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Design Optimisation of Muzzle Brake for Sniper Rifle

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ABSTRACT

Muzzle brakes (MBs) have a great effect on reducing the recoil force of weapons during firing. In this paper, optimum MB efficiency, MB force and recoil force for (12.7 mm x 99 mm) sniper rifle have been studied. The objective is to obtain the optimum area of side openings, inclination angle and number of chambers for the MB in order to increase the MB efficiency and MB force and thereby to decrease their coil force of the weapon. An analytical model for calculating MB efficiency, MB force and weapon recoil force for MBs of two, three and four chambers has been established. This Model is then utilised in combination with design of experiment and response surface method statistical techniques to develop a smooth response function which can be efficiently used in optimisation formulation. Finally, multi objectives generic algorithm optimisation method has been employed to find the optimum MB design parameters. The optimisation results show that the three or four chambers MBs have no significant effect on reducing the weapon recoil force compared with the two chamber MB for this sniper rifle.

Keywords: Muzzle brake; Recoil force; Efficiency; Sniper rifle

NOMENCLATURE

MB	Muzzle Brake
DOE	Design of Experiment
RMS	Response Surface Method
η	MB efficiency
V_M	Muzzle velocity
α_G	Coefficient of discharge of MB
α_ε	Coefficient of shape of MB
μ	Coefficient of hoof effect
φ_n	Inclination angle of side openings of the nth chamber
ν	The coefficient of real flow area of side opening
F_{MB}	Muzzle brake force
S	Area of bore cross section
β	Coefficient of the additional action of powder gases (AAPG)
æ	MB geometric index
m_p	Mass of projectile
m_w	Mass of propellant
p_m	Muzzle pressure
P_{EA}	Pressure at the end of after effect period
A_{F1}	Area of any front opening
A_{S1}	The real area of gas flow from side openings of first chamber
a_n	The length of opening of nth chamber
b_n	the width of opening of n^{th} chamber
B	Bravin's exponent of AAPG
R	Weapon recoil force

1. INTRODUCTION

The weapon designers for up to date sniper rifles need to increase the muzzle velocity of projectile simultaneously with keeping the least weight and recoil force of weapon.

After projectile departure – during the additional action of powder gases (AAPG) (may called after-effect), the discharged gases give additional impulse to the recoiling parts causing an increase of their recoil velocity and thereby increasing their recoil energy. The decrease of recoil energy is based on decreasing the impulse of discharged gases by introducing an opposite impulse.

Muzzle brakes (MBs) are devices attached or integral part of to the barrel muzzle in order to produce this required opposite impulse. They may have one, two or more chambers with side holes of different inclination angles to barrel axis (90^o or more).

Jiang[1], *et al*., conducted a numerical model, to simulate the wave dynamics process of muzzle flow. Their results demonstrated the obscure among the shock waves due to the effect of viscosity, turbulence, etc. They have clearly shown the development of turbulent intensity distributions and the flame front. Phan[2], developed a concept of muzzle brake design and testing by using a suitable spring arrangement. His study showed that a muzzle brake can be designed to be operative only during the gas ejection phase, preventing the effect of blast wave reflection. Kun[3], *et al*., developed an approximate model for MB performance regarding the impact force on MB. They used RMS to map the MB shape parameters with impact force on MB, then they utilised GA to optimise MB shape parameters. Based on Euler equations, Zhang[4], *et al*., investigated three different muzzle flow fields, the bare muzzle, the three-way and the multi-hole muzzle brakes numerically and then compared their numerical results with experimental ones to verify their model. Lei[5], *et al*. provided numerical CFD

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simulation to analyse the force and stresses of muzzle brake. The flow and the force of a muzzle brake was simulated to provide some reference to the structural optimisation of muzzle brake.

In this study, an analytical model has been considered for calculation of closed baffled type MB efficiency, MB force and the weapon recoil force for 12.7x 99 mm sniper rifle. Then (DOE) and (RSM) have been utilised to develop a smooth response function with the different design parameters for two, three and four chambers MBs, See a scheme of the MB in Fig. 1. DOE has been used to find the best possible combinations of the aforementioned design parameters that cover the whole design space. The MB efficiency, MB force and weapon recoil force have been calculated for each combination to complete the DOE matrix. Later, the Response Surface Method (RSM) has been employed to illustrate the change of response surfaces with different design parameters using fully quadratic polynomial equation. Finally, using the developed objective function, the optimum values of design parameters have been obtained by MOGA. This optimisation formulation has been developed to find the optimum design parameters which give the maximum MB efficiency and the maximum MB force and thereby the minimum weapon recoil force.

