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Corrosion of Retractable Type Fall Arresters

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Retractable type fall arresters constitute a most effective group of components used in personal protection systems protecting against falls from a height. They are designed primarily for outdoor use, which results in exposure to atmospheric factors associated with risk of corrosion of metal elements. This paper presents the results of a study, in which retractable type fall arresters were exposed to a simulated corrosive environment, a neutral salt spray. It discusses the development of corrosion processes depending on the duration of exposure to corrosive conditions. Tests demonstrated that corrosion of elements decreased their strength and impaired the functioning of mobile parts. The article presents methods of testing the correct functioning of devices, necessary for assessing their resistance to corrosion, which have been developed for this purpose. It also analyzes the correlation between corrosion-related damage of retractable type fall arresters and potential hazards for their users.

personal protective equipment against falls from a height   retractable type fall arresters
corrosion   neutral salt spray test

1. INTRODUCTION

Data concerning occupational accidents published annually in many European countries demonstrate that work on heights is still a very hazardous job. The practice of work organization in, e.g., civil engineering, power engineering, telecommunications, has shown that personal systems protecting against falls from a height are often the only method of protection. Such systems consist of

- an anchor device connected with the construction of the worksite;
- a connecting and shock-absorbing subsystem that makes a gentle fall arrest possible;
- a full body harness supporting the user's body during the fall and after fall arrest.

Retractable type fall arresters are currently one of the most effective groups of connecting and shock-absorbing subsystems used in personal systems protecting against falls from a height [1, 2, 3, 4, 5, 6]. The principles of their functioning and construction make it possible to protect the workers, who have to move in the vertical direction at their workplaces. The most important functions of retractable type fall arresters include protection of users, both at the worksite and on the way to and from the worksite, reduction in free fall distance, reduction in braking force to a safe value, imposing a vertical position of users with their legs directed downwards during fall arrest.

Both retractable type fall arresters and other parts of fall arresting systems are designed primarily for outdoor use, which results in exposure to atmospheric factors [7]. Corrosion of metal elements is one of the most serious consequences of such exposure [8, 9]. Its rate end effects are most pronounced in polluted industrial areas and some microclimates, e.g., at the seaside. Manufacturers of protective equipment and its users have reported corrosive processes, which may directly affect safety. Therefore, the Central Institute for Labour Protection – National Research

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Institute (CIOP-PIB) investigated the problem [10]. This paper presents the effects of corrosive processes affecting metal elements of retractable type fall arresters and the developed method of testing resistance of these devices to corrosion.

2. CONSTRUCTION AND THE PRINCIPLE OF FUNCTIONING OF RETRACTABLE TYPE FALL ARRESTERS

Observation of the development of corrosive processes on elements of retractable type fall arresters and of the effects of corrosion requires understanding of the internal structure of those devices. An analysis of typical devices used in the European Union has resulted in a list of essential elements (Figure 1):

- a retractable lanyard, made of wire rope (usually 4–5 mm in diameter) or webbing (usually 25–40 mm wide), one end of which is attached to the device drum and the other to the connector;
- a connector that is one end of the retractable lanyard and is used for connecting with the attachment point of a full body harness;
- a drum for reeling the retractable lanyard;
- a flat spiral spring connected to the drum;
- a system of pawls with springs;
- a toothed ring that blocks the pawls when the drum reaches specified rotational speed;
- a friction brake connected to the drum;
- casing with a fixture designed for mounting it on the anchor point on a worksite construction.

It is also important to realize that most elements of currently manufactured arresters are made of various metals and alloys (Table 1).

There are two working modes in the functioning of fall arresters. They are associated with the slow vertical movement of the user on

