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Application Quality Function Deployment (QFD) Tool in Design of Aero Pumps Based on System Engineering

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Abstract**—**Quality Function Deployment (QFD) was developed in 1960 in Japan and introduced in 1983 in America and Europe. The paper presents a real application of this technique in a way that the method of applying QFD in design and production aero fuel pumps has been considered. While designing a product and in order to apply system engineering process, the first step is identification customer needs then its transition to engineering parameters. Since each change in deign after production process leads to extra human costs and also increase in products quality risk, QFD can make benefits in sale by meeting customer expectations. Since the needs identified as well, the use of QFD tool can lead to increase in communications and less deviation in design and production phases, finally it leads to produce the products with defined technical attributes.

Keywords**—**Customer voice, engineering parameters, QFD, gear pump.

I. Introduction

THE goal of the paper is applying QFD tool in aero pump design. Since each product can be defined as a system, so the use of special tools in system engineering process causes that needs would be met. QFD was formed based on total quality control, it means that the control would be applied not only in production lines but also the needs should be considered before design phase. for the first time After World War II the Japanese companies focused on design quality [1], although before that the need to understand the design requirements was sensed but no normal system existed in order to transform customer needs to initial design [2], consequently QFD established as a design correction method for meeting customer needs. Design teams in suitable design of a product need to know what thing to be designed and also expectations of end users. QFD is a systematic method based on exact identification of customer needs and related to functional groups in companies; it means that by applying QFD the customer needs would be translated to design parameters and the details determined in product development.

II. Express and Development of QFD

A. General

QFD is a tool that customer requirements are identified in design phase, this process done by different methods including: brain storming, compliments search, Warranty logs, customer visitation and concentrated groups. Akao was named as father of QFD. He defined "the method for design quality development which helps to customer satisfaction and customer requirements and transition to considered goals in desired design and quality, then it being used in production phases [3].

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B. QFD Structure

The first stage of applying QFD is providing House Of Quality. The House is graphic tool in order to define the relationships between customer needs to product. Fig. 1 shows HOQ format:

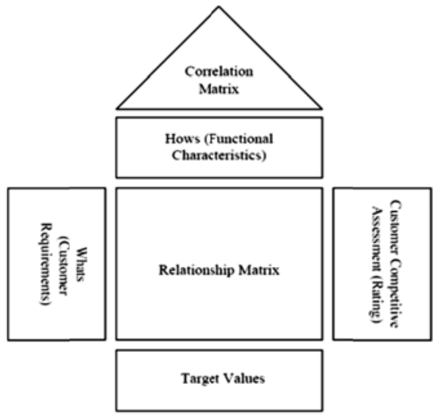

Fig. 1 HOQ Matrix [4]

C. Customer Needs

Firstly customer needs or WHATS are identified that may be stated as general and vague. The Japanese have called this stage " voice of customer''; these needs are expressed in different levels as primary, secondary, tertiary.

D. Engineering Attributes

Then engineering attributes or How's are selected based on customer needs and also should be measurable in a way that customer needs would be satisfied.

E. The Relationship between Customer Needs and Engineering Attributes

After putting Whats and Hows in house of quality, now the relationship between them is set by using symbols shown as:

- Strong relationship ⊙
- Medium relationship ○
- Weak relationship △

F. Customer Rating of the Competition

It expresses that how new product competes with other available products; this aspect of product is vital for competition and get new product. Acceptable competitive comparison information would be acquired by engineers and taking note of what customers says at trade shows and retail outlets. The rate which representing the competition for each requirements are given from 0 to 5.

G. Correlation Matrix

The designers in design process have challenges because of no information about the impact of each design parameters on other parameters and how these factors can be effective on customer needs. The relationships among them in QFD's roof guide product designer. In relative and absolute importance part, total of scores is brought at bottom of chart, it states that how much customer needs are met.

H. QFD Advantages

This technique enables organizations to be more competitive in design, have better quality and less cost furthermore it helps to develop new product.

- Decrease engineering's changes
- Decrease set up changes
- Meet customer requirements
- It is proactive instead of reactive

Fig. 2 shows the whole process of QFD, as it is considered that another advantage of which is transition the available knowledge among different stages and be sure of tracing the requirements in a way that all requirements would be met and also final product toward main needs is traceable.

III. Application QFD

In the paper application QFD for aero pumps has been done according to Fig. 2, since the considered pump is prototype so, 3 and 4 stages have been merged. Pump is a tool which gets the required mechanical energy from external power like electromotor and affects passing fluid consequently; so energy of fluid is increased in pump outlet and it leads to pressure and flow. A pump should make the required flow as continuous and stable besides generate the considered pressure or Head in all stages of pump working. Therefore, a designer should consider these conditions while designing a pump in order to meet all user needs.

