UDK: 355.0:061.6:614.97:44.615
COSATI: 15-05, 15-06, 20-06

A Comparative Study of the Field of View and the Optical Properties of Oculars of Military Protective Masks

Dušan Rajić[1)]
Tatjana Marković[2)]
Negovan Ivanković[3)]
Marina Ilić[2)]
Željko Senić[2)]
Maja Vitorović – Todorović[2)]

A large field of view and the corresponding optical characteristics of the ocular are among the most important tactical and technical demands placed upon the designer of protective masks, because these properties directly affect the combat effectiveness of soldiers in conditions where protective mask must be worn in a protective position because of a real radioactive, chemical and biological danger. In terms of stated properties, a new domestic protective mask, marked M3, is expected to match the quality level of modern foreign military protective masks and to be better than the existing protective masks Serbian Armed Forces (SAF) are equipped with. This new mask is in the process of adoption in the armament and military equipment of the SAF. In order to perceive fulfillment of this criterion, this paper presents the experimental results of the comparative tests of the field of view and the ocular optical properties of available samples of foreign and domestic protective masks.

Key words: **protective mask, field of view, ocular, optical characteristics, test results, comparative results, NBC protection**

Introduction

THE international community is making efforts to ban or restrict the use of radioactive, chemical and biological (RCB) combat means engaged in warfare as well as trying to prevent RCB terrorism and minimize possible occurrence of RCB accidents. An adequate system that is suitable for activation in case of RCB danger, besides monitoring [1], must also include a selection of quality protective equipment. Personal protective equipment includes mutually compatible devices for protection of the body and the respiratory organs of a man against RCB agents [2]. Respiratory protection is achieved by wearing different types of masks, half masks and respirators. The military protective mask is a filtering device that protects the respiratory system, the eyes and the face of the user from RCB contamination in the form of gases, vapors and solid and liquid aerosols [3]. In addition, it is intended to protect the soldiers from industrial toxic substances, if the appropriate filter is applied. In today's equipment of the SAF there is a family of protective masks - M2F (phonic) and M2FV (phonic and with accessories for fluid intake). According to international criteria of the quality of protective masks [4], stated domestic masks could be classified as generation III. In the equipment of modern armies, military protective mask generation IV emerged around 1985 (Fig.1).

Figure 1. British protective mask S10 as the first mask generation IV

The benefits of the S10 mask, as compared to the previous British S6 mask, are achieved by a higher protection level, improved voice and visual communication of the mask user, higher comfort, compatibility, ease of maintenance and installation of accessories for fluid intake [4]. The oculars are made of surface-treated polycarbonate and have a new spherical shape. The SF10 version of the mask made for special units has a built-in microphone on

1) University of Belgrade, Faculty of Technology and Metallurgy, Innovation Center, Karnegijeva 4, 11120 Belgrade, SERBIA
2) Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA
3) University of Defense, Military Academy, Pavla Jurišića Šturma 33, 11000 Belgrade, SERBIA

the inside (instead of a device for drinking water), and also has the option of installing another filter and additional oculars for the protection against a light flash of a nuclear explosion and mechanical impacts. The latest, improved S10 mask, marked FM12 (Fig.2), is a high performance mask. It is compatible with large-scale combat and other equipment. The facepiece is lightweight and has a design that provides very low breathing resistance and allows high comfort to the user.

Figure 2. British protective mask FM12

The Canadian protective mask, C4 (Fig.3), and its Norwegian variant, NC4, are one of better solutions of masks generation IV. For this mask, the spherical oculars are made of transparent polycarbonate which is injection molded. The mask has correction glasses.

Figure 3. Canadian protective mask C4

In Switzerland, the first mask generation IV is SM90. According to available data [4], this mask is adopted because of the possibility of approaching users with different anthropometric characteristics of the head. It is a mask of a high level of comfort, low breathing resistance, large field of view, which offers an option to use the correction glasses, has a good solution for the routing of inhaled air over the oculars to prevent them from fogging, good communication performances and the possibility of taking liquids. The facepiece is made of brombutil with the oculars made of glass. The correction glasses can be related to the oculars or inserted with specially assembled frames. The SM3 version of this mask has the option of central, left or right filter setting. Both versions are sophisticated and labeled as PM31 and PM33 (Fig.4). The basic versions of these masks in terms of anthropometry cover over 98% of the European population, and have the oculars made of polycarbonate with surface protection. Additional quality includes the increased hardness of the glass oculars, the embedded correction glass and the possibility of installing glasses for the protection against the flash of a nuclear explosion.

