QFDE Combined with TRIZ Framework to Formulate and Respond to Functional Design for a High Temperature Machine (HTM).

Butdee S.
IMSRC, Department of Production Engineering, Faculty of Engineering,
King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand
E-mail address: stb@kmutnb.ac.th

Trakunsaranakom C.*
IMSRC, Department of Production Engineering, Faculty of Engineering,
King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand
E-mail address: yong_k_mitnb@hotmail.com

Abstract
This paper proposes a functional design methodology to concern environmentally consciousness design of product. QFDE (Quality Function Deployment for Environment) combined with TRIZ(Theory of Inventive problem Solving) and FEM (finite element method) are employed. The QFDE is used to create a critical function to high pressure machine components. TRIZ is then validated step by step for innovative redesign. Then, the FEM is used to test the engineering machine specification. The experiment is successfully tested.

Keywords*: QFDE, TRIZ, FEM, High Temperature Machine (HTM)*

1 Introduction

Coating and glazing materials for small arms ammunitions needs a high temperature machine. Such materials are required homogenous propellants outside surface in order to be able to move with high velocities. Coating and glazing of grain propellant powder must be performed together in one step. Firstly, base grain is placed into a coating tank with water, moderant (methyl centralite) and glazing powder (graphite). The tank is then rotated with high temperature by the injection of live steam. A traditional high temperature machine is not effective to produce new ammunition. It is too big and manually control. This paper presents developments a small and efficient high temperature machine by redesigning based on the principle functional components. The existing machine produces only 300-450kg of propellant powder per time. The major machine's functions are prevention of explosion and environment damage as well as strengthen. The QFED, TRIZ and FEM methodology are employed to support redesigning process. The machine is then produced. The ammunitions are tested with the real machine gun and compare to a standard ballistic performance specification.

2 QFDE Methodology

QFDE [1] is a method to support eco-design developed by incorporating environmental aspects into QFD [2]. It consists of four phases [3]. The first step is to clarify the product positioning based on Voice Of Customer - VOC using Engineering Metrics (EM). The second step is comparison between the EM metrics with the product's components [4]. The QFDE is a systematic tool for eco-design with the original strong points of QFD [5]. The outputs from those two phases are identified to meet quality characteristics [6, 7]. One drawback of QFDE is that generating concrete solutions is totally on design engineers in spite of some suggestions given from the phase I and II. However, the QFDE method is easy to use for designing product. The calculated score accuracy for each design improvement is low because the correlation strengths between VOE and QC [6]. The components are represented only absolute number without considering whether they are positive or negative. The correlation table for QC facilitated in QFD is omitted.

3 TRIZ

TRIZ is the acronym for Teoriya Reshniya Izobretatelskikh Zadatch in Russian. It means theory of inventive problem solving [8] which is began in 1946 by Genrich Altshuller [9]. TRIZ is encompasses a series of tools, a methodology for generating innovative ideas [10] and solutions for problem solving. This theory comes from with the idea that every engineer can; become an inventor, solve very difficult problems, and propose innovative solutions [11]. TRIZ is an inventive problem solving method that increases the ability to solve creative problem. It has been the subject of many years of development [12]. It has been studied over a million successful patents. The TRIZ methodology is claimed that inventive problems can be codified classified and solved methodically [13]. TRIZ is based on three postulates [14]. The first is the postulate of existing objective laws which means engineering systems evolve according to a set of lows. The second is the postulate of contradictions which evolves with an engineering system in order to overcome one or more contradictions. The third is the postulate of the specific situation which concerns with the problem solving process taking into account of the specific problem peculiarities. A set of TRIZ tools are based on the postulates and derived from this patent analysis [15]. It consists of five characteristics as the following:

1. The contradiction principles are used to solve physical contradictions.
2. The separations principles are used to solve physical contradictions.
3. Substance-Field modeling and the inventive standard are used to transform technical systems.
4. A list of logical procedures is used for eliminating contradictions.
5. A system of laws show govern engineering system evolution.