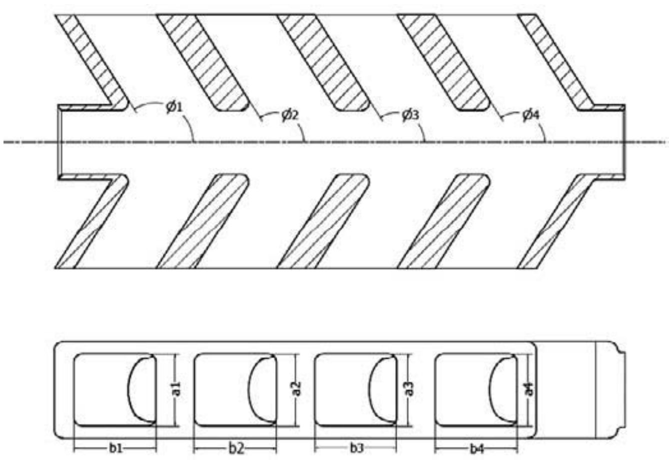

Figure 1. Scheme of 4 chamber MB with its design parameters.

2. MUZZLE BRAKE INDICES

The MB efficiency (η), which is the first used response parameter, depends on the coefficient of the (AAPG) Additional Action of Powder Gases (β), MB geometric index $(æ)$, mass of projectile (m_p) and mass of propellant (m_ω) [6]:

$$\eta = 1 - \left(\frac{m_p + æ.\beta.m_\omega}{m_p + \beta.m_\omega} \right)^2 \quad (1)$$

The coefficient (β) of AAPG can be calculated from the following formula:

$$\beta = \frac{1}{V_M}.\frac{2}{k}\sqrt{\frac{2k}{k+1}.\frac{p_M}{\rho_M}} \quad (2)$$

where, (V_M) is the muzzle velocity, (p_M) is the muzzle pressure, (ρ_M) is the density of gases at muzzle conditions and (k) is the specific heat ratio of gases.

Also, $(æ)$ is the MB index and it is calculated as:

$$æ = \frac{\alpha_\varepsilon}{\alpha_G}$$

where (α_G), (α_ε) are the coefficient of discharge of MB and the coefficient of shape of MB, respectively, and they are calculated as: geometric

$$\alpha_G = \frac{A_{F1} + A_{S1}}{A_M} = \frac{A_{F1} + A_{S1}}{A_{F1}} = 1 + \Delta \quad (3)$$

$$\alpha_{\varepsilon n} = \psi_n^{\,n-1} + \sum_{i=1}^{n} \Delta\,.\mu\,.\cos\phi_i.\psi_i^{\,i-1} \quad (4)$$

where (A_{F1}) is the area of any front opening, (A_{S1}) is the real area of gas flow from side openings of first chamber.

(μ) is the coefficient of hoof effect, and is given by: $\mu = \frac{2k+3}{2k+4}$, and (Δ) is the ratio of areas as : $\Delta = \frac{A_{S1}}{A_{F1}}$

(ϕ_n) is the inclination angle of side openings of the nth chamber, and (ψ_n) is the ratio of pressure in the nth chamber to that in first chamber, it is expressed as:

$$\psi_n = \left(\frac{A_{Fn}}{A_{Fn} + A_{Sn}} \right)^{\frac{2k}{k+1}} \quad (5)$$

The real flow area through rectangular side opening (A_{Sn}) is calculated as:

$$A_{Sn} = \nu.N.a_n.b_n$$

where (n) is the number of holes in each chamber (it equals 2 in this examined case), (a_n) is the length of opening of nth chamber (b_n) is the width of opening of nth chamber, (ν) is the coefficient of real flow area of side opening. This coefficient is assumed via flow analysis to be nearly (0,5).