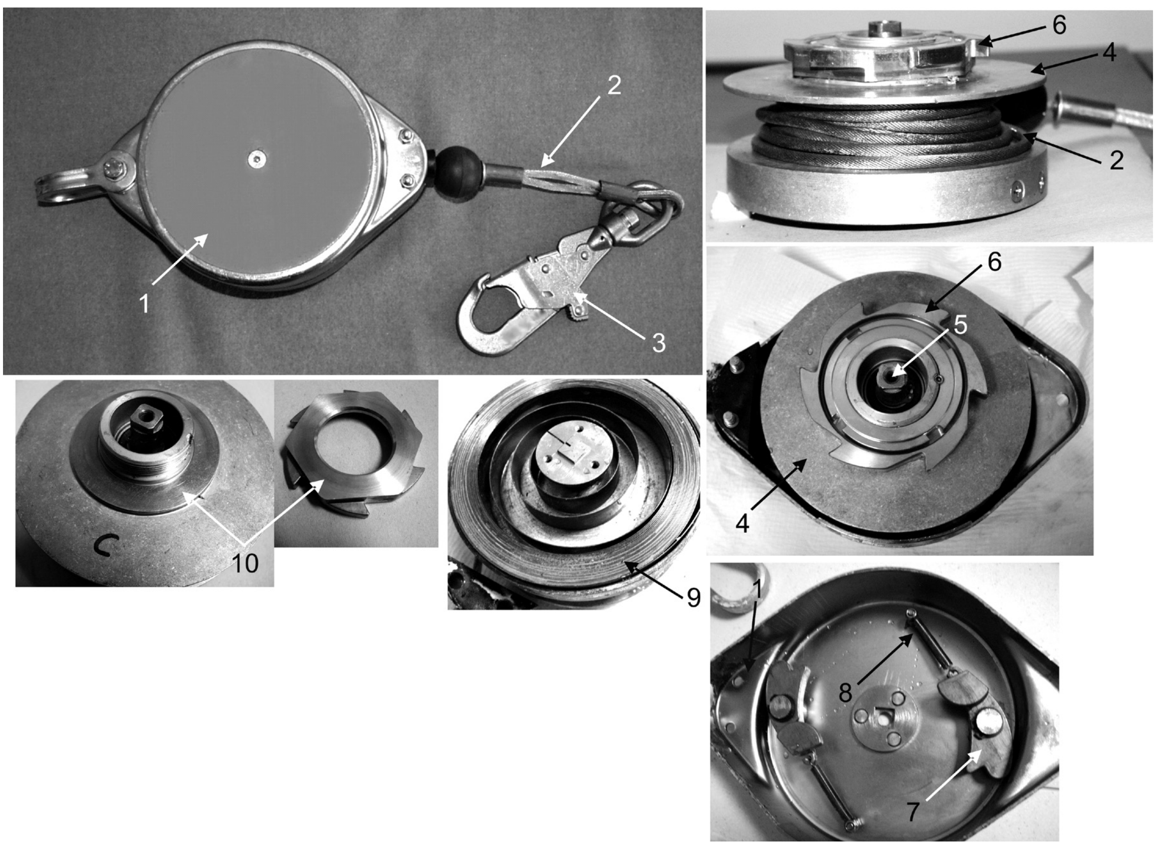

Figure 1. Construction of retractable type fall arrester. *Notes.* 1—casing, 2—retractable lanyard, 3—connector, 4—drum, 5—axle of drum, 6—toothed ring, 7—pawls, 8—springs of pawls, 9—spring of drum, 10—friction brake.

TABLE 1. Typical Materials Used in Retractable Type Fall Arresters

Element of Retractable Type Fall Arrester	Material
casing	deep drawn steel with zinc coating or plastic
retractable lanyard	quality steel with zinc coating or stainless steel
drum	aluminium alloy or constructional tonnage steel with zinc coating
spring of drum	spring steel (special purpose)
pawls	constructional tonnage steel with zinc coating or copper alloy
springs of pawls	spring steel (special purpose)
axle of drum	constructional tonnage steel with zinc coating or quality carbon steel
guiding element of retractable lanyard	copper alloy or stainless steel
other elements (axle of pawls, screws, pins)	constructional tonnage steel with zinc coating
body and gate of connector	constructional tonnage steel with zinc coating, stainless steel or aluminium alloy
spring of self-closing gate of connector	spring steel

the worksite, and with falling down as a result of losing contact with the worksite.

In the first case, slow unreeling of the wire rope (webbing) and putting the flat spiral spring under tension takes place when the user is moving away from the device, whereas when he is getting closer to it, the spring causes the wire rope (webbing) to reel back on the drum. In the second case, when the user starts to fall down, the rotational speed of the drum increases rapidly. When it exceeds the threshold value, the pawls are blocked by the teeth of the ring. This, in turn, causes friction braking to start. Thus, the kinetic energy of the object falling down is absorbed with a simultaneous reduction in the force exerted on the attachment point of a full body harness to a value ≤6 kN [5].

