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HYDRAULIC RESCUE EQUIPMENT FOR FIREFIGHTERS

Abstract. Authors deal with the topic relating to use of hydraulic extrication tools while technical interventions. They characterize the individual technical items used during extrication. They characterize material and technical equipment of rescue units emphasizing the need of systematic approach to any emergency situation relating to extrication of persons.

Keywords: Hydraulic extrication tool, hydraulic spreader/expander, hydraulic cutter, hydraulic elevating ram jacks, power unit, emergency situation, material and technical equipage.

HYDRAULICZNE WYPOSAŻENIE RATUNKOWE DLA STRAŻY POŻARNYCH

Streszczenie. Autor zajmuje się zastosowaniem narzędzi do wyciągania hydraulicznego w interwencjach technicznych w zakresie ratowania osób i bliżej charakteryzuje poszczególne elementy techniczne wykorzystywanych urządzeń ratowniczych. Charakteryzuje wyposażenie techniczne odpowiednich jednostek i podkreśla potrzebę systematycznego rozwiązywania każdej nadzwyczajnej sytuacji awaryjnej związanej z wydobywaniem osób.

Słowa kluczowe: narzędzie do wyciągania hydraulicznego, rozsiewacz hydrauliczny/ekspander, przecinak hydrauliczny, podnośnik hydrauliczny, jednostka napędowa, sytuacja awaryjna, materiał i wyposażenie techniczne.

There is an urgent need for modern, economical stronger and faster vehicles. This is a challenge to be bear with a modern epoch not only for rescuers but also for used extrication equipment. Demandingness of rescue activities is thus more difficult and demanding annually. Rescue activities are complicated by new automobile vehicles which are manufactured. Intervening units must overcome laminated glazing, high strong steel reinforcement that is able to cause damage or even eliminate hydraulic tools from operation.

Safety has become one of the most demanding features. It has become more complex system. There are widely discussed topics between men and machines. Among them there are especially accident simulation tests, vehicle interior design and body, as well as the occupational and pedestrian protection, accident avoidance scenarios, injury mitigation, legislation and technology changes.

Legal regulations and standards concerning the use of extrication equipment

Some of the regulations only partly pay attention to the theme, which aims at Fire and Rescue Service in general. Other regulations, on the contrary, deal with it and are closely specialized in it. There are especially the Minister of Interior's Order and the President of Fire and Rescue Service's Directions.

- Act No. 314/2001 Coll., on protection against fire as amended
- Act No. 315/2001 Coll., on Fire and Rescue Service
- Act No. 8/2009 Coll., on Road Traffic Act
- Act No. 124/2006 Coll. on Occupational Safety and Health and amending and modifying some Acts
- Act No. 264/1999 Coll., on technical requirements and reviewing accordance
- Decree of the Ministry of Interior of the Slovak Republic No. 611/2006 Coll. on firefighting units
- Decree of the Ministry of Interior of the Slovak Republic No. 162/2006 Coll. on firefighting technique and equipment characteristics and on particular conditions of operation and securing regular check thereof.
- Regulation of the Ministry of Interior of the Slovak Republic No. 26/2002 Coll. Slovakia.
- Directions of the President of Fire and rescue Service No. 20/2007, on the tactical and methodical practices of rescue service performance
- Directions of the President of Fire and rescue Service No. 31/2005, on technical and tactical parameters and on Fire and Rescue Service vehicle technical equipment

Among all the above mentioned legal regulations, it is important to mention the Regulation of the Ministry of Interior of the Slovak Republic no. 26/2002 Coll. Slovakia which specifies the requirements for safe work with extrication equipment or Decree of the Ministry of Interior of the Slovak Republic No. 611/2006 Coll. on firefighting units which defines the means of Fire and Rescue Service and requirements for their usage. Directions of the President of Fire and rescue Service No. 31/2005 on technical and tactical parameters of the Fire and Rescue Service.

