Future in Marine Fire-Fighting: High Pressure Water Mist Extinguisher with Abrasive Water Jet Cutting

Budućnost gašenja požara na brodu: vatrogasni aparati s pjenom pod visokim pritiskom i s abrazivnim oštrim mlazom

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Summary

This paper is dealing with the problem of extinguishing fire on ships and off-shore equipment characterized by high degree of danger caused by presence of explosive or life threatening substances. Special device Cold Cut System Cobra combining cutting possibility and production of water mist is presented. Its advantages and application possibilities are discussed. This fire extinguisher has been widely used for more than one decade but based on a literature search we suppose that its potential is not fully exploited in marine applications. In cooperation with fire-fighting rescue station in Silesian Ostrava laboratory measurement of reaction forces of Cobra slurry jet was realized at the Technical University of Ostrava. It was discovered that measured force was about 120 – 150 N therefore it represented approximately one third of the theoretical maximum value. The measured force appeared to change not only with the type of material but also with the thickness of the layer being cut, but the change was not significant from the point of view of handling the lance during intervention. Our research may deepen firefighter's knowledge of the tool they are working with and therefore improve safety of their work.

KEY WORDS

Fire fighting
Cold cut system Cobra
Reaction forces
Hand-held applications

Sažetak

Ovaj članak se bavi problemom gašenja vatre na brodovima i na pučinskoj opremi koja je karakterizirana visokim stupnjem opasnosti, koja je uzrokovana prisustvom eksploziva i supstancama koje ugrožavaju živote. Posebna naprava Cold Cut System Cobra kombinira mogućnost rezanja i proizvodnju vodene magle. Njene prednosti i primjena se diskutiraju. Aparati za gašenje se naveliko upotrebljavaju više od jednog desetljeća, a temeljeni su na istraživanju u literaturi i pretpostavljamo da njihov potencijal nije u cijelosti iskorišten u pomorskoj praksi. U suradnji sa stanicom za spašavanje i gašenje požara Silesian Ostrava labaratorijskim mjerenjima, reaktivne sile Cobra mlaza blata ostvarene su na Tehničkom Sveučilištu u Ostavi. Otkriveno je da su mjerene sile bile oko 120-150 N stoga su predstavljale jednu trećinu teoretske maksimalne vrijednosti. Izmjerena sila se izgleda mijenja, ne samo tipom materijala nego i debljinom sloja koji se reže, ali izmjena nije značajna s točke gledišta rukovanja lancetom za vrijeme intervencije. Naše istraživanje može produbiti znanje gasitelja o alatu s kojim radii stoga poboljšati njihovu sigurnost na radu.

KLJUČNE RIJEČI

gašenje vatre
cold cut system Cobra
reaktivne sile
aparati koji se drže u ruci

1. INTRODUCTION

Fire and water are good servants but bad masters. The most dangerous situation arises when they join together against man as for example in case of fires on ships or on off-shore platforms. Although there is plenty of water around in such events it is usually very difficult to manage the fire.

For example on 5 January 2016, the early-morning fire in the Mediterranean resort town of Marmaris (see Fig. 1) completely destroyed two motor yachts. The fire was reported at 2am and the ships were anchored in the harbour, but still it took firefighters four hours to bring the blaze under control [1].

Source: [1]

Figure 1 The fire on a multimillion-pound superyacht Barbie at a marina in Turkey

In August 2004, the Adriatic IV (a drilling jack up) was on location over the Temsah gas production platform, off Port Said, Egypt in the Mediterranean. The rig was drilling a natural gas well when a gas blowout occurred during drilling ops. Reports state that there was an explosion followed by fire which was initially contained on the jack-up. For reasons unknown, the fire then spread to the Petrobel-run platform where it continued to rage for over a week before being brought under control. More than 150 workers on the jack-up and platform were evacuated with no casualties, due in part to the prior recommendation that production activities be ceased as a precautionary measure. [2]

A fire is a fast flaming combustion process. It has been used for ages, in many sorts of application, but when an unexpected fire occurs, the consequences may be dramatic. Fires are responsible for deaths, injuries both physical and psychical and huge damage to properties [4].