3.1 *Technical contradiction solution system*

Altshuller [9] has classifed the contradictions into 39 parameters and in a similar way he identified 40 common principles which are used in exisitng patent in the forms of 39X39 square matrix. It is then identified 40 inventive principles associated with specific combinations of contradiction parameters. This matrix is called the Technical Contradiction Matrix.

3.2 *Physical contradiction solution system*

Altshuller et al. [9] identify a further level of abstraction from the technical contradiction. The technical contradiction is presented as two extremes of one feature, which is called a physical contradiction. A physical contradiction requires mutually exclusive states that relates to a function, performance or a component. The relationship between the technical and physical contradictions has been graphically illustrated, as shown in the Figure1. A technical contradiction between the parameter A and B are further abstracted to present the contradiction in terms of a common variable parameter C, which is the physical contradiction. TRIZ is used to support the concept of Axiomatic Design [16, 17] and Robust Design [18, 19].

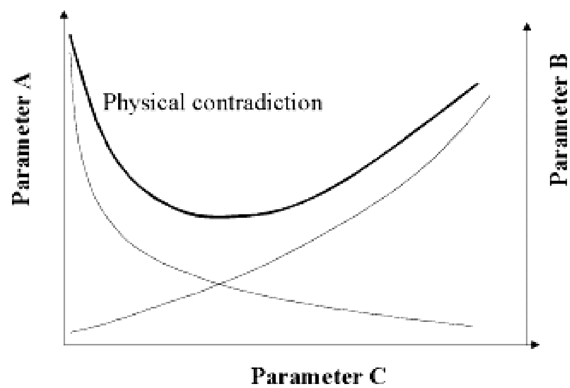

Figure 1: A graphical illustration of a physical contradiction [9]

4 FEM Method

The finite element method is a technique for obtaining approximate solutions to boundary value problems [20]. It has become the most popular and powerful numerical tool for solving problems [21, 22] in engineering and science. The term mixed methods has been used in the finite element method literature since the mid 1960s to denote formulations in which both the displacement [23]. The finite element equations for solid mechanics problems can be derived by applying the method of weighted residuals to the equilibrium equations [24]. It can be written in the conservation form as the followings,

$$\frac{\partial\{E_s\}}{\partial x}+\frac{\partial\{F_s\}}{\partial y}=0 \qquad (1)$$

Where the flux vector components $\{E_s\}$ and $\{F_s\}$ contain the stress components given by the equation (2).

$$\{E_s\}=\begin{Bmatrix}\sigma_{xx}\\ \sigma_{xy}\end{Bmatrix};\{F_s\}=\begin{Bmatrix}\sigma_{xy}\\ \sigma_{yy}\end{Bmatrix} \qquad (2)$$

The stress components are related to strain components by the Hooke's law, $\{\sigma\}=[C]\{\varepsilon\}$, where $\{\sigma\}$ is the vector of the stress components, $[C]$ is the matrix of the material elastic constants, and $\{\varepsilon\}$ is the vector of the strain components. To derive the finite element matrices using the flux based formulation, the method of weighted residuals is first applied to Equation (1) and can be written in a compact form [25] of the equation (3).

$$\int_{\Omega}[B_s]^T[\overline{N}]d\Omega\{\overline{\sigma}\}=\int_{s}[N]^T[\overline{N}]d\Gamma\{\overline{T_s}\} \qquad (3)$$

Equation (3) can be further employed to analyze two-dimensional crack propagation problems under mixed-mode loading. the node less variable elements are used to model the tested specimens. In order to improve the accuracy of the near-tip stress field, elements around the crack tip contain their mid-side nodes displaced from their nominal positions to quarter points. The six-node triangular elements are calculated to achieve high resolution accuracy near the crack tip. They forms a circular zone surrounding the crack tip have their mid-side nodes displaced from their nominal positions to quarter points of the tip [26]. The important parameters used in the linear elastic fracture mechanics are the stress intensity factors which are determined by the equation (4) and (5) as the followings

$$K_I=\frac{E}{3(1+\nu)(1+k)}\sqrt{\frac{2\pi}{L}}\left(4(v_b-v_d)-\frac{(v_c-v_e)}{2}\right) \qquad (4)$$

$$K_{II}=\frac{E}{3(1+\nu)(1+k)}\sqrt{\frac{2\pi}{L}}\left(4(u_b-u_d)-\frac{(u_c-u_e)}{2}\right) \qquad (5)$$