3. METHOD OF TESTING RETRACTABLE TYPE FALL ARRESTERS

An analysis of the technical condition of retractable type fall arresters withdrawn from use showed that corrosive processes could cause two very dangerous effects: decreased strength of individual elements (e.g., the springs of the pawls or the drum), and impaired functioning of mobile elements (e.g., the automatic gate of the connector).

That is why the following issues were selected for laboratory tests of the effect of a corrosive medium on retractable type fall arresters:

- the location of corrosion of the base metal in elements of fall arresters;
- the location of corrosion of protective coating e.g., zinc, in elements of fall arresters;
- the ability to fully withdraw the retractable lanyard from the drum and its self-reeling;
- the correct operation of the closing and blocking elements of the connector [11];
- the change in blocking distance H_B defined as the length of the retractable lanyard withdrawn during fall arrest of the test mass.

The study was carried out on eight pieces of seven types of devices representing various construction designs. Table 2 lists their characteristic features.

Laboratory tests were conducted to detect the points where corrosion developed and the effects of corrosion on the correct functioning of retractable type fall arresters. A corrosive environment was simulated with neutral salt spray (NSS) [12]. Corrosion resistance of metals and their alloys, certain metallic coatings (anodic and cathodic) and organic coatings on metallic materials was tested [13]. NSS is also used to test corrosion resistance of personal protective equipment protecting against falls from a height [14].

TABLE 2. Construction of Retractable Type Fall Arresters Used in Tests

Characteristic	Retractable Type Fall Arrester A1	A2	A3	A4	A5	A6	A7
Length of retractable lanyard (m)	15	4.5	5	6	15	10	4.5
Retractable lanyard	zinc-coated steel wire rope, 4 mm in diameter	zinc-coated steel wire rope, 5 mm in diameter	polyester webbing, 25 mm wide	zinc-coated steel wire rope, 4 mm in diameter	zinc-coated steel wire rope, 4 mm in diameter	zinc-coated steel wire rope, 4 mm in diameter	polyester webbing, 25 mm wide
Class of connector [11]	T	T	B	T	T	B	T
Connector body	zinc-coated steel	zinc-coated steel	zinc-coated steel	zinc-coated steel	zinc-coated steel	zinc-coated steel	zinc-coated steel
Casing	steel	steel	steel	plastic	plastic	steel	plastic
Interlocking mechanism	pawls connected with separate plate	pawls connected with casing	pawls connected with casing	pawls connected with drum	pawls connected with drum	pawls connected with drum	pawls connected with drum
Drum	aluminium alloy	aluminium alloy	aluminium alloy	aluminium alloy	aluminium alloy	aluminium alloy	aluminium alloy
Brake	internal with adjustment	internal without adjustment	internal without adjustment	internal without adjustment	internal without adjustment	internal with adjustment	internal without adjustment

Before the beginning of conditioning in a corrosive environment, the devices were specially prepared. This involved removing all lubricants and stains which could interfere with the access of the corrosive factor to the metal elements. The initiation of the corrosion process was thus prevented. The procedure of preparation for conditioning involved

- dismantling the casing of the device;
- removing mechanically all lubricants and stains with a soft cloth;
- washing the device with a soft brush in lukewarm water with a mild detergent and then leaving it to dry;
- washing the device in acetone at 30 ºC in an ultrasound washer (for 15 min);
- leaving the device to dry in a well-ventilated place for 30 min.

Then the fall arresters were re-assembled and blocking distance H_B was measured on a stand presented schematically in Figure 2.

The tested device (5) was mounted on a rigid load-bearing construction, consistent with the requirements of Standard No. EN 364:1992 with respect to natural frequency of vibration and deformation as a result of static load [14]. The retractable lanyard was connected to a flexible test mass (6). The test mass was a 5-kg cylindrical bag filled with sand. That solution eliminated stepwise action of retractable type fall arresters and thus the characteristic jerks of the test mass. Thus it was possible to measure blocking distance H_B.

Then the devices were conditioned in a corrosive environment using NSS with the following parameters:

- the pH of sodium chloride: 6.5–7.2;
- concentration of sodium chloride: 50 (±5) g/L;
- temperature inside the spray cabinet: 35 (±2) ºC;
- average rate of collection of solution: 1–2 ml/h for a horizontal collecting area of 80 cm^2;
- duration of conditioning: 24–185 h.