European standard EN 13204:2004 "Double acting hydraulic rescue tools for fire and rescue service use. Safety and performance requirements". This standard involves fire-fighting equipment, rescue equipment, cutting tools, hydraulic equipment, hydraulically powered equipment, hazards, equipment safety, safety measures, testing of performance characteristics, checks, emergency equipment, risk assessment, operation and maintenance. This standard is used also by manufacturers. These requirements should reflect any changes relating with vehicle development. It is also used by manufacturers of hydraulic extrication equipment.

Technical description of hydraulic equipment

Subject of new vehicle construction are mainly new deformation zones in the front vehicle part in case of frontal impact. Restraint rods against side-on impact are located in side vehicle doors. At the frontal impact, the size and system of wheels and engine deviation are important for protection of lower limbs of transported persons. There has been a discussion on high alloy steel for bodywork frames and on Titanium steel or reinforcement of the most important bodywork parts (pillars) by so-called steel strip which cannot be cut by hydraulic extrication equipment produced before 2002.

Each automobile production has own designing studios where safety engineers design bodyworks consisting of extremely hard safety frame that is understood as a safe area for travelers and that is surrounding by deformation zones capturing impact energy. Deformation zones absorbing impact energy help to minimize unwanted impact consequences. Side-on deformation zones located between outer door panel and inner cladding disperse impact energy on large area while shockproof stiffeners are intended for danger minimalization in case of side impact.

Creation and development of extrication equipment was connected with development of automobile industry and transport. It was just an increasing vehicle number as well as strengthened transport on transporting roads that brought also increasing number of accidents and injured persons. New technologies and materials development directly was connected with increasing of

speed and performance of transporting vehicles what besides clear advantages had also effect on accidents seriousness.¹

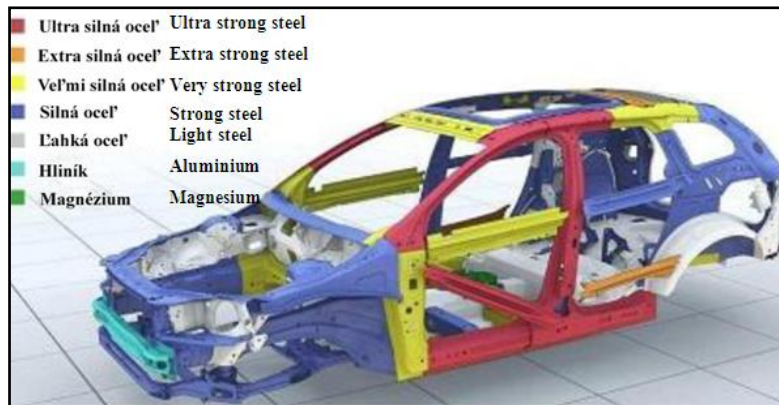


Fig.1. Volvo SX60 vehicle material production

The important fact is that relatively large percentage of all traffic accidents number is caused by lorries. It is necessary to take into account that mass and size of the vehicle has a great effect on traffic accident seriousness and consequences. Also development of highway and whole road network where increased traffic velocity as well as traffic density lead to many traffic accidents. It is necessary to mention also several railway accidents and crashes of vehicles and trains. All of these mentioned factors lead to the fact that many injured persons were captured in crashed transport means and it was necessary to extricate them as soon as possible.² Due to increased number and seriousness of traffic accidents, it was necessary to increase technical equipage, and speed and flexibility of responding members of firefighting and rescue units. Solution was represented in progressive putting in place of special extrication equipment required mostly at traffic accident response into the Fire and Rescue Corps units' equipage.

Extrication equipment is a significant technical tool required at traffic accident involving injured persons. Use of extrication equipment significantly shortens time for reaching victims in a crashed vehicle what fastens first aid rendering. Technical tools intended for direct extrication of persons can be classified in three basic groups:

- Hydraulic extrication equipment;

¹ Marcinek M., *Correlation of tested parameters of hydraulic cutters at cutting pillars of selected personal vehicles within technical interventions*, Zvolen: Technical university in Zvolen, 2012, p. 167.