E is the modulus of elasticity where as ***v*** is the Poisson's ratio. ***K*** is the elastic parameter defined by (3-4***v***) for plane strain and (3-***v***)/(1+***v***) for plane stress problems. ***L*** is the element length. The variables ***u*** and ***v*** are the displacement components in ***x***- and ***y***-directions. According to the maximum circumferential stress theory, the direction of crack propagation θ may be computed by the equation (6).

$$K_I\sin\theta+K_{II}(3\cos\theta-1)=0 \qquad (6)$$

Equation (6) implies that the crack propagates at zero angle θ for the pure mode I, and at non-zero angle in a mixed mode loading.

5 Proposed Design Methodology

In order to meet the machine functionality requirements, tree diagram is used as shown in the Figure 2. The high temperature machine consists of six main functional components; security, efficiency, material, geometry, convenience and environment. The variables are further given. Voices of customer for environment with engineering matrix for the new machine are created. Then, weight points which are related to environment are collected and given on the table QFDE. It determines the relationship between voices of customer for environment with engineering matrix. The environmental impact is ranked into three levels. The high impact score is given by 9 points. The medium impact score is given by 3 points and low impact score is given by 1 point. Table 1 shows the matrix of voices of customer for the QFDE method in the phase I. There are 24 items. Each item composes of the different customer's weight. The result shows the significant voices in the aspects of safe use from explosion, safe use from fire, unharmful to human's life and energy consumption respectively. Table 2 shows the metric of machine technical information which is required in the QFDE phase II. The result shows that the critical components are the power transmission, the coat and glaze tank and structural machine.