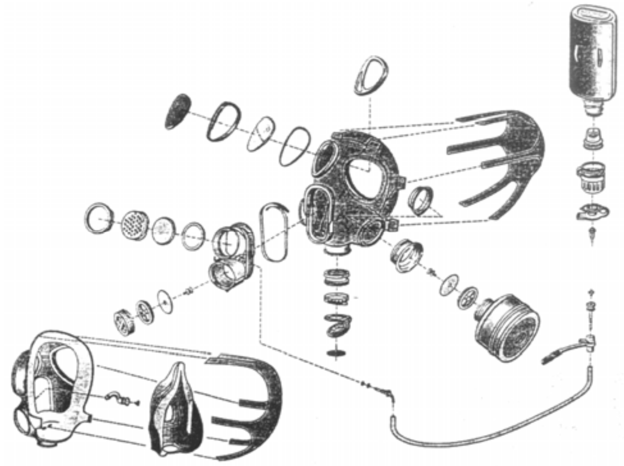

Figure 4. Swiss protective mask PM33 (displayed in parts)

The new concept and quality standards for the protection masks generation IV are established through the development of American protective masks, XM30-40. They were later developed by over ten manufacturers in the most developed countries worldwide. The American M40 protective mask replaced the M17 model. It has surface-reinforced polycarbonate oculars, optically corrected, placed in the metal rings that provide a large field of view. The protective oculars are installed over these oculars. The M40A1 version (Fig.5), as a completely original design, has a replaceable facepiece (based on rubber compound brombutil - etilenpropilendien monomer) over the existing one and provides additional resistance to the effects of agents.

Figure 5. American protective mask M40A1

The aim of the development of the new Serbian protective mask, M3 (Fig.6), has been to reach the level of quality of masks generation IV. This has been done by improving the quality of used materials necessary for its production, by increasing the overall comfort of the mask and the mask function expansion by installation of new subsystems. When a protective mask is worn in a protective position due to RCB danger, it reduces the user's field of view, thus reducing its combat effectiveness. It can further be reduced if the optical characteristics of the protective mask oculars are below the limits defined in the tactical-technical requirements. A good construction of a protective mask and a selection of high-quality materials for oculars can improve the field of view and the optical properties of oculars. A comparative examination of these parameters can lead to a conclusion which construction solutions give the best results and where the boundaries of these solutions are, which is one of the goals of this work.

Figure 6. Serbian protective mask M3 (in the protective position)

The content of the protective mask M3 kit includes the mask facepiece, the combined filter with the cap and the lid, the carrying case, cleaning accessories, the connection for the flask, the technical board, and a short guide for handling and mounting correction glasses. If necessary, the kit may also include correction glasses with a holder, secured in a bag pocket, and the user can shift them by himself. The mask facepiece consists of the facepiece body, the nasal insertion, the subassembly inhalation valve with the threaded connection for the filter, the exhalation valve subassembly, the oculars, the system for taking liquids, the voice unit and the system of elastic straps. The M3 mask allows the user to carry out complex combat operations and procedures when stationary and in motion. The M3 mask is compatible with a protective suit, a protective cape, a protective filtering suit and a helmet [2]. The M3 mask was designed using the CAD / CAM technique in order to provide better fitting to the user's head and thereby to allow maximum comfort. The M3 mask construction enables the usage of the combined filter by choice of the left or the right side, a better voice transmission with two voice membranes, fluid intake during the stay on the contaminated soil, possibility to correct the usage of glasses, ocular demisting and a better total field of view compared to the previous generation of Serbian protective masks.