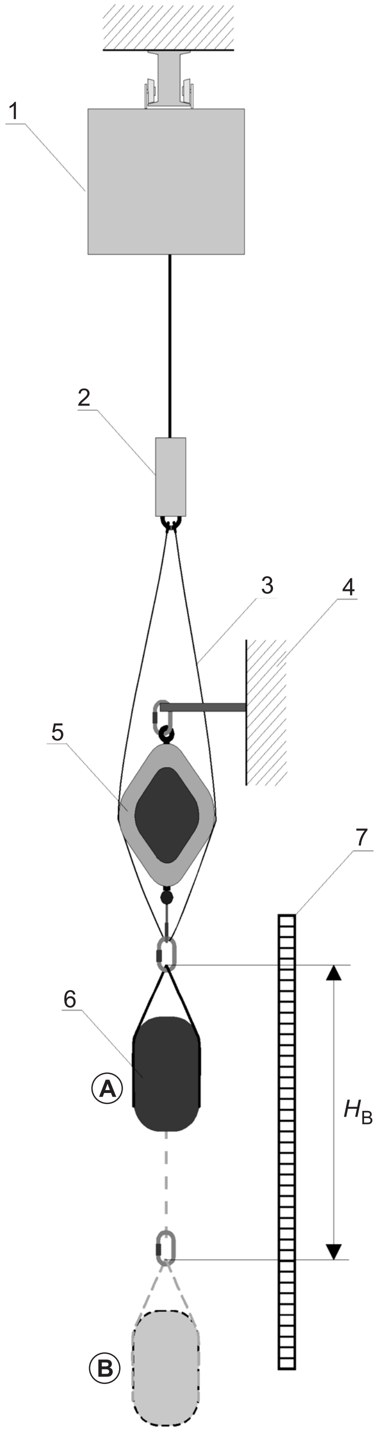

Figure 2. Test equipment for retractable type fall arrester. *Notes.* A—state before fall, B—state after fall, 1—power winch for lifting and lowering test mass, 2—quick release device, 3—flexible connector, 4—rigid construction, 5—retractable type fall arrester, 6—flexible test mass, 7—flexible rule.

The devices were conditioned with two methods: (a) with complete casing, a fully withdrawn retractable lanyard and suspended with a retractable lanyard opening in the casing directed upwards; and (b) with the casing dismantled and the retractable lanyard fully wound on the drum. Method (a) more accurately simulated the actual using conditions, whereas (b) made it possible for the corrosive factor, to penetrate deeply the elements of the device.

After the prescribed period, the devices were removed from the chamber, inspected, and photographed. Then they were placed again in the testing chamber. After the conditioning, to fix the product of corrosion, the devices were left to dry for ~1 h. Then they were rinsed with lukewarm water to remove sodium chloride deposits and loose product of corrosion, and left to dry. The devices conditioned without the casing were re-assembled.

The final stage of the tests involved checking whether unobstructed full withdrawal from the casing and full self-reeling of the retractable lanyard was possible; checking correct functioning of the closing and blocking elements of the connector; and measuring blocking distance H_B.

4. RESULTS

Exposure to a corrosive environment simulated with NSS caused several dangerous effects in the tested fall arresters. Two types of deposits on elements of the devices were most visible: grayish-white, the effect of the corrosion of the protective zinc coating or aluminum alloys; and reddish-brown, the effect of the corrosion of steel. The formation of deposits depended on the type of devices, method of exposure to the corrosive factor (with or without the casing) and duration of conditioning. Table 3 summarizes the results.

As it follows clearly from the comparison of exposure effects, in the case of devices conditioned with, or without, their casing, the second method caused significantly more rapid corrosion during the same time. Figure 3 illustrates sample progress of corrosion for device A4, conditioned with the casing, whereas Figure 4 illustrates the same for device A6, conditioned without the casing.