Thus, the geometric index for nth chamber muzzle brake is expressed as:

$$æ_n = \left[\psi_n^{\,n-1} + \sum_{i=1}^{n} \Delta\,.\mu\,.\cos\phi_i.\psi_i^{\,i-1} \right].\frac{1}{1+\Delta} \quad (6)$$

The decrease of recoil force is based on decreasing the impulse of product gases that act on recoiling parts in direction of recoil for same length of barrel of a particular gun. The ratio of gases impulse when using MB to that without using MB is essential for calculating the recoil parameters. This impulse ratio (χ) is given by:

$$\chi = \frac{æ.\beta - 0.5}{\beta - 0.5} \quad (7)$$

During the AAPG period without using MB, the weapon recoil force is the force of powder gases pressure:

$$P_B = P_M.e^{-\frac{t'}{B}} \quad (8)$$

where, (B) is the Bravin's exponent of AAPG and it can be calculated as shown in Eqn. 9:

$$B = \frac{(\beta - 0.5)m_w.v_M}{S\left(P_M - P_{EA}\right)} \quad (9)$$

Also, (t') is the time variable during AAPG measured from muzzle point. It has the range: $(0 \le t' \le t'_{EA})$. P_M is the pressure inside the barrel at the muzzle point. P_{EA} is the pressure at end of after effect period ≈ 0.18 MPa. S is the area of bore cross section.

During the AAPG period when using MB, the weapon recoil force is the force of powder gases pressure:

$$P_{B(MB)} = \chi.P_M.e^{-\frac{t'}{B}} \tag{10}$$

where $\chi.P_M$ is the weapon recoil force (R) at the muzzle moment when using a muzzle brake.

Accordingly, the course of muzzle brake force (F_{MB}) during the AAPG period:

$$F_{MB} = P_B - P_{B(MB)} = (1-\chi).P_M.e^{-\frac{t'}{B}} \tag{11}$$

Thus, the MB force at the muzzle moment (at the beginning of AAPG), which is the third used response parameter will be:

$$F_{MB} = (1-\chi).P_M \tag{12}$$

In order to maximise the MB efficiency and the MB force and hence minimising the weapon recoil force, the following design parameters have to be optimised: The length of side opening (a), the width of side opening (b), the number of chambers (n), and the angle of inclination (ϕ) of side opening of each chamber to the barrel axis.

It is important to mention that the above equations have been solved considering the following ballistic inputs:

Propellant type	Nitro glycerol with RT value = 1.117 MJ/Kg	Propellant mass	13.75 gm
Propellant density	1650 Kg/ m³	Projectile mass	40.3 gm
Barrel length	1.095 m	Projectile type	Ball
V_M	1000 m/s	P_M	40 Mpa

3. DESIGN OPTIMISATION FORMULATION

In this optimisation problem, the objective is to find the optimum design parameters which maximise the efficiency, maximise the MB force and minimise the weapon recoil force of the weapon.

3.1 Design Parameters

The design parameters are considered as: length of nth chamber side opening (a_n), width of nth chamber side opening (b_n) and the angle of inclination (ϕ_n) of side opening of nth chamber to the barrel axis, where (n) is the number of MB chambers either two or three or four.

3.2 Constraints

Constraints here have been considered as inequality constraints for the upper and lower bounds of the design parameters as shown in the following inequality[7]:

Lower Bound ≤ Design Parameter ≤ Upper Bound

The design parameters bounds are as shown in Table 1.

Table 1. Design parameters bounds

Design parameter	a_1, mm	a_2, mm	b_1, mm	b_2, mm	ϕ_1, degree	ϕ_2, degree
Lower bound	16.89	16.89	14.4	14.4	90	90
Upper bound	25.34	25.34	21.6	21.6	140	140

3.3 Creation of Objective Function

The objective of the optimisation process is to find the parametric values that maximise or minimise the so called objective function. The objective function is a mathematical expression describing a relationship between the design parameters and the output efficiency, MB force and the weapon recoil force, in this examined case.

To create objective function for the pre-mentioned design parameters, the statistical technique DOE has been used to find the best combinations of these design parameters which can describe the whole design space. To complete the DOE matrix, the values of the response (efficiency, muzzle brake force and the weapon recoil force) have been calculated using the analytical model for each raw in the DOE matrix. Then, fully quadratic response equations have been illustrated using RSM to show the variation of the output with the different design parameters. Finally, these surfaces have been considered as the objective function in the optimisation process.