The experience shows that manufacturers of armament and military equipment often exaggerate the characteristics of their products, in order to make better sales at the world market. Only experimental verification of the declared data can determine their accuracy. The aim of this study is to verify experimentally whether a new domestic M3 protective mask (it is in the final stage of development and the adoption into the SAF armament and military equipment) is better than the existing domestic M2F and M2FV protective masks (already in the SAF armament and military equipment) in terms of their optical properties. In addition, the aim is to verify experimentally if it is at the quality level of foreign protective masks generation IV. For that purpose, samples of available foreign protective masks and three models of Serbian military protective masks were used for a comparative experimental study of the field of view as well as for the most important optical properties of the ocular such as ocular integral transparency in the visible spectrum, spherical optical power, astigmatism, beam deflection (prismatic) and image distortion.

Experimental part

Field of view

The field of view means the total spatial extent of stationary sources of visual information that causes irritation of the stationary eye [5]. The total field of view is the field wich is obtained by looking with both eyes. The folded or stereoscopic field of view is a part of the total field of view which can be seen by one eye. The viewing angle is the angle formed by the peripheral and the central visible beam. The average values of visual angles in the main directions are:

a) on the temple 85°
b) above the temple 55°
c) above 45°
d) up on the nose 55°
e) on the nose 60°
f) down on the nose 50°
g) down 65°
h) down on the temple 85°

The course of the process with a sequence of activities:

The detailed procedure for testing the field of view of protective masks is described in the Serbian military standard [5]:

- carefully place the protective mask on the model of the head, with both eyes lit up,
- adjust the protective mask facepiece until the visors contours are symmetrical to the semicircular layer (calotte),
- adjust the protective mask strap tension to achieve its proper fitting on the artificial head;
- add the positions of the field of view into the apertogram for each eye separately (including light sources), using the grid lines as starting points,
- using the planimeter, carefully measure the areas of the total field of view and the folded field of view (the field of view is the deepest line passing through any point),
- calculate the field of view as a ratio of the measured and the natural field of view by Stoll (112 cm^2), which is given on a printed apertogram in the following form:

$$PV=(PV_{zm}\cdot 100)/PV_p \quad (1)$$

where is:

PV - protective mask field of view (%),
PV_{zm} - area of the measured field of view (cm^2),
PV_p - area of the natural field of view by Stoll (112 cm^2).

- The folded field of view is calculated in the same manner as the total field of view, where the natural folded field of view is 39 cm^2:

$$PRPV=(PRPV_{zm}\cdot 100)/PRPV_p \quad (2)$$

where is:

PRPV - protective mask folded field of view (%),

$PRPV_{zm}$ - area of the measured folded field of view (cm^2),

$PRPV_p$ - area of the natural folded field of view by Stoll (39 cm^2).

Equipment for measuring the field of view

The equipment for measuring the field of view consists of:

- apertometer,
- planimeter, REISS precision 3005, Germany

Apertometer

The apertometer is an apparatus in a hemispherical form intended for laboratory measurement of the protective mask field of view. It consists of an artificial head and a callote. The artificial head is made according to DIN 58641 standard. The callote is cast from metal, and its diameter is 610 mm. Inside the calotte, the grid with steps of 10° is drawn. The left and right sides of the callote are molded sequels which include the angle greater than 90°. The light sources are lamps of 12 W and 14 W built-in artificial head with possibilities to operate individually or jointly. The power is supplied through an AC adapter of 12 V. The light sources are connected through the artificial head and its mount with standard cables. The light sources provide a clear outline of the illuminated surface on the inside of the callote. Within 90° is 78.8% (100 cm^2) of the natural field of view, and out of 90° is 21.2% (12 cm^2) of the natural field of view.

Apertogram

The apertogram (Fig.7) is the apertometer projection in the plane, on which the polar angles of the circle in steps of 10° are shown in addition to the projection of visual angles.

