractable type fall arrester.

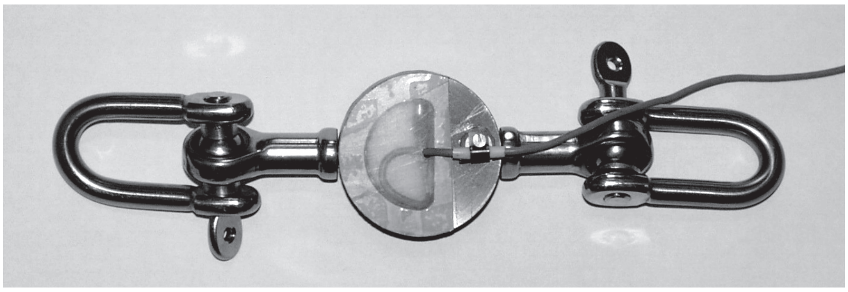

Figure 5. Construction of the accelerometer housing.

suspend the test mass under and coaxially with the retractable type fall arrester, a connector (7) made of steel wire rope 2 mm in diameter and equipped with appropriate terminals is used. Such a design guarantees that the pendulum motion of the test mass during fall arrest is minimized. A power winch (1) is used to lift and lower the test mass before and after the tests. It also makes it possible to place it in the correct initial position before the fall (with an initial pull-out length of the retractable lanyard).

The quick release device used in the test stand is operated through a controlling device (8). The device additionally synchronizes the moment (with a certain time-lag) of quick release device jaws opening with the beginning of data recording by the measuring system. The test stand presented here is equipped with a steel test mass (5) with a modular structure, which makes obtaining the desired mass within the 5–15-kg range possible.

The test stand is equipped with an electronic measuring system used for measuring and recording the signal of test mass acceleration. The essential elements of the measuring system include:

- an accelerometer (6), type 7265A (Endevco, USA), with a ±100-g measurement range and 0–800-Hz band,
- an amplifier (10), type 106 (Endevco, USA), with an inbuilt low-pass analog filter (9), with cut-off frequency f_g = 100 Hz (–3 dB),
- a personal computer with a measuring card (11), type DAP-1200e (Datalog, Germany) with a 12-bit a/d converter.

The accelerometer (6) is the first element of this measuring system. It measures the acceleration of the test mass in the vertical direction. Preliminary tests demonstrated the necessity to use a transducer with a ±100-g measurement range, protecting that element from potential damage due to a significant overload. The accelerometer is placed in a housing shown in Figure 5, which makes it possible to install it between the connector of the retractable lanyard and the suspension eye of the test mass.

The accelerometer (6) co-operates with the amplifier (10) and a low-pass analog filter (9). These elements are responsible for amplifying the signal from the accelerometer and for eliminating interference higher than 100 Hz, generated by both mechanical and electrical phenomena. The signal from the amplifier (10) is transmitted to a single input of a measuring card (11). Preliminary tests demonstrated that, for measuring purposes, the use of a sampling frequency equal to f_p = 10 kHz and observation time of ca. 5 s is convenient. Thanks to the measuring card and the accompanying software, a set of data containing ca. 50,000 samples of the acceleration signal can be recorded during a single test. The controlling device (8) operates in such a way that data recording starts before the fall of the test mass.

The test stand is equipped with software developed in Turbo Pascal [10]. The software calculates the velocity of the test mass at the moment the interlocking mechanism is activated. This is accomplished according to an algorithm shown in Figure 6.

At first the software inputs the measurement data recorded with a DAP-1200e type measuring card to the hard disk of the computer. These data represent the signal of the acceleration of the test mass recorded as a ca. 100-kB file, which corresponds to ca. 50,000 signal samples recorded with the sampling frequency f_p = 10 kHz. The recorded acceleration signal includes the following stages of the test:

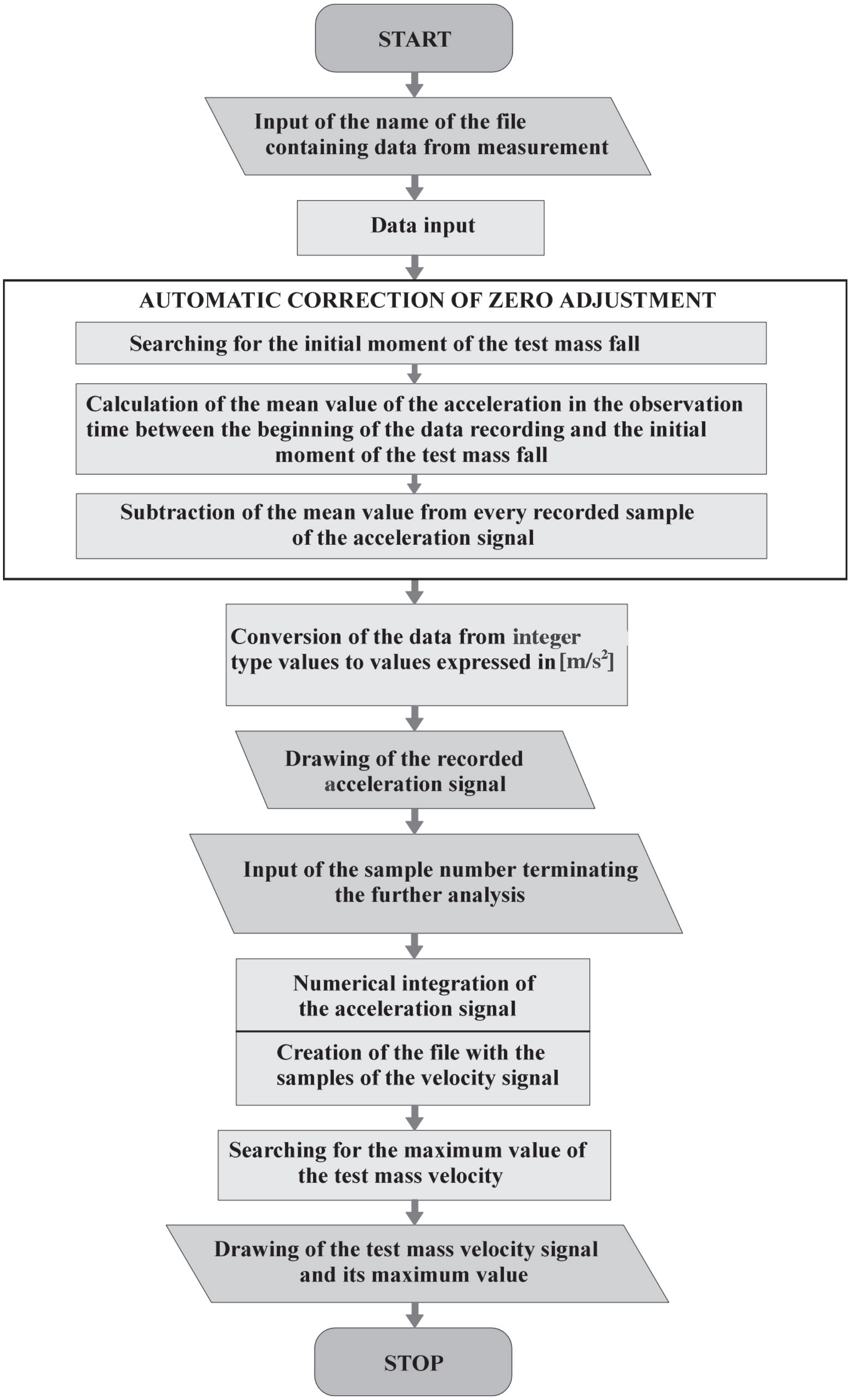

Figure 6. A block diagram of the computer program for calculating the test mass velocity.

- suspension of the test mass in the quick release device,
- fall of the test mass,
- suspension of the test mass on the retractable type fall arrester after fall arrest.

The total test mass observation time is then ca. 5 s.

The input of the measurement data takes place after the user provides the name of the file where they were saved during the test.

In the next stage, the software carries out an automatic correction of the zero adjustment of the system including the accelerometer, the amplifier and the measuring card. The correction is performed on the basis of an analysis of the acceleration signal period, during which the test mass is suspended in the quick release device. The first step to this end is to determine the initial moment of the fall of the test mass. This is accomplished by comparing the value of an acceleration signal sample with the arithmetic mean of previous samples (starting from the beginning of the data set collection). If the absolute value of the analyzed sample is higher by a given threshold value than the arithmetic mean of the previous ones, it is assumed to be the initial moment of the fall of the test mass. Then, the mean value of the samples for the observation time defined by the first sample and the sample corresponding to the initial moment of the fall of the test mass is calculated. The mean value is then added, with the opposite sign to every sample of the recorded signal of acceleration.