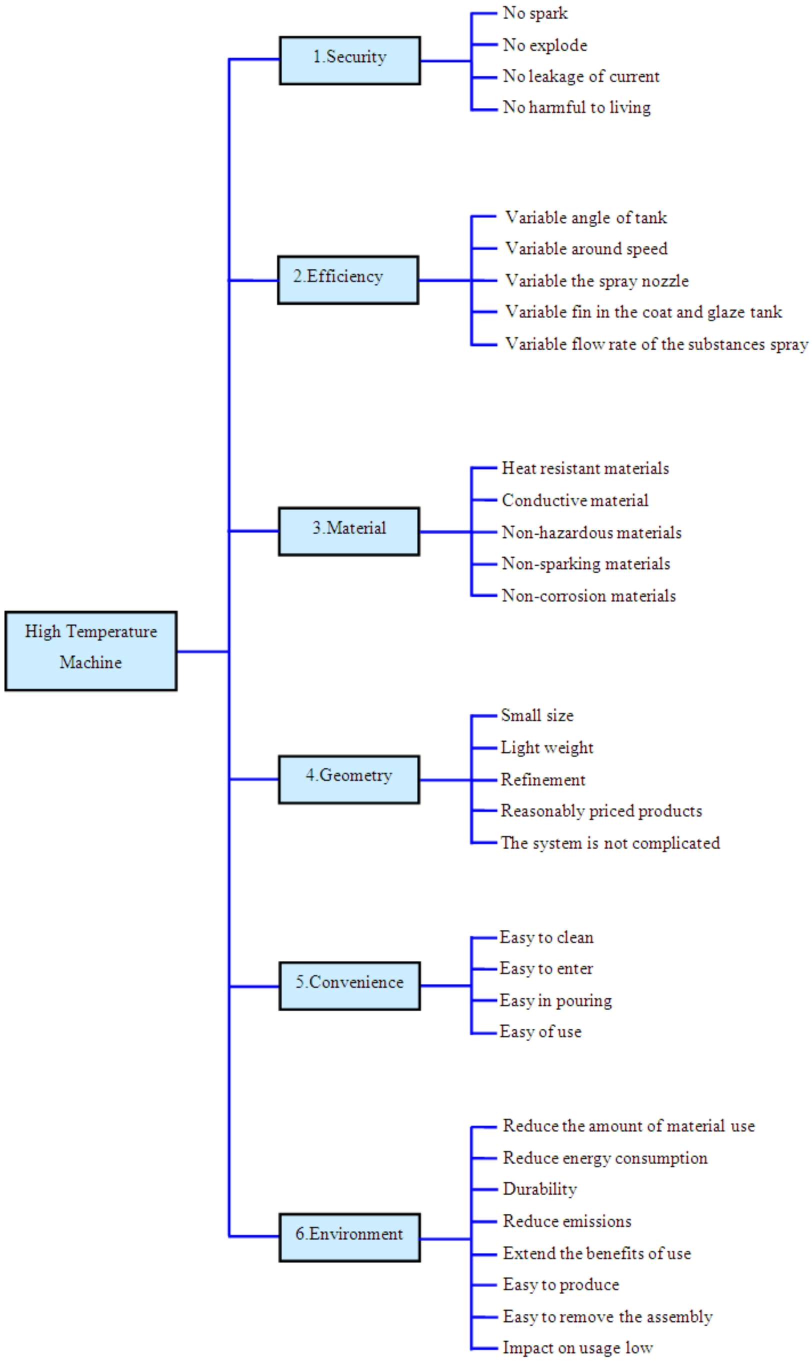

Figure 2: Tree Diagram of the HTM.

Table 1: Voices of Customer

QFD for Environment Phase I Voice of Customer	Customer Weight	Engineering Matrix																	
		1.Use safe from the explosion	2.Use safe from fire	3.Not harmful to living	4.The variable speed	5.Tilt adjustment angle	6.Adjust the flow rate	7.Weight	8.Volume	9.Number of parts	10.Number of different materials	11.Strength	12.The useful life of mechanical	13.The amount of energy required	14.Temperature, Vibration, Magnetic wave	15.Amount of air pollution	16.Amount of water pollution	17.Amount of soil pollution	18.Reduce the use of hazardous materials
1.No explode, No spark	9	9	9	9										9	3				3
2.No leakage of current	9	9	9	9	3								3	9	3				
3.No harmful to living	9	9	9	9							3		3		1				
4.Can adjust around speed	9			3	9			3	3		1	3	1	3	3	3			
5.Can adjust angle fin, tank	3					9		3	3				1	1					
6.Can adjust flow rate of spray	1						9		3		1		1	3	3	1			
7.No sparking materials	9	9	9	3							3		3						3
8.Heat resistant materials	3	9	3	3							3	3	3			3			
9.Good conduction materials	1										9		3	3	3				
10.No corrosion materials	1		3	3						3	3	9	9			1	1	1	3
11.No hazardous materials	9	9	9	9												3	3	3	3
12.Small size, Light weight	3				9	3		9	9	3	3	9	9	9	3				
13.System is not complicated	1				3	1	1			1				1	1				
14. Reasonably priced products	1									3	3	3	3						
15.Easy to use	3				3	3	3			1				1					
16.Easy to enter, in pouring	3	1	3		1	3				1				3	1	1			
17.Easy to clean	3			3		3		1	1	3	3					1	1	1	1
18.Reduce the amount of materials used	3				3			1	1	3	3	3	3	3	3				
19.Reduce energy consumption	1				3	1	3						3	9	3				
20.Reduce emissions	3			3												9	9	9	9
21.Easy to produce, to remove the assembly	3				3	3	3		3	9	3			3					
22.Durability												3	9						
23.To affect on usage low	3			3									1	1	1	3	3	3	1
24.Extend the benefits of use	1				3	3				1	3	3	3						
Raw Score		435	426	417	174	77	31	69	81	68	127	96	157	268	124	89	67	67	117
Relative Weight		0.150	0.147	0.144	0.060	0.026	0.010	0.023	0.028	0.023	0.043	0.033	0.054	0.092	0.042	0.030	0.023	0.023	0.040