² Marcinek M., *Simulation of crisis situations of the national and international crisis management as a support for crisis managers' education*, Žilina: FSI ŽU, 2011, p. 117.

- Pneumatic extrication equipment;
- Mechanic extrication equipment.

Hydraulic extrication equipment

Hydraulic extrication equipment represents the most significant part of the equipage of responding Fire and Rescue Corps units. Its force operational ranges and mutual compatibility of individual items allow large use as regards extrication of captured persons. It can be divided into several parts that together assembly one unit.

Power unit

Engine power unit serves as a source for pressure energy production. It consists of:

- Hydraulic pump
- Loading frame
- Safety valve
- Tank for hydraulic oil
- Manifold distribution valves

Hydraulic piston radial two-stage pump creates in the hydraulic circuit a pressure 1.5 MPa at the first stage and 72 MPa in the second stage.

Power units are divided according to number of pressure outlets to the one-branch power units and the two-branch ones that can supply a power for:

- one tool /STO - Single Tool Operation/
- two tools simultaneously /MTO - Multiple Tool Operation/
- two tools alternatively /ATO – Alternative Tool Operation/

Another possible division way is according to engine powering:

- powered by combustion engine
- powered by electric engine.

For better handling with power units, a hose reel is installed as a part thereof with two pairs of 20 m high pressure hoses with quick action couplings or single hose line. The hose reel can be operated independently but also with pressured hoses. It can be affirmed on the side or front frame wall of the power unit. The disadvantage is an increasing mass of the power unit. Individual powering possibilities have their advantages and disadvantages. In a case of distance longer than the hose length, the power unit can be taken off and located closer to an accident site; while the electric powering, which supplies a continuous power, has an operation radius from the electric power source limited by sum of pressure hoses length and electric cable length.

Table 1. Technical data of power units

Aggregate	E 330 L	V 330	V 40 Silent	V 50 Turbo
Motor	Electric motor 220V/50Hz	four-stroke petrol engine	four-stroke petrol engine	four-stroke petrol engine
Oil volume	2 l	2 l	2 l	4 l
Output power	0.5 kW	1.3 kW	1 kW	2.6 kW
Operation pressure	630 / 700 bar	630 / 700 bar	630 / 700 bar	630 / 700 bar
EN - class	STO	STO	ATO	MTO
Mass	19 kg	18 kg	24 kg	28 kg

Pressure hoses and hose reel

They serve for pressure energy transport from engine unit to an adapter of extrication equipment. One or two pairs of 20 m pressure hoses distinguished by colours are assembled to the hose reel. One hose from the pair always supplies oil to the working part of the extrication equipment and the second one this oil takes off. Another possibility is a pressure energy distribution by one hose line. For connecting pressure hoses are used quick action couplings with safety locking.

Hydraulic spreader

It serves for expansion, opening door deformed at traffic accident, squeezing of frame pillars and their removing, lifting the loads and for approach. Chain parts with quick action couplings significantly spreading use of hydraulic spreader tool are important accessories. They are divided according to force magnitude by which they act on spreading path.

Table 2. Technical data of spreading tools

Spreader	SP 35	SP 40	SP 60	SP 80
Spreading force	42 – 93 KN	48 – 118 KN	68 – 245 KN	90 – 470 KN
Tensile force	38 KN	48 KN	77 KN	105 KN
Spreading	615 mm	710 mm	815 mm	620 mm
Mass	17.7 kg	19.4 kg	24.9 kg	25 kg
EN- class	AS 35	LHS 40	BS 63/810-25	CS 87/600-25

Hydraulic cutter

Hydraulic cutter is intended exclusively for cutting and separating of bodywork parts, e.g. roof using cutting blades. It can be used for flat or profiled section materials. They cannot be used for axles, leaf springs, or steering wheel where cutter damage threats. Hydraulic cutters are divided according to power and maximal opening of cutting blades.