3.3.1 Design of Experiments

Design of experiments, (DOE), is an approach to develop an investigation strategy that maximises knowledge using minimum of resources. In many applications, the scientist is constrained by resources and time, to study the numerous factors that affect these complex processes using trial and error methods. Instead, (DOE) is a governing tool that permits for multiple input factors to be manipulated determining their effect on an expected output (response)[8].

In this study, central composite design two level full factorial technique has been used. Appendix A shows the DOE Matrix after calculating efficiency, MB force and weapon recoil force.

3.3.2 Response Surface Method

The main objective of response surface method (RSM) is to examine the relationship (surface) between each response with the pre-mentioned design parameters. Generally, RSM depends on the nature of the fitted model which can be obtained using regression analysis to formulate a polynomial function. A fully quadratic fitting model has been used here[9] and[10]. For the case of two chambers with six design parameters, the fully quadratic response surface equation can be written as:

$$\begin{aligned} f = {} & A_o + A_1 a_1 + A_2 a_2 + A_3 b_1 + A_4 b_2 + A_5 \varphi_1 + A_6 \varphi_2 + \\ & A_7 a_1 a_2 + A_8 a_1 b_1 + A_9 a_1 b_2 + A_{10} a_1 \varphi_1 + A_{11} a_1 \varphi_2 + \\ & A_{12} a_2 b_1 + A_{13} a_2 b_2 + A_{14} a_2 \varphi_1 + A_{15} a_2 \varphi_2 + A_{16} b_1 b_2 + \\ & A_{17} b_1 \varphi_1 + A_{18} b_1 \varphi_2 + A_{19} b_2 \varphi_1 + A_{20} b_2 \varphi_2 + A_{21} \varphi_1 \varphi_2 + \\ & A_{22} a_1^2 + A_{23} a_2^2 + A_{24} b_1^2 + A_{25} b_2^2 + A_{26} \varphi_1^2 + A_{27} \varphi_2^2 \end{aligned} \tag{12}$$

Using the information from the DOE matrix, the constants in this equation are determined and the response surfaces for efficiency, muzzle brake force and weapon recoil force are obtained. The MB efficiency change with the design parameters are as shown in Figs. 2-4.

Figures 2-4 show the change of the MB Efficiency with the different design parameters. It is clear that one can estimate from these response surfaces, where the minimum/maximum values of the response function is, regarding each design parameter. The same response surfaces for muzzle brake force and weapon recoil force are obtained with the different design parameters.

4. RESULTS AND DISCUSSIONS

4.1 Optimisation Techniques and Optimum Design Parameters

Generally, the objective function has only one output response. But in this case the following requirements have to be satisfied: (a) Maximising efficiency, (b) Maximising Muzzle brake force, (c) Minimising the weapon recoil force. To solve this optimisation problem which has three objective functions, the Multi Objective Genetic Algorithm (MOGA) has been used to get the optimum values of design parameters[11]. It is important to mention that the MOGA has been done using the ANSYS 18 optimisation toolbox. For more understanding of the effect of optimisation process, the optimum design parameters with respect to each output response, two output responses have been found. It is important to mention that the differences between the values of the optimum parameters in all considered cases are very small, however for more accuracy, the optimisation considering the three objectives responses (efficiency, MB force and recoil force) will be used for finding the optimum design parameters for two, three and four chambers MBs. Tables 2 - 4 show the optimum design parameters for two, three and four chambers.

4.2 Sensitivity of Design Parameters

The sensitivities of each design parameter with the different output responses for two, as shown in Fig. 5[12,13].

Figure 5 shows that the angle of inclination of the second chamber (ϕ_2) is the most sensitive design variable that has significant effect on all output responses for two chambers muzzle brake.

For three and four chambers MBs, it was found that the lengths of first and second chambers (a_1 and a_2) and the angle of inclination of the third chamber side openings (ϕ_3) are the most sensitive design variables that have significant effect on efficiency and recoil force while the angle of inclination of the second chamber side opening (ϕ_2) is the most sensitive design parameter that has significant effect on MB force for three chambers muzzle brake.

However for the four chambers MB, it was found that the angle of inclination of first and second chambers side openings (ϕ_1 and ϕ_2) have significant effect on all output responses while the width of the second chamber side opening (b_2) has significant effect on MB force only for four chambers muzzle brake.