TABLE 3. Location of Corrosion and Its Impact on the Functioning of Retractable Type Fall Arresters

Fall Arrester	Conditioning (h)	Corrosion: Location	Corrosion: Impact
A1	48	brake disc, toothed ring	not tested
	120	a/a; pawls, connector	not tested
	168	a/a; casing, spring of drum, axle of drum	permanent blocking of pawls, serious problem with withdrawing retractable lanyard, serious problem with opening of connector
A2	48	connector *	not tested
	120	connector (rusty deposit), spring of drum	not tested
	168	a/a; casing, springs of pawls	no appreciable problems
A4	48	connector, elements of casing, spring of drum	not tested
	120	a/a; retractable lanyard	not tested
	168	a/a; springs of pawls, elements of friction brake	minor problems with withdrawing retractable lanyard and with opening of connector
A5	48	connector, elements of casing, spring of drum	not tested
	120	a/a; retractable lanyard	not tested
	168	a/a; springs of pawls, elements of friction brake	serious problem with opening of connector, failure of self-closing of connector, minor problem with withdrawing retractable lanyard, problem with self-reeling of retractable lanyard
A6	24	retractable lanyard*, connector*	not tested
	48	a/a; springs of pawls, casing	not tested
	120	a/a; connector, retractable lanyard, spring of drum, springs of pawls, axle of drum, ring with teeth	not tested
	185	a/a; brake disc	serious problem with withdrawing retractable lanyard
A7 (without casing)	72	drum*, spring of drum, elements of friction brake	not tested
	144	a/a; axle of pawls, axle of drum	serious problem with withdrawing retractable lanyard, lack of self-reeling of retractable lanyard
A3 (without casing)	72	springs of pawls, casing, axle of pawls, spring of drum, drum*, axle of drum	not tested
	96	a/a; crack of spring of pawl, elements of friction brake	minor problems with withdrawing retractable lanyard and with opening of connector
A6 (without casing)	48	springs of pawls, axle of drum, axle of pawls, spring of drum, retractable lanyard*	not tested
	72	a/a; connector	not tested
	96	a/a; brake disc	not tested
	144	a/a; crack of spring of drum, retractable lanyard	minor problem with withdrawing retractable lanyard, lack of self-reeling of retractable lanyard, minor problem with opening of connector

Notes. Red-brown or white-gray tarnish indicated corrosion; *—white-gray tarnish; a/a—more intensive corrosion in the above locations.

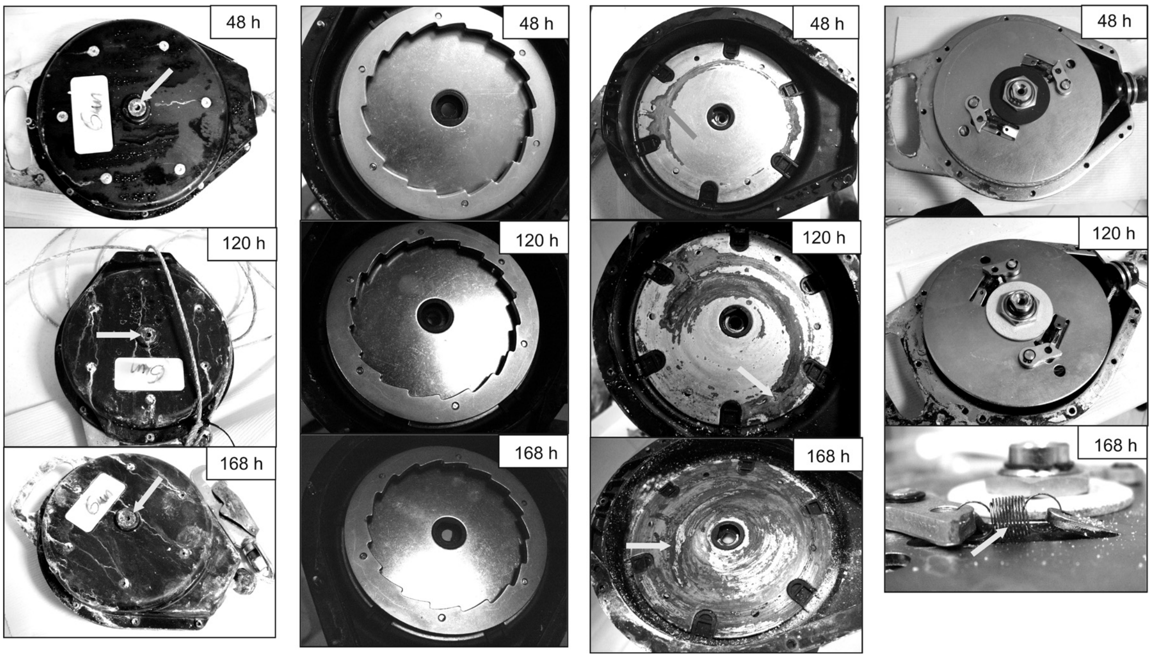

Figure 3. The effects of a neutral salt spray (NSS) test on retractable type fall arrester A4.