It is very important to prevent fires, and reduce the number of them. On the second hand, if a fire still starts, it is necessary to take the appropriate action to tackle it at an early stage. In such case the property damage will be lower and damage of human lives may be avoided. The optimal way to inhibit the fire depends on its type, namely on the extent of fire, type of ventilation and presence of dangerous substances. The Maritime and Coastguard Agency continuously examines issues of fire protection on various types of decks and, e.g., discuss the high fire load and the effectiveness of existing sprinkler systems. Their reports draw two important conclusions: (1) the international shipping industry should coordinate their efforts and their knowledge, (2) programs with large-scale fire tests should be carried out to increase the understanding regarding fires and fire scenarios including important factors [5].

One of the most successful way of extinguishing fire in sea conditions is exploitation of the special device Cold Cut System Cobra produced by Swedish company Cold Cut Systems. Cobra is the only device which enables to create a protective water curtain without increasing the risk of burns from overheated

Source: [3]

Figure 2 The fire on a gas production platform near Port Said, Egypt in the Mediterranean steam. Cobra includes two very important operations in fire-fighting: cutting through the external walls surrounding the space smitten by fire and at the same time effective extinguishing by means of water mist.

In 2013 there were about 600 of units all over the world [4]. Today 1000 Cutting Extinguisher systems are installed in everything from small vans to specially built Rescue Services vehicles in more than 30 countries. There were 30 new Cobras delivered to Czech Republic last year.

2. WATER MIST

Water has favourable physical properties for fire suppression. It has extremely high heat capacity of 4180 $J \cdot kg^{-1} \cdot K^{-1}$ and its latent heat of vaporization is also very high 2,257 $MJ \cdot kg^{-1}$ therefore it is able to absorb a substantial part of thermal energy from flames and burning fuels. This transfer of energy takes place during evaporation process, i.e. transition of water to steam. Such process leads to substantial increase of volume. This increase depends on temperature at which the process is realized and also on pressure conditions, namely if the process is realized in open air, where we can consider the pressure to be normal (101 325 Pa) or in a closed space in which evaporation is accompanied by increase of pressure. The first case can be easily evaluated from ideal gas state equation: One kilogram of water represents approximately 1 dm^3 and at the same time mol of water. When it changes to steam its volume can be calculated by the following formula

$$V = \frac{nRt}{p} = \frac{55,6 \cdot 8,314 \cdot 373(873)}{101325} = 1,700\,(3,980)\,\mathrm{m}^3 \qquad (1)$$

It represents 1700 times growth for 100 °C, and even 3980 times growth at 600 °C. Such expansion of water vapour is accompanied by extensive dilution of oxygen and fuel vapours and therefore by decrease of their concentrations close to the fire. This is the most important way how water evaporation inhibits the combustion process.

For successful fire extension, it is necessary to absorb thermal energy as quickly as possible. The process of endothermic heat transfer takes place on the exchange boundary layer. Therefore evaporation of water should be enhanced by increase of its surface. It is much more effective from this point of view to deliver water to the target volume in the form of small droplets than by the full stream. Splitting 1 cm^3 into droplets of 0,1 mm gives 1,9 million droplets, offering a total contact surface of 6000 cm^2 (0,6 m^2). For the same volume of water, dividing by ten the size of the droplets allow an increase of contact surface to a factor of a hundred. It is also important to have small droplets in order to have a sufficient rate of attenuating shielding, as well as suspension time in the air long enough to vaporize water in gaseous form instead of on a wall, on the ceiling or on the floor [6]. Water should be atomised in very small droplets, which will remain long enough in the atmosphere before reaching the floor; and should have a low flow rate. Having water sprayed into dense fog in the atmosphere is called water mist.

3. COLD CUTTING SYSTEM COBRA

Equipment CCS Cobra – Cold Cut System Cobra is a high-pressure cutting fire-extinguisher which could be exploited primarily for:

- Cutting through various construction materials and through-hole cutting;
- Fire extinguishing;
- Cooling and temperature reduction in space occupied by the fire;
- Operation in explosive environment namely pumping of fuels [7].