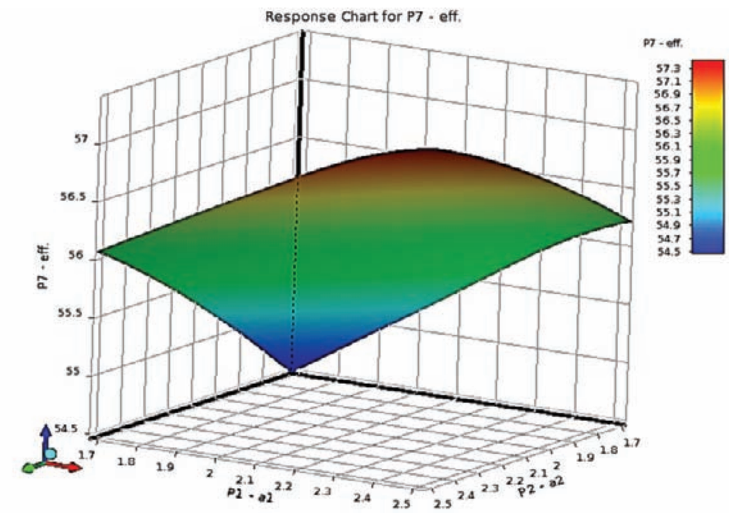

Figure 2. Efficiency change with the side opening length (a_1 and a_2) for two chambers MB.

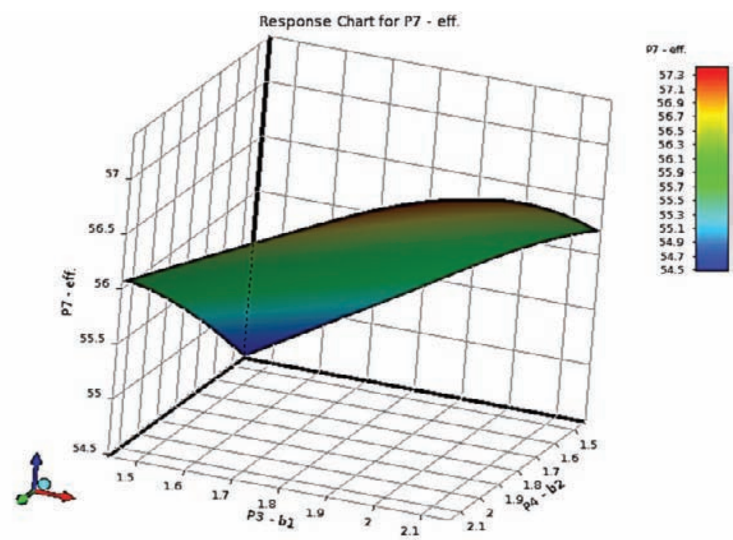

Figure 3. Efficiency change with the side opening width (b_1 and b_2) for two chambers MB.

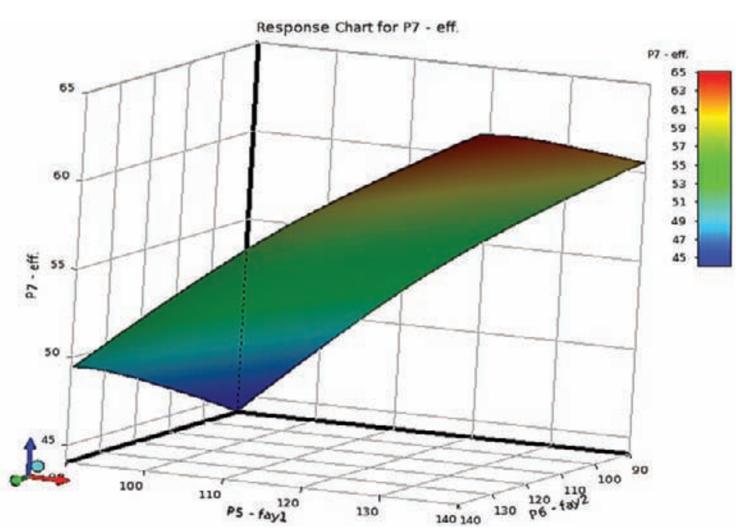

Figure 4. Efficiency change with the angles of inclination (ϕ_1 and ϕ_2) for two chambers MB.