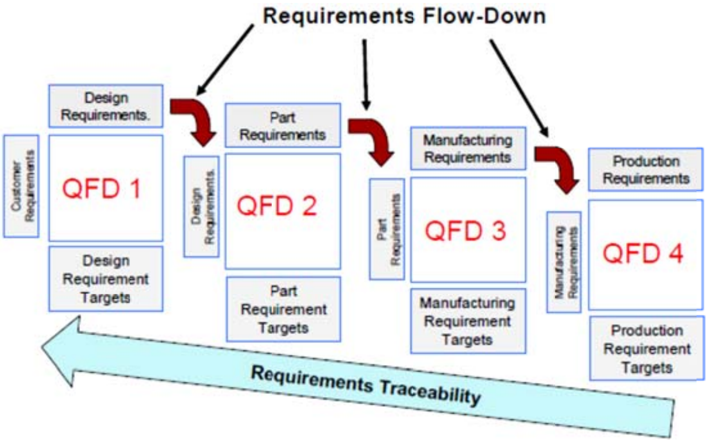

Fig. 2 Overall QFD Transfer Process [5]

Gear pumps combined by two or some gears which one is driver and others are driven, the entered force to pump by driver gear transfers to driven one. The gear of a pump is same as pump's heart; its most important function is transition of fluid. Aero pumps are considered as products with narrow markets so, customers have enough technical knowledge about their requirements. In order to reduce the risk here customer requirements and technical requirements have lots in common. Therefore, it is important to define precisely customer requirements. According to recent researches, customer technical requirements for considered pump as Fig. 5 in phase 1 QFD. The needs are defined as primary one then secondary or even more divisions.

In continuous impact of technical parameters of pump and organizational difficulty are put on chart besides relationship between parameters in chart's roof as Fig. 6. Then in right part of chart, the considered pumps in comparison with competitors are shown in Fig. 7. In addition, the phase 1, QFD chart is shown in Fig. 8.

To proceed should formed phase 2 and 3 QFD charts. The phase 2, design parameters, and QFD chart are shown in Figs. 9 and 10. In addition, the phase 3, design parameters in manufacturing and QFD chart are shown in Figs. 11 and 12.