The equipment Cobra cuts materials by means of high pressure water jet (in terms of water jetting branch it should rather be called medium-pressure device – terms used by firefighters have quite different meaning than those used by water-jet staff). During the cutting period of operation abrasive is mixed into the water stream, so that the abrasive water jet is formed. The principle of mixing is rather similar to slurry jet, nevertheless the pump of the system is operating with pure water and abrasive is added immediately at the end of the pumping part of the system. Cobra is working with pressure up to 30 MPa. At the moment of cutting through the abrasive feeding is switched off and the narrow water jet is turning into a cloud of water mist and steam. This mixture is very effective in cooling and extinguishing respective fire zones. The cutting itself is not accompanied with substantial growth of temperature. This cutting method is therefore applicable also in the explosive environment of dangerous and flammable substances, supposing they allow contact with water.

4. REACTION FORCES - THEORETICAL CALCULATION

Theoretical calculation of reaction forces generated within high energy liquid jet operation enables us to determine with how much force the fluid jet acts when it is cutting a perpendicular obstacle. At the same time, on the basis of these forces, we can find the size of the forces acting on the lance operator. Amount of the kickback, acting on the lance operator, can indicate the difficulty of handling as well as the extent of physica l demands for its mastery. Knowledge of these parameters of the liquid jet is required to manage the safe handling and hence reduce the risks for operators and surrounding staff.

Calculation of forces in flowing liquid is based on the conservation of momentum. Momentum change $\Delta\vec{p} = \int_{v_1}^{v_2} m\mathrm{d}\vec{v}$ is equal to impulse of force $\vec{I} = \int_{t_1}^{t_2} \vec{F}\mathrm{d}t$. In case of one-dimensional problem we can express this relation by the equation:

$$\int_{v_1}^{v_2} m\mathrm{d}v = \int_{t_1}^{t_2} F\mathrm{d}t \qquad (2)$$

If the force is constant or if we introduce an average force the impulse of which acting throughout the time interval $\Delta t = t_2 - t_1$ is equal to the overall impulse of force of the jet, we can write:

$$\overline{F} = \frac{1}{t_2 - t_1}\int_{v_1}^{v_2} m\,\mathrm{d}v = \frac{mv_2 - mv_1}{t_2 - t_1} = \frac{m\Delta v}{t_2 - t_1} \qquad (3)$$

We have derived that the impact of the continuous jet field on a stationary plate held normal to the jet can be calculated from knowledge of input and output velocity of the jet. Most often we are interested in the normal force acting on the obstacle. In such case only change of velocity projection into normal is important for momentum shift, average force is calculated by formula:

$$\overline{F} = \frac{m}{t_2 - t_1}\left(v_2\cos\alpha_2 - v_1\cos\alpha_1\right) = Q_m\left(v_2\cos\alpha_2 - v_1\cos\alpha_1\right) \qquad (4)$$

where v_1, v_2 are input and output velocities and α_1, α_2 are angle of incidence and angle of reflection, Q_m is mass flow rate of the jet fluid, i.e. in case of abrasive water jet it represents mass flow rate of the slurry.

During drilling a hole in a solid material the angle of incidence is usually near 90°. Water interacts with grains of material and either it is reflected backwards or it continues moving forward carrying eroded material with it. The reflected water cannot move exactly backwards as there is the input jet occupying the space. Moreover we must take into account that the jet loses part of its energy in interaction with drilled material and so its output velocity is smaller than the input one. Therefore it is impossible to forecast the change of momentum of the jet exactly. Nevertheless we can calculate the maximum momentum change represented by the case when all the mass of water jet is reflected backwards and compare it with experimental results.

Cobra water flow rate is according to producer data Q_V = 50 l per min = 8,33·10^{-4} m^3·s^{-1}, consumption of abrasive is m_a = 4 kg·min^{-1} = 0,067 kg·s^{-1}. As the specific mass of the abrasive is ρ_a = 4390 kg·m^{-3}, the abrasive volume flow rate is $Q_a = m_a / \rho_a$ = 0,152·10^{-4} m^3·s^{-1}. As the abrasive material is not solvable in water the resulting volume flow rate of the slurry should be the sum of both volume flow rates.