Table 2. Optimisation results considering efficiency, MB force and recoil force optimisation for two chambers

	Candidate point 1	Candidate point 2	Candidate point 3
a_1 (mm)	25.06584864	25.018717	25.15953315
a_2 (mm)	24.52483027	24.93284045	24.93020029
b_1 (mm)	21.16306542	20.86659119	20.82592652
b_2 (mm)	21.40912887	20.9323348	21.12326116
ϕ_1 (deg)	139.6968239	139.7584157	139.691655
ϕ_2 (deg)	135.8947361	135.5074598	134.4940794
η (%)	67.02904993	66.98573184	66.94824953
χ. pm (N)	-8761.799419	-8744.05211	-8733.989184
F_{MB} (N)	13905.08601	13892.59138	13882.00493

Table 3. Optimisation results considering efficiency, MB force and recoil force optimisation for three chambers

	Candidate point 1	Candidate point 2	Candidate point 3
a_1 (mm)	24.30258193	24.97171913	24.48813624
a_2 (mm)	25.23113057	24.97487416	25.20145253
a_3 (mm)	23.65720062	24.02743103	24.63795472
b_1 (mm)	20.9916184	21.50222869	21.37048969
b_2 (mm)	20.8532091	21.39433265	21.31743021
b_3 (mm)	20.78878951	20.69881684	21.49584404
ϕ_1 (deg)	138.5139741	138.1297569	138.221951
ϕ_2 (deg)	137.6947319	137.944316	137.2847968
ϕ_3 (deg)	139.5481085	135.7386437	127.6722435
η (%)	68.93105085	68.87291729	68.73412153
$\chi . p_m$ (N)	-9278.04001	-9261.113053	-9221.659438
F_{MB} (N)	14464.44843	14461.08778	14431.62005

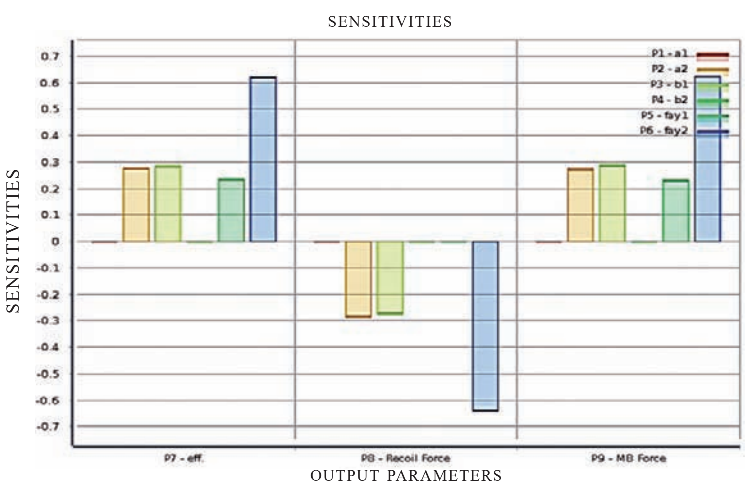

Figure 5. Sensitivity of the objective functions for different design parameters for two chambers MB.

Table 4. Optimisation results considering efficiency, MB force and recoil force optimisation for four chambers.

	Candidate Point 1	Candidate Point 2	Candidate Point 3
a_1 (mm)	24.89880912	24.65980765	24.7274839
a_2 (mm)	25.20088723	20.39026601	25.21194523
a_3 (mm)	22.97447581	24.62817882	24.43395303
a_4 (mm)	24.98823773	24.8816158	24.96997418
b_1 (mm)	21.45899174	21.30742155	21.41600698
b_2 (mm)	21.40174412	21.5681269	21.26055713
b_3 (mm)	21.2857355	21.39497921	21.336788
b_4 (mm)	20.90097777	19.84582457	21.19155061
ϕ_1 (deg)	138.7788277	138.8430759	138.7703926
ϕ_2 (deg)	139.7974091	139.5837936	139.8450129
ϕ_3 (deg)	137.4127232	137.2826169	133.6532787
ϕ_4 (deg)	137.5456293	130.9068952	137.2350544
η (%)	69.53684224	69.49606089	69.48643659
$\chi . p_m$ (N)	-9462.031867	-9449.981651	-9447.141564
F_{MB} (N)	14718.80374	14716.15561	14714.93972

4.3 Productive Design Parameters

For easy manufacturing of the MB, the values of side opening length, width and the angle of inclination should betaken as nearest integer values, (a_n=25 mm, b_n=20 mm and φ_n=138 degree). Then efficiency, MB force and recoil force values have been calculated from analytical model and through the optimisation formulation, from which the accuracy of optimisation has been calculated.