Table 2: Machine Technical Information

QFDE Phase II Technical information	Component Characteristics					
	Phase I relative weight	Power transmission	Coat and glaze tank	Machine structure	Set spray substances	System operation
1. Use safe from the explosion	0.150	9	9	1		1
2. Use safe from fire	0.147	9	9	1	1	1
3. Not harmful to living	0.144	9	9		1	1
4. The variable speed	0.060	9	9		1	1
5. Tilt adjustment angle	0.026	3	9			
6. Adjust the flow rate	0.010				9	3
7. Weight	0.023	3	3	9	3	
8. Volume	0.028		3	3	1	
9. Number of parts	0.023	9	9	9	3	9
10. Number of different materials	0.043	9	9	3		
11. Strength	0.033	9	9	9	3	
12. The useful life of mechanical	0.054	9	3	9	9	3
13. The amount of energy required	0.092	9	3		3	3
14. Temperature, Vibration, Magnetic wave	0.042	9	9	9	3	
15. Amount of air pollution	0.030	9			9	
16. Amount of water pollution	0.023				9	1
17. Amount of soil pollution	0.023				9	
18. Reduce the use of hazardous materials	0.040	9	9	9	9	3
Raw Score		7.869	6.963	2.589	2.431	1.319
Relative Weight		0.371	0.328	0.122	0.114	0.062

Table 3: Comparison of the Discrimination between QFDE and TRIZ for the Power Transmission Design.

QFDE Phase II Technical Characteristics	Phase I relation weights	QFDE With TRIZ	The TRIZ Contradiction matrix
Use safe from explosion Use safe from fire No harmful to living	0.150 0.147 0.144	↔	External harm effects the object
The amount of energy required	0.092	↔	Use of energy by moving object
The variable speed	0.060	↔	Adaptability or versatility
The useful life of mechanical	0.054	↔	Duration of action by a moving object
Number of different materials	0.043	↔	Loss of time

Table 3 presents the comparison of the discrimination between QFDE and TRIZ for the power transmission design. The result shows that the TRIZ contradiction metric for the power transmission design contains external harm effects the object. Table 4 presents conceptual design for development the power transmission using TRIZ method. The result shows that the TRIZ principal no.29 is frequently occurred.

Table 4: Conceptual Design for Development the power transmission.

Worsening Feature / Improving Feature		Device comple -xity	TRIZ 40 principals			
External harm effects the object	Technical contradiction	36	22	19	29	40
Use of energy by moving object		36	2	29	27	28
Adaptability or versatility		36	15	29	37	28
Duration of action by a moving object		36	10	4	29	15
Loss of time		36	6	29	-	-

Table 5: Comparison of the Discrimination between QFDE and TRIZ for the HTM Design.

QFDE Phase II Technical Characteristics	Phase I Relation weights	QFDE With TRIZ	The TRIZ Contradiction matrix
The amount of energy required	0.092	↔	Power
The useful life of mechanical	0.054	↔	Duration of action by a moving object
Number of different materials	0.043	↔	Quantity of substance/the matter
Temperature, Vibration, Magnetic Wave	0.042	↔	Temperature
Weight	0.023	↔	Weight of moving object

Table 6: Conceptual Design for development the HTM Tank

Worsening Feature / Improving Feature		Shape	TRIZ 40 principals			
Power	Technical contradiction	12	29	14	2	40
Duration of action by a moving object		12	14	26	28	25
Quantity of substance/the matter		12	35	14	-	-
Temperature		12	14	22	19	32
Weight of moving object		12	10	14	35	40

Table 5 presents the comparison of the discrimination between the QFDE and TRIZ of the HTM design. The result found that the TRIZ contradiction for the HTM composes of power duration of action by the major object, quantity of substance the water, temperature and weight of the major object. Table 6 presents the comparison of chemistry physics of propellant between standard and the actual results. It is found that the test is satisfaction.

As shown in the table 6, the principle of article 14 is frequently occurred. It refers to the spherical concept to make an object surface to be flat and smooth curve. Finally, a new high temperature machine is redesign based on the previous analyzed. Finally, a new HTM is redesign as shown in the Figure 3.