In the subsequent step, the program converts the data from integer type values [10], corresponding to the quantization levels of the measuring card a/d converter, to the values expressed in m/s^2. Then, the program displays in a graphic form the whole signal of the acceleration of the test mass and expects the user to provide the data number terminating further analysis. When this value is given by the user, the program commences the calculation of the signal of the velocity of the test mass. For the purpose of calculating the velocity of the test mass, the program utilizes the algorithm of trapezoidal integration [11]. The consecutive values of the samples of the velocity of the test mass are recorded in a newly created data file. After completing the integration algorithm, the program searches for the maximum velocity value reached by the test mass during its fall.

The last stage of the program involves displaying in a graphic form the signal of the velocity of the test mass and giving its maximum value.

5. VERIFICATION TESTS

The designed test stand was subjected to tests, the aim of which was to check the applicability of the developed test method and to perform metrological verification.

The first stage involved verification of the measuring software by means of a numerical simulation of acceleration signals, which were saved in the computer memory in the form of data files. The files were analogous to those obtained as a result of measuring the acceleration signal with the DAP-1200e measuring card, that is, consisting of ca. 50,000 data each, with the data recorded as integer type values [10], with the sampling frequency f_p = 10 kHz.

The first simulated test signal presented in Figure 7, case A, took a rectangular form of a maximum value (integer) equal to 1680, which corresponds to the acceleration of 10.059 m/s^2. The data values for the time intervals from 0 to 1 s and from 4 to 5 s equalled 0. Calculating, using an analytic method, the value of maximum velocity for that acceleration signal, the result of V_{maxt} = 30.177 m/s was obtained. Then the signal was processed by the program operating the test stand with the following results:

- V_{max} = 30.18 m/s,
- the initial moment of the fall corresponded to the data recorded at number 10001,
- the constant component of the signal prior to the initial moment of the fall was 0,

which demonstrated that the program operation for test signal A was completely correct.

The second simulated test signal presented in Figure 7, case B, also took a rectangular form of a maximum value (integer) equal to 1716, which corresponds to the acceleration of 10.275 m/s^2. Data for the time intervals:

- from 0 to 1s had a triangular course with the amplitude of 72 and the constant component equal to 36,
- from 4 to 5s had the value of 36,

which correspond to the case when under actual measuring conditions the acceleration signal is “shifted” by the value of 36 (acceleration —0.215 m/s^2). This case simulates inaccurate