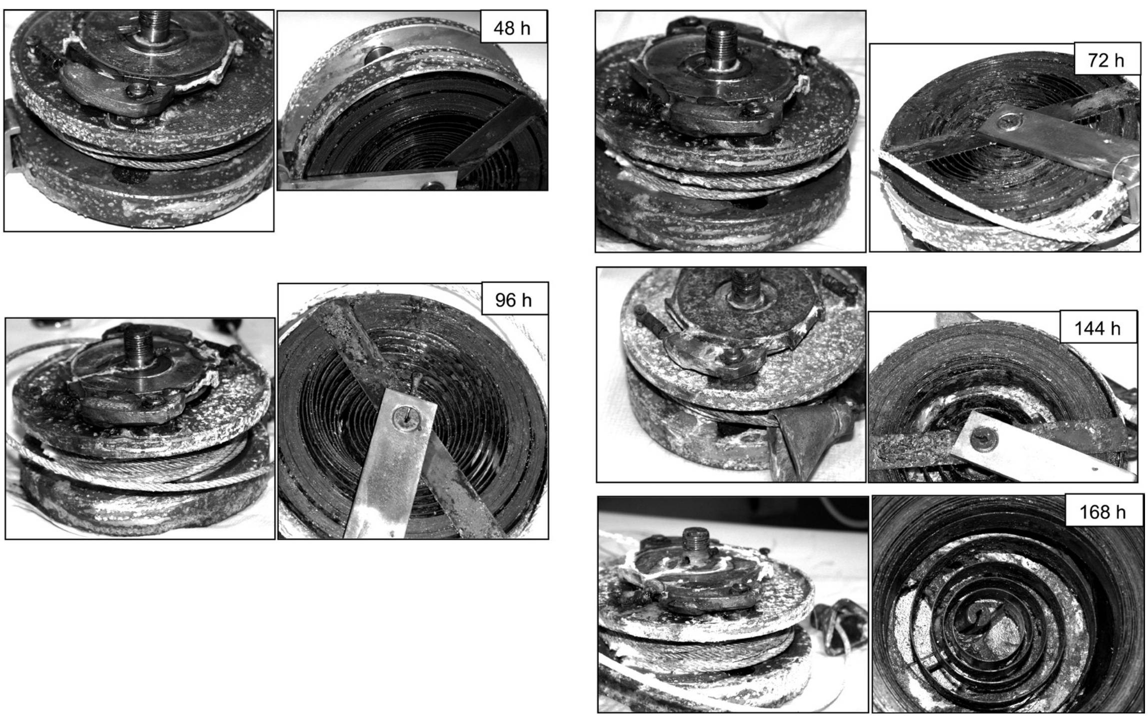

Figure 4. The effects of a neutral salt spray (NSS) test on retractable type fall arrester A6 conditioned without casing.

In the case of devices conditioned with the casing, the signs of corrosion of protective zinc coating and steel appeared the earliest on the elements most exposed to the salt spray, i.e., on the connectors (devices A2, A4, A5 and A6).

In devices A5 and A6, signs of corrosion appeared also on connecting elements of the casing (e.g., rivets and springs), as well as on the drum spring, after 48 h of exposure. After 120 h of conditioning, corrosion also appeared on the drum spring in devices A2 and A6, and additionally on the retractable lanyard, pawls and pawl springs. Longer exposure periods resulted, among others, in corrosion of internal and external surfaces of the casing, pawl and drum axles and toothed rings. In addition to the observed superficial corrosive changes, in the case of devices A3 and A6, conditioned without casings, there was a fracture of the pawl spring and drum spring (Figure 4).