Table 3. Technical data of hydraulic cutters

Cutters	S 140	S 180	S 260	S 270	RS 165	RS-170
Opening	140 mm	180 mm	260 mm	270 mm	165 mm	170 mm
Maximal round bar diameter	Ø 22 mm	Ø 30 mm	Ø 32 mm	Ø 36 mm	Ø 36 mm	Ø 43 mm
Mass	9,1 kg	13,5 kg	14,9 kg	17,4 kg	16,8 kg	18,9 kg
EN - class	D	G	H	H	BC-165-F	BC 170-H

Hydraulic combined tool

It is a combination of hydraulic cutter and hydraulic spreader in a one tool. It can be used for spreading, cutting, squeezing, elevating and approaching. Special cutting knives are equipped with blades enabling cutting metal sheets as well as profiled materials.³ When using combined tools, a combination with chain harness or spreader adapter is possible. They are divided according to performance (Table 4) and power unit – with engine or mechanical power energy.

Table 4. Technical data of combined tools

Combined tool	HANDVARIO SPS 250 H	VARIO SPS 330	VARIO.SPS 400
Opening	250 mm	330 mm	425 mm
Opening force	40–83 KN	36–90 KN	48–726 KN
Tensile force	–	32 KN	58 KN
Maximal round bar diameter	Ø 22 mm	Ø 25 mm	Ø 35 mm
Mass	10.4 kg	13 kg	18.5 kg
EN – class	–	F	H

³ Marcinek M., *Testing program according to principles for testing firefighters' accoutrement and armoury GUV 67.13 Hydraulic extrication equipment. Methodical guidelines for revision of WEBER HYDRAULIK equipment*, Praha: Generální ředitelství VPO, 2001, p. 42.

Hydraulic spreading ram jack

It serves for pushing off, supporting and pulling off construction parts or to enlarge openings created by hydraulic spreader or combined tool. When using terminal adapters together with chain harness and changeable footing, it is a suitable accessory to increase action ability of intervening rescuers.⁴ Spreading rams are divided according to working piston into double-acting (Table 5) and telescopic.

Table 5. Technical data of double acting rams

Spreading ram	RZ 1- 850	RZ 2-1250	RZ 3-1600
Pressure force	120 KN	120 KN	120 KN
Tensile force	23 KN	23 KN	23 KN
Initial length	530 mm	750 mm	1100 mm
Piston stroke	320 mm	500 mm	500 mm
Final length	850 mm	1250 mm	1600 mm
Mass	12.5 kg	16 kg	18.5 kg

Hydraulic pedal cutter

Extremely light and compact cutter intended for use in confined spaces as one-hand tool. It serves for removing pedal at foot capturing during traffic accident. They are divided according to cutting jaws size (Table 6).

Table 6. Technical data of pedal cutters

Pedal cutter	S 30	S 50
Width of jaws	33 mm	50 mm
Maximal round bar diameter	Ø 15 mm	Ø 16 mm
Mass	3.7 kg	4.5 kg

Hydraulic extrication equipment with electric-hydraulic power

Rescue extrication equipment with 12 V direct current integrated battery electric-hydraulic power has manifold use. Due to unchangeable performance when comparing with classically powered tools, they are flexible and have unlimited action radius. They do not consume many space, are quiet and ecological (Table 7).

⁴ Marcinek M., *Hydraulic extrication equipment*, Product catalogue WEBER HYDRAULIK for the Czech Republic and Slovak Republic. Praha: Generální ředitelství VPO, 2003, p. 12.