Velocity of the slurry should be calculated from the continuity equation. For unworn abrasive tube with diameter d = 2,2 mm the cross area of the nozzle mouth will be $A = \pi\left(\frac{d}{2}\right)^2$ and so the velocity of the slurry should be:

$$Q_V + Q_a = A \cdot v = \pi\left(\frac{d}{2}\right)^2 \cdot v \Rightarrow v = \frac{4(Q_V + Q_a)}{\pi d^2} = 223\ \mathrm{m\,s^{-1}} \qquad (5)$$

The change of momentum reaches its maximum in case of normal impact of the jet (α_1 = 0°) and backword reflection (α_2 = 180°). The equation (4) thence leads to:

$$\bar{F} = Q_m\left(v\cos 0° - v\cos 180°\right) = 2vQ_m \approx 402\ \mathrm{N} \qquad (6)$$

Our theoretical analysis led to the conclusion that maximum reaction force generated by slurry jet of the CCS Cobra should be 402 N.

5. REACTION FORCE MEASUREMENT – DRILLING OF HOLES IN STEEL SHEETS OF VARIOUS THICKNESSES

Measurement of reaction force with device CCS Cobra was realized at the Laboratory of the liquid jet at the VŠB – Technical University of Ostrava. The experiment was realized thanks to the courtesy of Firefighting Rescue Station Ostrava, North-Silesian region. Cobra lance was fixed to special holder (Fig. 3) equipped with piezoelectric force sensor Kistler 9301B with declared sensitivity -3,261 pC/N. The measurement was evaluated by program LabVIEW SignalExpress. The program outputs were plots of time course of amplifier voltage in mV (Fig. 4-7) enabling simple transformation to the force value using conversion:

Only one abrasive vessel with volume 10 l and mass 20 kg could be used during the experiments. Consuming 4 kg.min^{-1} of abrasive material Cobra could operate for 5 minutes. This was the most limiting factor for our measurement.

The measurement was aimed at determination of the kickback force and the time necessary to drill through material – so called perforation time. Three different thicknesses of special high-resistant steel Hardox 500 were used for the experiment. Another type of steel (W.Nr. 1.057 or DIN norm: St 52-3, thickness 10 mm) with different tensile strength was used for comparison (see Table 1).

- Hardox 500, sheet with thickness 6 mm;
- Hardox 500, sheet with thickness 10 mm;
- Hardox 500, sheet with thickness 15 mm;
- steel W.Nr. 1.057, sheet with thickness 10 mm;

Source: authors

Figure 3 Fixation of the output lance of the system Cobra

Table 1 Characteristic parameters of the experimental materials

Material	tensile strength	elasticity modulus	density	hardness	grain size
	[MPa]	[MPa]	[kg·m^{-3}]	[HB]	[μm]
Hardox 500	1679	217	7856	516	22.1
steel 1.057	443	206	7772	126	23

Source: Data sheets and additional measurements of authors

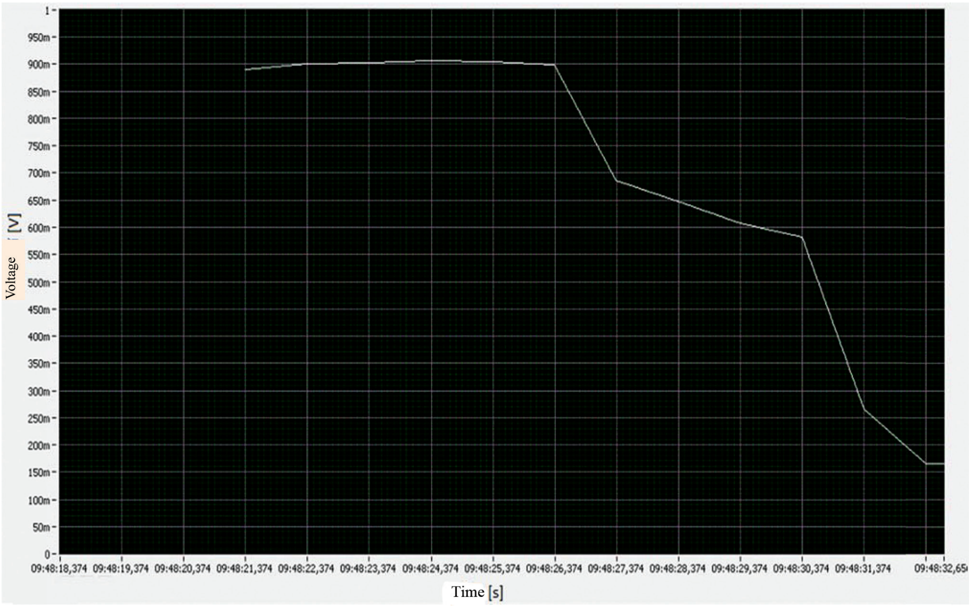
The standoff distance (the distance between the nozzle mouth and drilled material) was set to 16 mm. This was equal to the distance used for cutting and drilling with the hand applicator of Cobra. The time was measured manually the start-stop moment of stopwatch was controlled both visually (the water mist with abrasive stopped spouting backwards) and by significant change of acoustic signal.