Corrosive changes, developed on the structural elements of retractable type fall arresters, exerted an effect on the functioning of these devices. Manual tests demonstrated that deposited products of corrosion, both of protective zinc layers and underlying steel, increased friction drag between mobile elements. This especially affected the connectors at the end of retractable lanyards, and was manifested in practice by

- difficulties in unblocking and opening of the connectors (devices A1, A3, A4, A5, A6);
- difficulties in rotation of the connector element protecting the retractable lanyard from twisting;
- failure of the self-closing gate of the connector (device A4).

Deposition of corrosion products in the elements of the blocking mechanism, on the axle of the connector gate and between the gate and the body of the connector can be regarded as the main cause of the observed effect.

Negative effects of corrosions were also observed in the functioning of the internal mechanism of retractable type fall arresters, comprising the drum with the spiral spring and the retractable lanyard. Deposition of corrosion products caused the following problems impairing the correct functioning of the devices: (a) withdrawing of retractable lanyard difficult or completely impossible; and (b) self-reeling of retractable lanyard difficult or completely impossible.

Effect (a) was mainly caused by an increased resistance associated with drum movement and adherence of retractable lanyard loops. For device A1, the resistance associated with retractable lanyard withdrawal was so increased that manual withdrawal became practically impossible. Complete impossibility of withdrawal of the retractable lanyard could also result from blocking of the drum by pawls, whose springs had broken due to corrosion (device A3 conditioned without the casing).

Effect (b) was due to corrosion of the spiral spring of the drum. Corrosion led to adherence of spring coils, impairing its efficient functioning. An extreme example of corrosion effects of this type was device A6, in which, during the conditioning without casing, the drum spring broke without any external stimulus, making self-reeling of the retractable lanyard absolutely impossible.

The final stage of the study involved testing the effects of corrosion on the functioning of the devices under dynamic conditions by measuring blocking distance H_B for each device during flexible test mass fall arrest. Figure 5 illustrates the results.

An analysis of the results leads to the following observations: (a) in all the investigated cases, the mean value of blocking distance $\overline{H}_B$ obtained for the devices subjected to conditioning was higher than that obtained for nonconditioned devices; and (b) for devices A2, A5 and $A6_1$ the value o H_B obtained in the first test after conditioning was significantly higher than H_B obtained from the next 10 tests.

Correlation of the obtained test results with observations of corrosion on the structural elements of retractable type fall arresters showed that the main cause of an increase in $\overline{H}_B$ was corrosion of the mechanism of the pawls and the elements determining the resistance of drum rotation. Corrosion of the pawls, their springs and axles caused that larger forces were required to set them in motion. The drum had to reach higher rotational speed on retractable lanyard withdrawal, which, in turn, led to an increase of test mass fall distance. In extreme situations, the device could be completely incapable of blocking the retractable lanyard.

The drum had to reach appropriate rotational speed for the pawl mechanism to start working. When the resistance of drum movement increased significantly as a result of deposition of corrosion