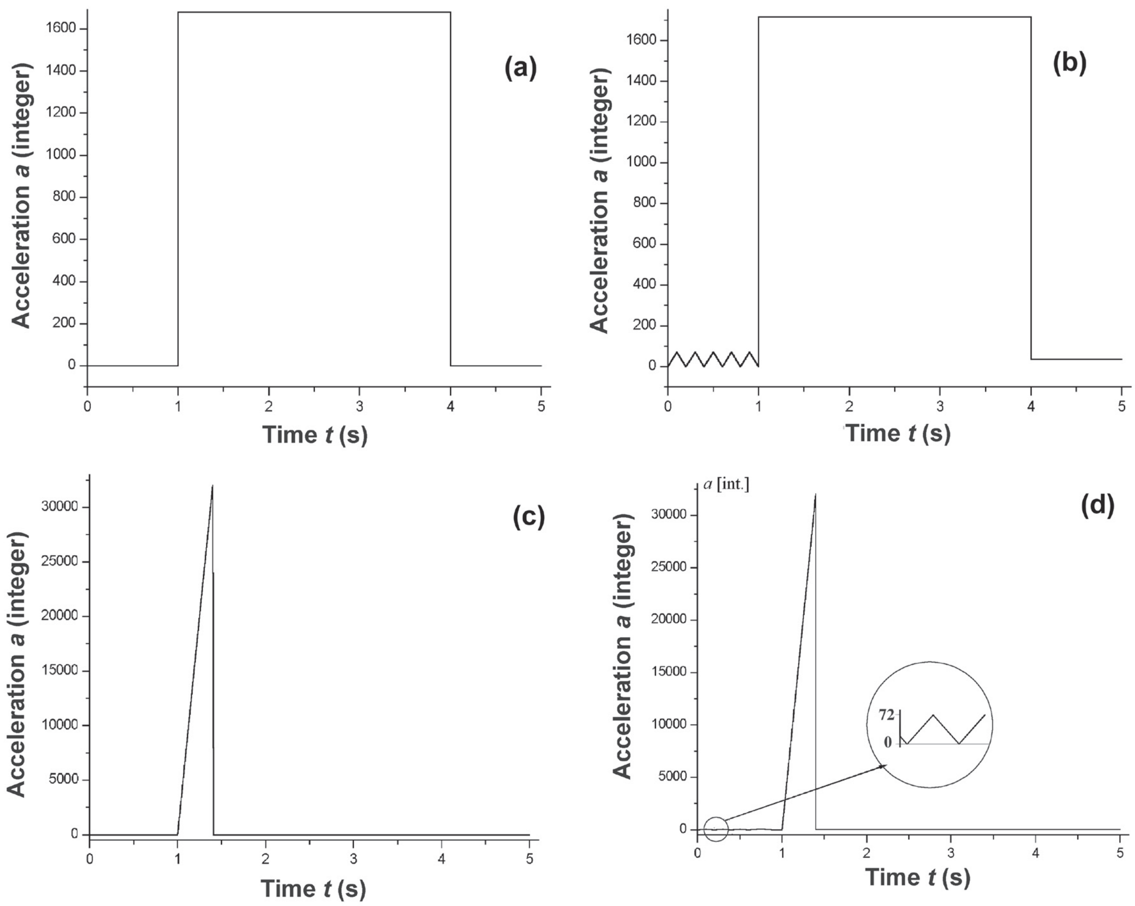

Figure 7. Test signals applied to verify the computer program.

zero adjustment of the equipment for measuring acceleration and the presence of interference. Calculating, using an analytic method, the maximum velocity value for that acceleration signal, resulted in obtaining the value of V_{maxt} = 30.177 m/s. Then the signal was processed by the program operating the test stand and the following results were obtained:

- V_{max} = 30.18 m/s,
- the initial moment of the fall corresponded to the data recorded under the number of 10001,
- the constant component of the signal prior to the initial moment of the fall was 36,

which demonstrated that the program operation for test signal B was completely correct.

The third simulated test signal presented in Figure 7, case C, had the form of a single sawtooth pulse with a maximum (integer) value equal to 32000 (acceleration—191.601 m/s^2). Data from the time intervals from 0 to 1s and from 1.4 to 5s had values equal to 0.

Calculating, using an analytic method, the maximum velocity value of V_{maxt} = 38.32 m/s was obtained. As a result of the tested program processing the C signal processing, the following results were obtained:

- V_{max} = 38.33 m/s,
- the initial moment of the fall corresponded to the data recorded under the number of 10007,
- the constant component of the signal prior to the initial moment of fall was 0.017.

Those results indicate that the initial moment of the fall was identified with a 0.6-ms error in comparison with the results of theoretical calculations. Such an effect is due to a slow increase of the leading edge of the test signal C and the use of the threshold of detecting the beginning of a fall of p = 48, the value of which is optimal for an analysis of actual acceleration signals. The detection of a "delayed" beginning of the fall resulted in the constant component of the acceleration signal being shifted by the program by 0.017. However, this value is negligibly small and had no effect on the result of calculating V_{max}. Additionally, it should be mentioned that, as demonstrated by laboratory tests with respect to signals obtained during measurements of the acceleration of the test mass, the pulse leading edge corresponding to the beginning of a fall is steeper than in the C test signal. Thus, identying the initial moment of a fall is not a problem. Summing up the investigation with the test signal C it can be said that it also demonstrated that the program operated correctly.

The fourth simulated test signal presented in Figure 7, case D, took the form of a sawtooth pulse of a maximum value (integer) equal to 32036 (acceleration—191.817 m/s^2). The data in time intervals:

- from 0 to 1s had a triangular course with the amplitude of 72 and the constant component equal to 36,
- from 1.4 to 5 s had the value of 36.

As a result, the test signal of D was a combination of B and C signals. Calculating, with an analytic method, the value of the maximum velocity for that acceleration signal, the result of V_{maxt} = 38.32 m/s was obtained. As a result of processing the acceleration signal with the tested program, the following parameters were obtained:

- V_{max} = 38.33 m/s,
- the initial moment of a fall corresponded to the data recorded under the number of 10007,
- the constant component of the signal prior to the initial moment of a fall was 36.017.

The result, like in the case of the C signal, demonstrates negligibly small differences between the theoretical values and those obtained with the program, which confirms that it is correct.

As the result of the verification of the measuring software was completely positive, the second phase of the verification of the whole test stand was carried out. The verification method was based on the principle of a detailed reproduction of the actual test conditions of the retractable type fall arrester. Thus, the measuring system in Figure 4 was used with the only difference involving the use of a steel wire rope of a 2.5-mm diameter and ca. 0.5 m long instead of a retractable type fall arrester (12). In order to perform the verification test, the quick release device (2) was adjusted to such a position so as to obtain the test mass (5) free fall distance h equal to: h = 0.1, 0.3, 0.5 m, respectively. The free fall distance h was set with a ±2 mm accuracy. Then the test was performed in such a way as if a retractable type fall arrester had been installed on the stand. The V_K results obtained in the test were compared with the appropriate values calculated from the following equation for terminal velocity in free fall:

$$V_{KT} = \sqrt{2gh} \tag{1}$$

where V_{KT}—terminal velocity in free fall, g—acceleration of gravity, h—free fall distance.