Table 2 shows that maximum kickback values for CCS Cobra equipment are in the range 120 – 150 N for both measured types of steel. The measured value of reaction force of the thinnest sheet of Hardox (6 mm) should be excluded from the final evaluation, because it was distorted by incorrect calibration at the beginning of measurement. It can be seen in Table 2 as well that the input hole into the material is not a circle but its shape is rather an ovoid. Its size depends on the type of material and on the penetration time, but it can also be influenced by even slight inclination of the lance, because the stand-off distance is quite big compared to those commonly used for cutting or drilling [8-11].

Table 2 Measured values of kickback with CCS Cobra drilling of steel sheets

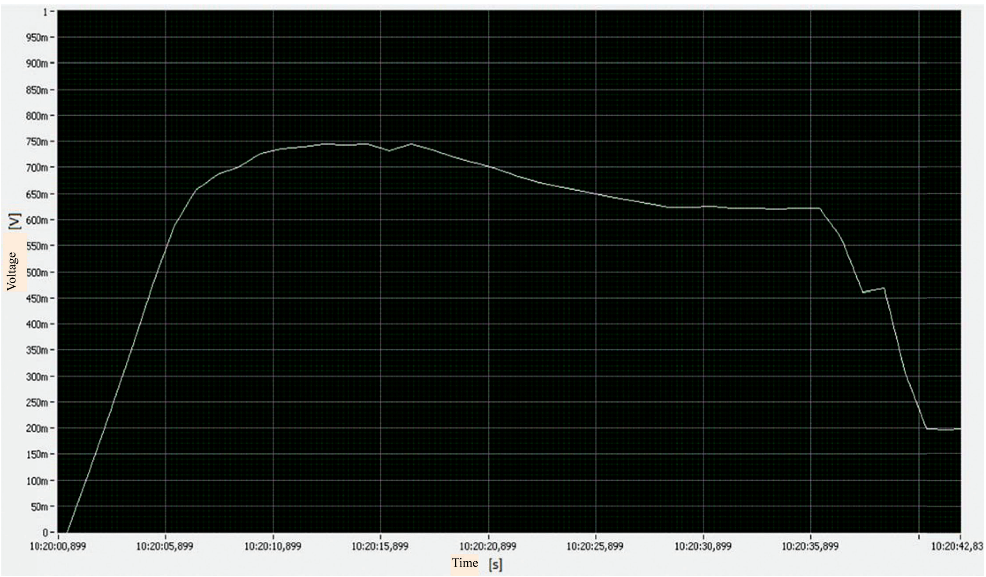
Material	thickness	voltage	kickback force	penetration time	dimensions of the entrance hole	
					length	width
	[mm]	[mV]	[N]	[s]	[mm]	
Hardox 500	6	900	180*)	15.5	2,2	1,9
Hardox 500	10	750	150	38	2,5	2,1
Hardox 500	15	600	120	91	3,1	2,4
steel 1.057	10	620	124	33	2,7	2,2

*) value is probably distorted by incorrect calibration at the beginning of measurement
Source: authors



Source: authors

Figure 4 Drilling of Hardox 500, thickness 6 mm – data distorted by incorrect calibration