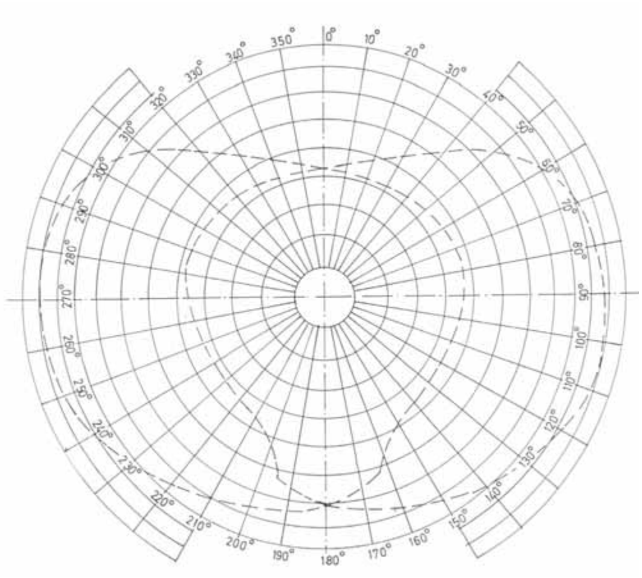

Figure 7. Apertogram

Planimeter

The planimeter is an instrument for measuring the size of flat surfaces. The total field of view of the protective mask on the model of the head must be at least 80% in relation to the total field of view without protective masks. The total field of view was tested by the method described in the standard [5].

Measuring the optical properties of protective masks

The required optical characteristics of protective masks are defined through their tactical-technical requirements, which are verified according to standards [6-10]. Due to the unavailability of these data for foreign protective masks, the tactical-technical requirements for the M3 protective mask are referred to in this paper. The ocular transparency to a visible light wavelength of 420 nm to 780 nm must be at least 85%. The spectral transmissions through the oculars in the field of visible light must not deviate more than 5% compared to the average value of the transmission in the entire range. The figure distortion, with visible light passing through the oculars, must not be greater than ± 2%.

The oculars should not have optical intensity, whereas the following deviations are allowed:

- spherical intensity: 0.25 ± Dpt,
- astigmatism:± 0.25 Dpt,
- prismatic effect:± 0.25 PrDpt.

The optical characteristics were studied on the optical bench Salvadoris Firence, Officcine Galileo, Italy, with a collimator *f* = 1781 mm, except for the integral transparency in the visible part of spectrum, which was measured on the device "Odeltron", Old Deft, USA, with the S 20 photocathode and a green filter for the correction of the spectrum to the human eye.

Results and discussion

The total field of view with the M3 protective mask on the model of the head must be at least 80%, compared to the total field of view without protective masks [10]. For foreign protective masks, this parameter as tactical-technical data is not available. The field of view is measured on the following protective masks:

- Italian (IMMD)
- French (ARFA)
- British (AVON S10),
- Canadian (C4),
- U.S. (M40A1)
- Swiss (SM3)
- domestic (M2F) and (M2FV)
- domestic (M3).

All measurements and processing of the results were performed according to the standard [5].

The measured values of the field of view are shown in Fig. 8.

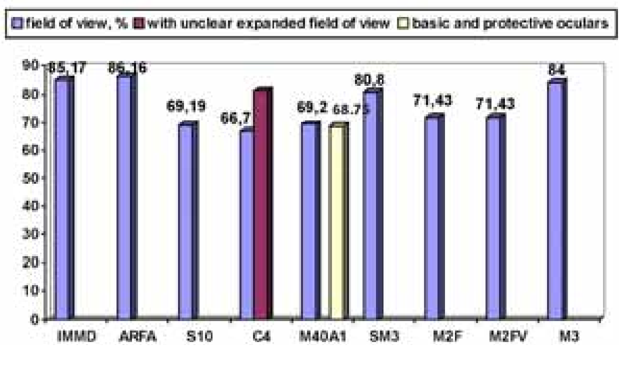

Figure 8. Field of view of the tested protective masks

Fig. 8 shows that the total field of view of the M3 protective mask is 84% and it is greater than the total field of view with the M2F and M2FV protective masks, in which the value was about 70%. The value of the total field of view of the M3 protective mask is at approximate level as in some foreign protective masks of generation IV: Swiss SM3 mask (80%), Swedish F2 masks (88%), and better than the field of view measured in S10 (69.2%), C4 (66.7%) and M40A1 (69.2%).

Comparing the results in Fig.8, it was observed that the protective masks marked IMMD, ARFA and SM3 have bigger fields than the others. The IMMD and ARFA protective masks are of a panorama type, so a bigger field of view was expected. The increased field of the SM3 protective mask is probably a result of its small size, which is incompatible with the size of the artificial head used to determine the field of view of mid-sized protective masks on the existing apparatus; therefore, the obtained result is unreliable and may be rejected.