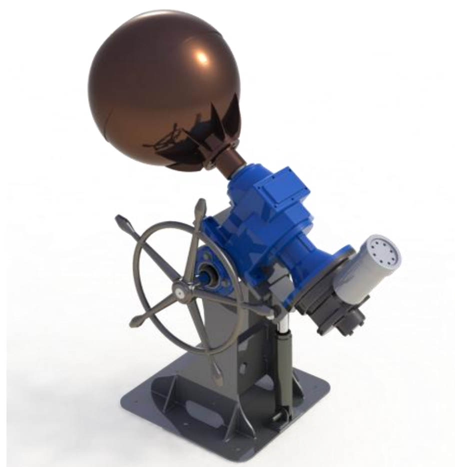

Figure 3: Redesign of the HTM

6 Results of experiment

The propellant powder coated and glazed experiment which is produced by the redesign machine is classified into 3 types type A, type B and C. Each type contain 10 samples. They are 30 samples. Table 7 shows the result of chemistry physic testing. Then, the ballistic performance is tested. The process of coating and glazing propellant powder is associated with ballistic performance test include as followings;

1. Chamber pressure test or barrel test together with copper crusher gauge and bulled test.
2. Muzzle velocity test, projectile velocity measurement and bulled test.
3. Standard deviation of Muzzle Velocity, using a computer calculation processing and display.

Table 8 shows the ballistic test of the DNT 6%. The test is performed by 4 shots. The pressure mean is 3812.9 bars whereas the velocity is 896.18 m/s. The result is shown by the graph as shown in the Figure 4.

Table 7: Chemistry physics Comparison test of the Propellant

CHEMISTRY PHYSICS TEST		
Chemistry Analysis	Specification	Results
Nitrocellulose	98%	98.19%
Diphenylamine	1.20%	1.12%
Potassium Sulphate	0.80%	0.69%
Dinitroluene	9%	6.25%
Graphite	0.70%	0.84%
Moisture Content	0.8-1.2%	1.11%
Total Volatile Content	2.5% Max	1.60%
Ash Content	0.60%	1.02%
Alkalinimity ($CaCo_3$)	0.1-0.4%	0.02%
Abel Heat Test	≥ 10 Minutes	26 Minutes
Methyl Violet Test	≥ 40 Minutes	55 Minutes
Absolute Density	1.55g/ml min	1.61 g/ml min
Bulk Density	880g/l min	944.84 g/l min

Table 8: Ballistic Test of the DNT 6%

List of Rounds :	Pressure	Velocity
Units	[bar]	[m/s]
1. RTA. Bullet	3845.5	891.05
2. RTA. Bullet	3969.8	898.33
3. RTA. Bullet	3599.5	882.50
4. RTA. Bullet	3837.0	912.85

Statistic Evaluation :	Pressure	Velocity
Units	[bar]	[m/s]
Mean	3812.9	896.18
Max	3969.8	912.85
Min	3599.5	882.50
Range	370.3	30.35
SD. Of MV.	154.7	12.86

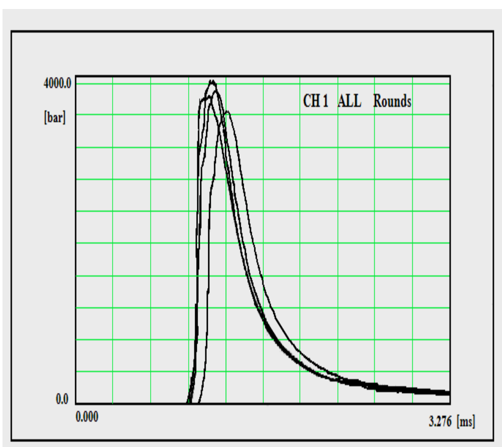

Figure 4: The result shown at DNT 6%

7 Conclusions

This paper has presented the methodology of QFDE combined with TRIZ to support a new high temperature machine redesign. Then, such machine is analyzed by finite elements method. The sample bullets are produced and tested by firing a real gun machine. The result is compared to the standard ammunition. The speed is in between 890-950 m/s. The experiment result is 951.71m/s. Therefore, the test is satisfaction.

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