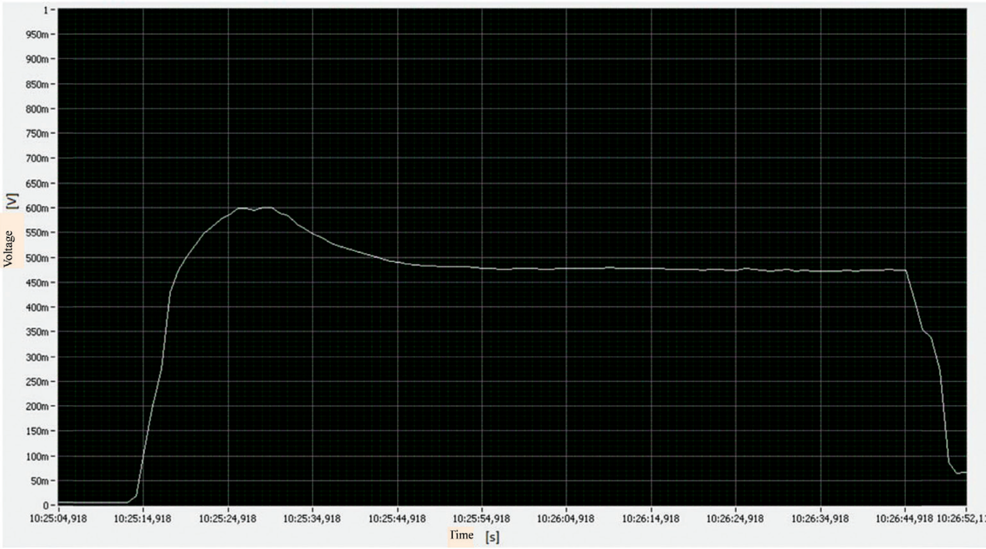
Source: authors

Figure 5 Drilling of Hardox 500, thickness 10 mm

6. CONCLUSION

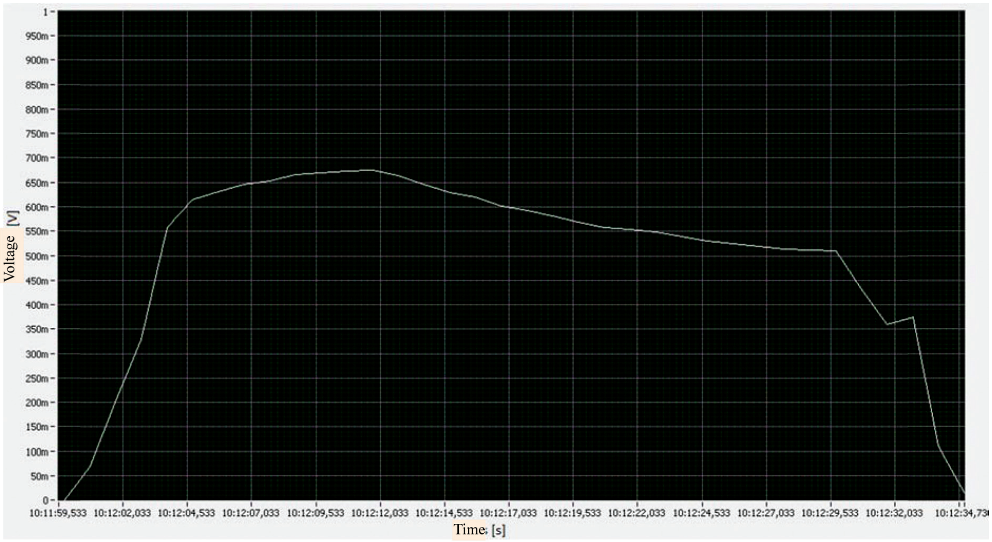
The aim of this paper was to introduce to broaden awareness about the cutting extinguisher CCS Cobra. Our research enables to get more acquainted to this smart device and especially to its manual handling. Several important and interesting findings were made.

Based on the momentum conservation a formula for calculation of the maximum possible reaction force was derived. With commonly used Cobra parameters, i.e. flow-rate 50 l and pressure 25 MPa the value of this kickback force was determined to be 402 N.



Source: authors

Figure 6 Drilling of Hardox 500, thickness 15 mm



Source: authors

Figure 7 Drilling of steel W.Nr.: 1.057, thickness 10 mm

In order to verify this result and to compare the theoretical considerations with real practise, the kickback measurement with device CCS Cobra was realized in the Laboratory of the liquid jet at the Technical University of Ostrava. The experimental results led to the conclusion that real reaction force represents from one forth to one third of the calculated maximum values. The measured values surprisingly seemed to be dependent not only on the tensile strength of the material but also on its width. Thick plate appeared to produce less reactive force. This finding could be partially explained by the widening of the hole made into the material due to long penetration time and successive change of the angle of reflection but this explanation is not exhaustive. More thorough research carried on with more materials would be necessary to prove or eliminate this hypothesis.

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