Table 7. Technical data of hydraulic extrication equipment with accumulator power

Tool	SP 35 A	S 140 A	SPS 330 A
Spreading force	34-170 KN	–	40-90 KN
Maximal round bar diameter	–	22 mm	25 mm
Tensile force	29 KN	–	32 KN
Maximal opening	615 mm	140 mm	330 mm
Tensile distance	530 mm	–	400 mm
Mass	22 kg	13,5 kg	17 kg

Hydraulic extrication equipment with mechanical power

They are hydraulic tools intended for special use or for efficiency increasing of used hydraulic extrication equipment; for example:

- set for opening door;
- set for stroking;
- manual hydraulic pump;
- manual combined tool.

Accessories of extrication equipment

Among technical tools used by the Fire and Rescue Corps units at traffic accidents belong not only equipment mentioned above but also tools that do not serve for direct extrication of persons from crashed vehicles.⁵ They are prevalently tools intended for protection responding rescuers as well as injured persons. They are:

- airbag arrester
- spring glazing breaker.
- set for work with glazing;
- saw for sawing glued safety glazing;
- technical tools for protection injured persons (blanket, tent canvas, etc.) enabling protection of injured persons against further injury that can be these persons be exposed during rescue activities; e.g. broken pieces and fragments, sharp edges, etc.;
- technical tools for stabilization of crashed vehicle (cascade prisms, struts, etc.) prohibiting further shakes of crashed vehicle that lead to worsening of health condition of injured persons;

⁵ Dworzecki J, *Prvky bezpečnostního systému v silniční dopravě*, Karlovy Vary: „Karlovarská právní revue“, 2011. No. 1, p. 129–144.

Comparison of times required for opening and closing of selected types of hydraulic cutters

Based on scientific research of this discussed topic, we can compare three individual types of hydraulic extrication equipment as regards working arms rate (Table 8). As shown on the Figure 2a) opening and closing times are different. It is connected with the angle φ (rad) that is calculated from adequate arm area. For closing time we can state that with decreasing φ (rad) value, the closing time increases.

Table 8. Comparison of times required for opening and closing of hydraulic cutters

Hydraulic cutter	opening time (s)	closing time (s)	φ (rad)	ω opening	ω closing
				(rad.s-1)	(rad.s-1)
Holmatro-3040 NCT	8,448	5,278	3,142	0,372	0,595
Holmatro-4035 GCP	7,258	5,682	2,047	0,282	0,360
Weber S-260	10,47	7,252	1,734	0,166	0,239

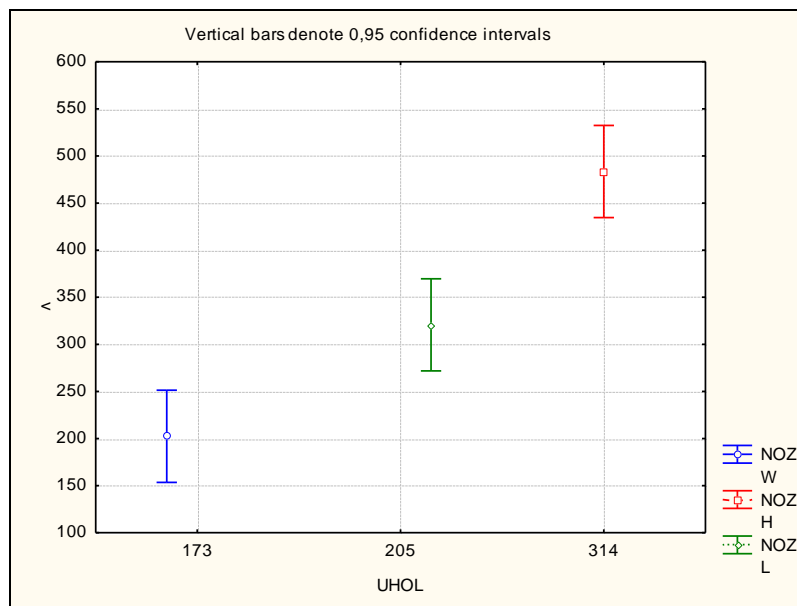


Fig. 2 Mutual comparison of studied parameters for hydraulic cutters

C) Graphical expression of 1-factor analysis of influence of hydraulic cutter angle on cutting speed. Legend: Angle 173 - W-S260, 205 - H-3040 and 314 - H-4035; v is speed (rad/s); and abbreviations: NOZ W – Weber S260, NOZ H Holmatro H-3040 NCT a NOZ L - Holmatro-4035 GCP.