The accuracy of optimisation can be calculated by determining the error between results from analytical model and optimisation formulation using the following equation:

$$\text{error}(\%) = \frac{\text{Results from optimisation formulation} - \text{Reults from analytical model}}{\text{Values from analytical model}} \times 100$$

Table 5 shows that the error of optimisation process is too small which reveals to the accuracy of optimisation process.

5. CONCLUSIONS

The developed analytical model to calculate MB efficiency, MB force and weapon recoil force, which then combined with (DOE) and (RSM) is an efficient technique to illustrate the change of response surfaces with the different design parameters. Also, using the developed objective function, the optimum design parameters values can be obtained by MOGA. The results of this optimisation

Table 5. Values of all output parameters and error of optimisation

	Analytical model			Optimisation formulation			Error (per cent)		
Response	**η (%)**	**F_{MB} (N)**	**$\chi . p_m$ (N)**	**η (%)**	**F_{MB} (N)**	**$\chi . p_m$ (N)**	**η**	**F_{MB}**	**$\chi . p_m$**
Two chambers	66.34	13725.4	-8538.3	66.399	13730.01	-8584.2	0.09	0.0335	0.5373
Three chambers	68.873	14453.09	-9266	68.769	14431.11	-9230.2	0.151	0.152	0.38625
Four chambers	69.477	14630.91	-9443.8	69.278	14624.99	-9385.1	0.285	0.0404	0.621

problem may show the following conclusions:

(i) The values of output responses (efficiency, muzzle brake force and weapon recoil force) in the three and four chambers MBs do not give a big change with respect to that of two chambers MB, thus they do not have a great effect in reducing recoil energy compared with two chambers MB. So it is recommended to use two chambers muzzle brake.

(ii) From the results of various optimisations on two chambers muzzle brake, it was found that the difference between optimum design parameters with respect to each output response is very small, however for more accuracy, the optimisation considering the three objectives responses (efficiency, MB force and recoil force) has been used for finding the optimum design parameters for two, three and four chambers MBs.

(iii) From manufacturing point of view, values of design parameters are taken approximated to nearest integer values. In addition, the values of efficiency, MB force and weapon recoil force are calculated using the analytical model and the optimisation formulation. For this investigated case, it was found that the error between the optimisation results and the analytical model results is too small which reveals to the accuracy of the used optimisation formulation.

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In the current study, he is involved in literature review, optimisation formulation, results analysis, organised the study and in writing of the manuscript.

Dr Mohamed H. Aboul received his BS in Mechanical Engineering from Military Technical College, Cairo, Egypt, and MSc from Vaaz Academy, Brno, Československá and PhD from Ensam, Paris, France respectively. He is currently working as an Associate Professor in Weapons and Ammunition Department in Military Technical College, Cairo, Egypt. His research interests are gun mechanics and design, solid mechanics, and fluid dynamics.
In the current study, he is involved in analytical modelling of MB indices.

APPENDIX 'A'