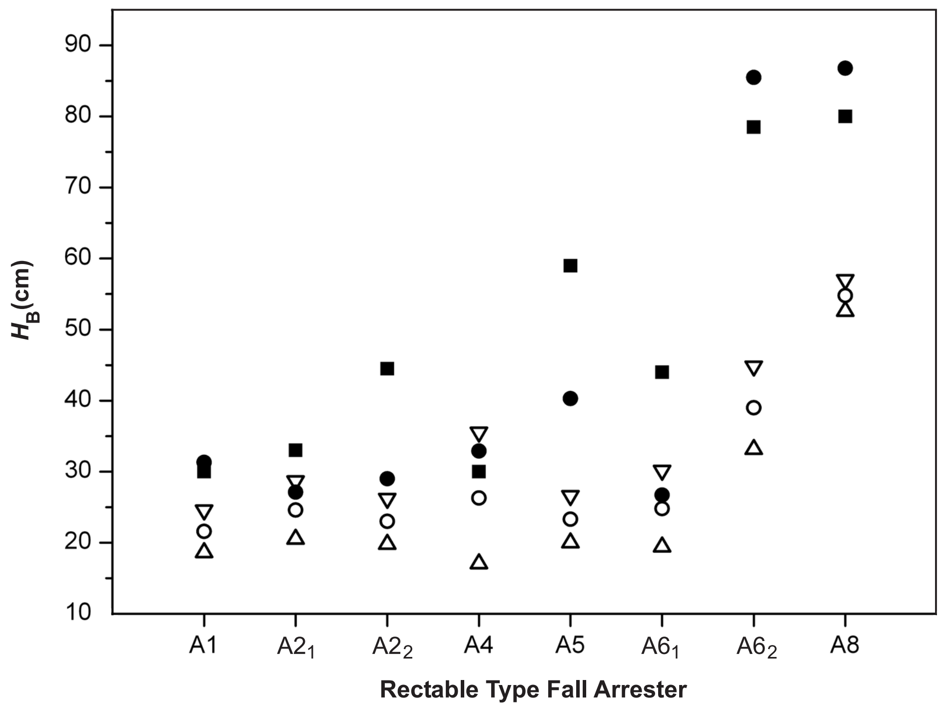

Figure 5. Tests results of retractable type fall arresters. *Notes.* A1–A7—types of devices, A2$_1$, A2$_2$,A6$_1$, A6$_2$—devices of the same type, ○—mean value of blocking distance from tests without conditioning, ●—mean value of blocking distance $\overline{H}_B$ from tests with conditioning, △—$\overline{H}_B$ – *SD*, ▽—$\overline{H}_B$ + *SD*, ■—H_B result of the first measurement after conditioning.

products, an increase of test mass fall distance was required.

Sometimes corrosion products deposited on the internal elements of retractable type fall arresters were partially chipped during fall arrest by the device. Therefore, in the consecutive tests of the same device blocking distance H_B was reduced and the problems with retractable lanyard withdrawal and its self-reeling became less significant. The values of H_B and $\overline{H}_B$ for devices A2, A5 and A6$_1$ (Figure 5) present this phenomenon.

5. CONCLUSION

Several conclusions can be drawn from the presented test results, with respect both directly to the laboratory findings, and to their consequences regarding safety of the users of retractable type fall arresters and their proper protection against falls from a height.

The most important conclusion is that corrosive changes affecting even a very small area can pose a serious threat for proper functioning of devices, and, consequently, for their users' safety. The most serious risk is a failure to arrest the fall, which may result from

- breaking of any of the load-bearing elements of the device (e.g., body of the connector, retractable lanyard) as a result of corrosion of the base material (e.g., steel);
- failure of the pawl mechanism and, consequently, no drum blockade (e.g., as a result of increased resistance during the movements of the pawls on their axles);
- detachment of the nonclosed connector (e.g., due to loss of the self-closing function).

The consequences of corrosion of pawl mechanisms and elements of friction brakes may include deterioration of the conditions of fall arrest. It can be demonstrated by an increased distance of fall arrest, as a result of which the user is at risk of collision with elements of the workplace or with the ground, and by increased dynamic forces affecting the user through full body harness, which poses a risk of internal injuries. Corrosion may also make using devices more difficult, e.g., by increased resistance of retractable lanyard withdrawal or problems with opening the connectors.

The hazards characterized here indicate unequivocally that the problem of corrosion is so serious in the case of retractable type fall arresters that it should be solved at three levels: manufacturers of the devices, notified bodies assessing their construction and end users. The manufacturers should use materials with adequate resistance to corrosion or effective protections against it. The design of new constructions should consider their reliability in the case of deposition of corrosion products, especially where access is difficult.

The task of the end users of the protective devices, as well as of persons responsible for the maintenance of personal protective equipment used in companies is also very important. These persons should have relevant knowledge and technical facilities to be able to detect corrosion both on internal and external elements. This problem is especially important when equipment is used in an aggressive industrial environment, e.g., in the vicinity of chemical plants, in sea climate, etc.

The reliability of retractable type fall arresters supplied to end users in the European Union is also assessed by notified bodies testing and evaluating these products. Harmonized Standards No. EN 360:2002 [5] and EN 364:1992 [14] are the current bases for testing and assessing conformity of retractable type fall arresters with the requirements of Directive 89/686/EEC. Those standards do not specify either the method or the scope of testing these devices after they have been conditioned in a corrosive environment. Taking into consideration the results of the tests discussed here, such testing should include

- the functioning of the connector;
- blocking distance, which should not differ significantly from that measured before the conditioning;
- proper full withdrawal of the retractable lanyard;
- automatic full self-reeling of the retractable lanyard into the casing of the device.

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