In the C4 protective mask, the oculars have a specific form of "a cup"; therefore, in Fig.8, the unclear field of view is indicated (only unclear contours of objects are seen from the side). For the M40A1 protective mask, Fig.8 clearly shows the result of measuring the field of view with the basic and protective ocular used for protection against mechanical damage and sunlight.

Based on the results obtained from these measurements, it can be concluded that the literature data for the field of view for some foreign protective masks that are not of a panorama type (e.g. C4 field of view greater than 90%), are of a commercial character and unrealistic.

The results of measuring the optical properties of the oculars are shown in Table 1, and include the determination of:

- integral transparency in the whole visible spectrum, *T*(%),
- spherical optical intensity, *P* (Dpt),
- astigmatism, *A* (Dpt),
- prizmatic or cornering light beam, *D* (PrDpt),
- distortion of image, Dist (%).

Table 1. Oculars optical characteristics of foreign and domestic protective masks

Characteristic	*T* (%)	*P* (Dpt)	*A* (Dpt)	*D* (PrDpt)	Dist. (%)
M40A1	89	0	0	1.30	0
Protective glass M40A1	91	0	0	0	0
M40A and protective glass M40A1	82	-	-	1.30	0
C4	89	0	0	0.14	0
M2F, M2FV	89	-0.25	0.25	0.20	0
M3	96	≤ 0.1	≤ 0.1	≤ 0.80	0
AVON S10	91	0	0	0.58	0
ARFA	83	0	0	0.29	0

On the basis of these results, we can conclude that the oculars of all tested protective masks have satisfying transparency (except for the flexible polyurethane mask of a panorama-type (ARFA)) and satisfying optical characteristics, except for the oculars of the American protective masks which have a high value for deflecting a light beam, which causes a deformation of the image. The comparative study of materials, components and complete foreign and domestic protective masks enabled obtaining the quantitative indicators to compare their characteristics and evaluate and fulfill the tactical and technical requirements for the M3 protective mask (all of this is done under the same experimental conditions). The number of foreign masks was limited to one sample of a medium size, except for the Italian one (two samples). Because of the limited number of samples, the obtained results are accepted with some caution. Despite these problems, the results were used to draw certain conclusions. It was found that the Italian and French masks have the largest field of view, which was expected since both are of the panorama type. Among binocular protective masks, the Swiss SM3 has the largest field of view. These protective masks satisfy the tactical and technical requirements for the field of view of the M3 protective mask.

The construction of the M3protective mask facepiece, ie. the installation of two small valves in the nasal insert enabled a steady flow of air into the nasal insert interior as well as better evanescent of the oculars with the separation of the hot and cold air. The possibility of using combined filters on the left and right side, and the possibility of correction glasses usage significantly facilitates the performance of users' combat actions, especially for left-handed people and those with weaker eyesight.

Conclusion

In relation to the M2F and M2FV protective masks currently in operational use in the SAF, the M3 protective mask, which is in the process of adoption in the armament and military equipment of the SAF, has significant improvements, both in the field of protection against RCB agents and in terms of comfort for its wearer. The field of view of the M3 protective mask is 84% and it is at the level of the latest protective masks generation IV, while being significantly higher in relation to the M2F and M2FV protective masks, where the value is 70%. For the M3 protective mask, the improvement of the quality of materials has been achieved by using brombutyl rubber for the body of the mask facepiece and the nasal implant, natural rubber for the development of the inhalation and exhalation valve and a single layer of transparent polycarbonate in the production of oculars.

On the basis of the obtained results of the optical properties testing, it can be concluded that the M3 protective mask oculars as well as the oculars of all other investigated protective masks have satisfying transparency (except for the ARFA flexible polyurethane mask of the panorama type) and satisfying optical characteristics (except for the oculars of the American protective mask which has a high value for deflecting a light beam, which causes a deformation of the image).

The increase of the M3 protective mask total comfort is achieved by a new construction of the facepiece body and the nasal implant, by a new constructional solution to tighten the mask strap system on the users head and by a new construction and selection of the ocular position on the facepiece body.