Mutual comparison of opening and closing times of hydraulic cutters and calculated radial speed

Based on our measurements (Table 8) we can state that as regards opening time the fastest is testing model H-4035 CGP hydraulic cutter, followed by the H-3040 NCT type and the last one is the W-S 260 model. As regards closing times, the fastest is H-3040 NCT type tightly followed by the H-4035 CGP type, and the last one is the W-S 260 type. From the practical standpoint taking into account the cutter mass, as regards cutter mass and resulting physical exertion during work, the more favourable is H-4035 CGP cutter. During practical part of the experiment another positive point confirming this statement appeared- an advantage of one-hose H-4035 CGP cutter connection with power unit; while cutters H-3040 NCT and W-S 260 were connected by two-hose system. At the H-4035 CGP cutter type this connecting option was more suitable when comparing with the two-hose system as regards rescuers moving rate with the tool during cutting and cutter handling. The two-hose system used to get jammed, create loops and required greater attention at cutter moving and appeared relatively stiffly.

When taking into account also time required for connecting two quick action couplings compared with time for one H-4035 CGP coupling, we can state that cutter H-4035 CGP seems to be the most suitable from this practical comparison. To make clear the total quality of operation tested tools as regards ergonomics and on basis of gained practical experience during experiments carrying out we can judge also way of operating cutters. In this case we took into account FRC members' opinions and their statements based on practical situations from responses with hydraulic extrication equipment when ergonomically more suitable is to use tools of the H type. This way is much more suitable mostly at work and handling cutter above the shoulder height where operation is more convenient and less demanding than operation the W type cutter.

Summary

Rescue of involved persons trapped in vehicles at traffic accidents is a continuously developing topic.⁶ Every rescue response is specific and unique. The choice of rescue equipment and tools always depends on the intervention commander who is fully responsible for situation seriousness evaluation and

⁶ Dworzecki J., *Traffic in Poland. Diagnosis of safety components*, [In:] *Metodológia a metodika analýzy zdrojov ohrozenia vnútornej bezpečnosti SR*, Bratislava: Akadémia Policajného zboru, 2011, p. 66–74.

consequently for choice of rescue tools. The equipment used in an actual situation is affected also by other factors.

Requirements laid on extrication equipment are unambiguously determined by vehicles that are produced and are driven on roads. It depends on extrication equipment producers who have to judge these requirements and to produce devices that can handle and overcome new technologies used for vehicles production. This technical equipment leads mostly to shortening time required for intervention but also to protection of intervening firefighters and increasing their safety. At the last, but not the least, it improves ergonomics of controlling and operation of extrication equipment what not in small extent saves intervening rescuers force.

Regarding growing requirements relating to vehicle safety, research in this field becomes more intensive and new innovative solutions appear regularly. It can be seen that older vehicles are not equipped by all modern safety elements available on current market not only for their high financial demand but mostly due to vehicle production year or from producer's reasons who does not install these elements into his vehicles on contrary with other producers..

Safety of vehicle crew is on a value pedestal but new vehicles seem to be a threat for extrication equipment. Modernization of hydraulic extrication equipment should be growing arithmetically wit new vehicles production. Saving of human lives represents seconds that can be prolonged even into several minutes which can cause even fatality for a human being due to more complicated vehicle bodywork combined together with passive safety elements. If a human has not got oxygen input up to 5 minutes, a non-reversible damage of brain cells occurs resulting in physical organism damage or even with a fatality phenomenon.

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