For the evaluation of the obtained results, relative error was used. It was defined as follows:

$$\Delta_V = \frac{V_K - V_{KT}}{V_{KT}} 100\% \tag{2}$$

The experiment carried out for three aforementioned h values demonstrated that the Δ_V error did not exceed ±2%, which confirmed the test stand operated correctly and achieved the assumed measurement accuracy.

In the final stage of assessing the stand, tests of retractable type fall arresters were also carried out. Their aim was to check the functionality of the stand and the possibility of performing the tests in no longer than 90 s from the end of the conditioning, which is a requirement specified by European Standard No. EN 364:1992 [8]. The obtained results demonstrated the possibility of effective testing using the test stand in the time not exceeding 60 s between the end of conditioning and the fall of the test mass.

6. CONCLUSION

Summing up this research, it should be stated that its objective, that is, preparation of an improved method of testing retractable type fall arresters subjected to conditioning simulating extreme atmospheric conditions at the worksite and exposure to industrial pollution, has been fully achieved. The introduced improvement together with the test stand ensure that the results of retractable type fall tests are free from the effects of the force causing automatic tensioning of the retractable lanyard and stepwise acting of the interlocking mechanisms. Consequently, it is possible to assess retractable type fall arresters more objectively than with the previous method. It is also noteworthy that this test method and the design of the test stand still comply with the general requirements of the relevant European Standards No. EN 360:1992 [2] and EN 364:1992 [8].

The improved method, together with the test stand, has been incorporated in the system of testing personal fall protection equipment carried out for certification purposes. Its implementation should result in increased safety of people working at a height.

As demonstrated by research carried out in the CIOP-PIB in 2003, the test stand described here can also be used successfully in research on the performance of the devices. The recorded signals of test mass acceleration are especially useful for the assessment of the self-locking function of retractable type fall arresters. These signals, with appropriate interpretation, make it possible to determine why a device does not work correctly. As a result, the new test stand can be used for in research and development related to new designs of retractable type fall arresters.

REFERENCES

1. European Committee for Standardization (CEN). Personal protective equipment against falls from a height—fall arrest systems (Standard No. EN 363:1992). Brussels, Belgium: CEN; 1992.
2. European Committee for Standardization (CEN). Personal protective equipment against falls from a height—retractable type fall arresters (Standard No. EN 360:1992). Brussels, Belgium: CEN; 1992.
3. International Organization for Standardization (ISO). Personal fall-arrest systems—part 3: Self-retracting lifelines (Draft standard No. ISO/FDIS 10333-3:2000). Geneva, Switzerland: ISO; 2000.
4. International Organization for Standardization (ISO). Personal fall-arrest systems—part 6: System performance tests (Draft standard No. ISO/DIS 10333-6:2002). Geneva, Switzerland: ISO; 2002.
5. Sulowski AC. Fall protection systems—classification. In: Sulowski AC, editor. Fundamentals of fall protection. Toronto, Ont., Canada: International Society for Fall Protection; 1991. p. 285–301.
6. Sulowski AC. Fall protection systems—selection of equipment. In: Sulowski AC, editor. Fundamentals of fall protection. Toronto, Ont., Canada: International Society for Fall Protection; 1991. p. 303–20.
7. Baszczyński K, Bargieł H, Karlikowski M, Korycki R, Zrobek Z, Kamańczyk P, et al. An analysis of the influence of wet, low and high temperatures on safety parameters of energy absorbing components containing textile elements [unpublished test report]. Warszawa, Poland: Central Institute for Labour Protection (CIOP); 1999. In Polish.
8. European Committee for Standardization (CEN). Personal protective equipment against falls from a height—test methods (Standard No. EN 364:1992). Brussels, Belgium: CEN; 1992.
9. Mess Top Engineering Gesellschaft für Meßtechnologie mbH. PIAS version 3.1—manual. Martinsried, Germany Mess Top Engineering Gesellschaft für Meßtechnologie mbH; 1994.
10. Borland International. Borland® Pascal with objects. Language guide 7.0. Scotts Valley, CA, USA: Borland International; 1992.
11. Björck Ĺ, Dahlquist G. Numerical methods. Warszawa, Poland: PWN; 1987. In Polish.