The functions of the M3 protective masks have increased in number with the addition of a new filters carrier subassembly on the right-hand side thus allowing a more efficient use of the mask for left-handed users while targeting as well as with the addition of the correction glasses carrier for users with impaired vision and with the addition of the auxiliary voice membrane for better voice transmission.

The M3 rotective mask fulfills all the requirements of tactical and technical quality and in this sense represents a significant improvement in relation to the Serbian military protective masks of previous generations, marked M2F and M2FV. Owing to its optical and overall characteristics, the M3 protective mask is at the level of most modern devices of personal respiratory protection generation IV.

Acknowledgments

The Ministry of Education and Science of the Republic of Serbia supported this work, grant no. TR34034 (2011-2014).

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Received: 23.07.212.

Komparativna studija polja vida i optičkih osobina okulara vojnih zaštitnih maski

Veliko vidno polje i odgovarajuće optičke karakteristike okulara su među najznačajnijim taktičko-tehničkim zahtevima koji se postavljaju pred konstruktore zaštitne maske, jer ove karakteristike neposredno utiču na borbenu efikasnost vojnika u uslovima kada zaštitna maska mora da se nosi u zaštitnom položaju zbog realne radioaktivne, hemijske i biološke opasnosti. Od nove domaće zaštitne maske oznake M3, koja se nalazi u fazi usvajanja u naoružanje i vojnu opremu Vojske Srbije (VS), očekuje se da u pogledu navedenih karakteristika, bude bolja od postojećih zaštitnih maski kojima je trenutno opremljena VS, a na približnom nivou kvaliteta najsavremenijih inostranih vojnih zaštitnih maski. U cilju sagledavanja ispunjenosti ovog kriterijuma, u radu su prikazani eksperimentalni komparativni rezultati ispitivanja vidnog polja i optičkih karakteristika okulara na uzorcima dostupnih inostranih i domaćih zaštitnih maski

*Ključne reči***: zaštitna maska, vidno polje, okular, optičke karakteristike, rezultati ispitivanja, uporedni rezultati, NHB zaštita.**

Сравнительное исследование поля зрения и оптических свойств глазного военных защитных масок

Большое поле зрения и соответствующие оптические характеристики глазного относятся к числу наиболее важных тактических и технических требований, стоящих перед дизайнерами защитных масок, так как эти характеристики напрямую влияют на боеспособность солдат в условиях, когда они должны носить защитные маски в требуемом положении, из-за реальных радиоактивных, химических и биологической опасностей. От новой отечественной защитной маски с этикеткой М3, которая находится в процессе принятия в вооружение и военную технику сербской армии (АС), ожидается, что в силу своих характеристик будет лучшей, чем существующие защитные маски, которым в настоящее время оснащена сербская армия (АС), а на примерном уровне качества самых современных иностранных военных защитных масок. Для того чтобы оценить соответствие с этим критерием, в этой статье приведены сравнительные результаты экспериментальных исследований поля зрения и оптических свойств глазного рельефа образцов, доступных иностранных и отечественных защитных масок.

Ключевые слова: **защитные маски, поле зрения, глазной, оптические характеристики, результаты тестов, сравнительные результаты, НХБ защита.**

Etude comparative du champ visuel et de l'oculaire optique chez le masque protecteur

Le grand champ visuel et les caractéristiques correspondantes optiques de l'oculaire sont parmi les plus importantes exigences tactiques et techniques qui se posent aux constructeurs des masques protecteurs car ces caractéristiques influent directement à l'efficacité combative des soldats dans les conditions où le masque protecteur doit être porté en position de protection à cause du réel danger radioactif, chimique ou biologique. On espère que le nouveau masque protecteur national M3 qui est encore en phase d'adoption par l'Armée serbe soit meilleur que les masques protecteurs qui équipent actuellement l'Armée serbe . On s'attend aussi que ses qualités soient au niveau des masques protecteurs étrangers les plus modernes. Dans le but de percevoir l'accomplissement de ces critères on a présenté les résultats expérimentaux comparés sur les recherches du champ visuel et des caractéristiques optiques d'oculaire à partir des exemplaires des masques nationaux et étrangers disponibles.

Mots clés: **masque protecteur, champ visuel, oculaire, caractéristiques optiques, résultats d'essais, résultats comparés, protection ABC.**