DOE matrix for two chamber M.B

No	a_1 (mm)	a_2 (mm)	b_1 (mm)	b_2 (mm)	ϕ_1 (deg)	ϕ_2 (deg)	η (%)	F_{MB} (N)	χ. *pm*
1	2.105	2.105	1.8	1.8	115	115	56.2318	11064.105	-5877.02
2	1.68	2.105	1.8	1.8	115	115	55.3459	10846.305	-5659.22
3	2.53	2.105	1.8	1.8	115	115	56.904	11230.823	-6043.74
4	2.105	1.68	1.8	1.8	115	115	55.3943	10858.153	-5671.07
5	2.105	2.53	1.8	1.8	115	115	56.8507	11217.565	-6030.48
6	2.105	2.105	1.44	1.8	115	115	55.3555	10848.666	-5661.58
7	2.105	2.105	2.16	1.8	115	115	56.8984	11229.436	-6042.35
8	2.105	2.105	1.8	1.44	115	115	55.4036	10860.415	-5673.33
9	2.105	2.105	1.8	2.16	115	115	56.8456	11216.306	-6029.22
10	2.105	2.105	1.8	1.8	90	115	47.0317	8899.2562	-3712.17
11	2.105	2.105	1.8	1.8	140	115	63.0621	12823.294	-7636.21
12	2.105	2.105	1.8	1.8	115	90	53.543	10409.638	-5222.55
13	2.105	2.105	1.8	1.8	115	140	58.3578	11595.934	-6408.85
14	1.85934	1.85934	1.59191	1.59191	100.549	100.549	47.6485	9038.1943	-3851.11
15	2.35065	1.85934	1.59191	1.59191	100.549	129.45	51.4408	9911.0533	-4723.97
16	1.85934	2.350659	1.59191	1.59191	100.549	129.45	52.1422	10076.194	-4889.11
17	2.35065	2.350659	1.59191	1.59191	100.549	100.549	49.442	9446.9177	-4259.83
18	1.85934	1.85934	2.00808	1.59191	100.549	129.45	51.4364	9910.0172	-4722.93
19	2.35065	1.85934	2.00808	1.59191	100.549	100.549	49.4759	9454.6955	-4267.61
20	1.85934	2.350659	2.00808	1.59191	100.549	100.549	49.4346	9445.2043	-4258.12
21	2.35065	2.350659	2.00808	1.59191	100.549	129.45	52.747	10219.551	-5032.46
22	1.85934	1.85934	1.59191	2.00808	100.549	129.45	52.1316	10073.681	-4886.6
23	2.35065	1.85934	1.59191	2.00808	100.549	100.549	49.4344	9445.1722	-4258.09
24	1.85934	2.350659	1.59191	2.00808	100.549	100.549	49.5024	9460.8038	-4273.72
25	2.35065	2.350659	1.59191	2.00808	100.549	129.45	53.3528	10364.065	-5176.98
26	1.85934	1.85934	2.00808	2.00808	100.549	100.549	49.427	9443.4562	-4256.37
27	2.35065	1.85934	2.00808	2.00808	100.549	129.45	52.7392	10217.7	-5030.61
28	1.85934	2.350659	2.00808	2.00808	100.549	129.45	53.3512	10363.69	-5176.6
29	2.35065	2.350659	2.00808	2.00808	100.549	100.549	50.8209	9766.0976	-4579.01
30	1.85934	1.85934	1.59191	1.59191	129.45	129.45	59.5995	11912.872	-6725.79
31	2.35065	1.85934	1.59191	1.59191	129.45	100.549	58.224	11562.067	-6374.98
32	1.85934	2.350659	1.59191	1.59191	129.45	100.549	57.4814	11375.095	-6188.01
33	2.35065	2.350659	1.59191	1.59191	129.45	129.45	61.6911	12457.927	-7270.84
34	1.85934	1.85934	2.00808	1.59191	129.45	100.549	58.2091	11558.302	-6371.22
35	2.35065	1.85934	2.00808	1.59191	129.45	129.45	61.8487	12499.577	-7312.49
36	1.85934	2.350659	2.00808	1.59191	129.45	129.45	61.6818	12455.468	-7268.38
37	2.35065	2.350659	2.00808	1.59191	129.45	100.549	60.3367	12103.313	-6916.23
38	1.85934	1.85934	1.59191	2.00808	129.45	100.549	57.4733	11373.073	-6185.99
39	2.35065	1.85934	1.59191	2.00808	129.45	129.45	61.6829	12455.759	-7268.67
40	1.85934	2.350659	1.59191	2.00808	129.45	129.45	61.6147	12437.761	-7250.68
41	2.35065	2.350659	1.59191	2.00808	129.45	100.549	59.6537	11926.806	-6739.72
42	1.85934	1.85934	2.00808	2.00808	129.45	129.45	61.6736	12453.297	-7266.21
43	2.35065	1.85934	2.00808	2.00808	129.45	100.549	60.3309	12101.823	-6914.74
44	1.85934	2.350659	2.00808	2.00808	129.45	100.549	59.6411	11923.573	-6736.49
45	2.350659	2.3506592	2.008088	2.00808	129.45	129.45	63.2961	12886.34	-7699.26