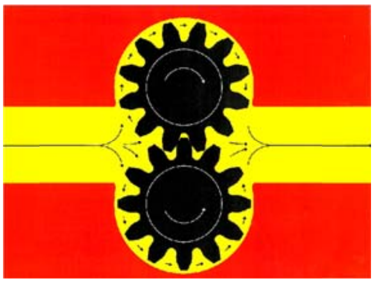

Fig. 3 Gear pump operation

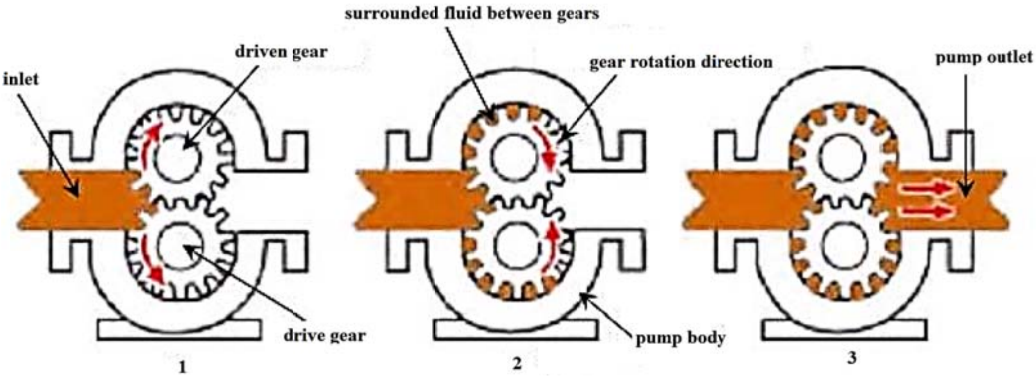

Fig. 4 Fluid transfer on gear pump

Whats (REQUIREMENT)		How	importance
primary	secondary	tertiary	
performance	Pump Characteristic	min fuel flow @ max. speed and max pressure	5
		min fuel flow @ max. speed and min pressure	4
		min fuel flow @ idlle speed and max pressure	4
		min fuel flow @ idlle speed and min pressure	4
		min fuel flow @ min. speed and max pressure	5
	max torque		4
	max power		3
	rotation direction-CCW		4
physical characteristic	length		3
	width		3
	height		3
	dry weight		3
maintenance	mean time to repair		3
	total maintenance man houre		3
life cycle cost	initial costs, purchase price (pump, system, pipe, auxiliary services)		4
	installation and commissioning cost (including training)		3
	operation costs (labor cost of normal system supervision)		4
	maintenance and repair costs (routine and predicted repairs)		4
	down time costs(loss of production)		3
	enviromental costs(contamination from pumped liquid and auxiliary equipment)		4
	decommissioning/disposal costs (including restoration of the local environment and disposal of auxiliary services).		2
reliability	mean time between removals		5
	mean time between failure(MTBF)		5
regulation	endurance characteristic	100 hours or 600 cycle at high temprature(+120° c)	4
		300 hours or 1800 cycle at room temprature	4
		20 hours or 120 cycle at low temprature(-54 °c)	3
	fire resistance	at 1090 °C for 5 minutes	5
	fuel pump capable of operated for 5 hours at design maximume engine performance at 30,000 feet,		4
	fuel pump cavitation, 47 hours at intermediate rated speed and maximume requiered flow and pressure(ARP 492)		5
	low lubricity , resistance to deterioration, 100 hours, (ARP 1797)		5
	accelerated aging, minimum temp. 71°C, minimume 168 hours		3
	vibration-MIL- STD- 810		4
	fuel type	primary fuel: MIL-T-5624, Grade JP4	4
		alternate fuel	3
	enviroment condition	humidity resistance- 95% or higher humidity	4
		maximume and minimume fue inlet pressure, 8-50 psia	3
		minimume & maximume temprature (-54°C to 90°)	4

Fig. 5 Customer requirements

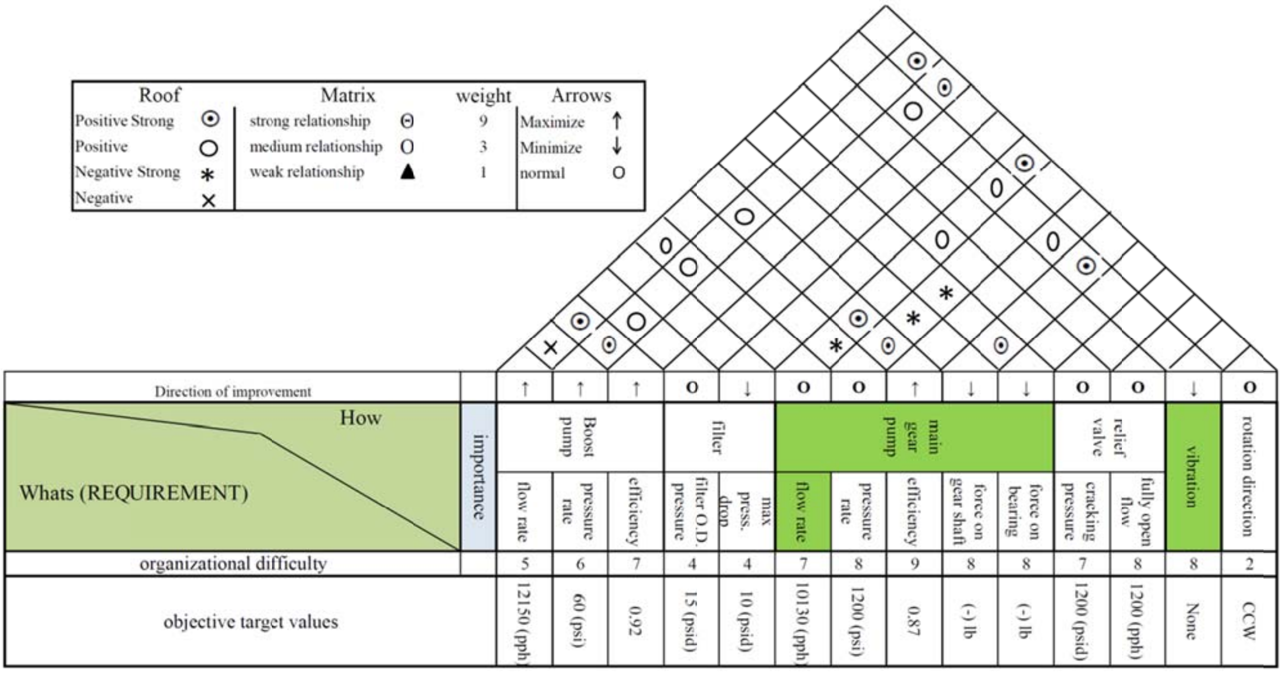

Fig. 6 Quality house's roof

primary	secondary	tertiary	importance	1	2	3	4	5
performance	Pump Characteristic	min fuel flow @ max. speed and max pressure	5				□	Δ
		min fuel flow @ max. speed and min pressure	4				□	Δ
		min fuel flow @ idlle speed and max pressure	4				□	Δ
		min fuel flow @ idlle speed and min pressure	4				□	Δ
		min fuel flow @ min. speed and max pressure	5				□	Δ
	max torque		4				Δ	□
	max power		3				Δ	□
	rotation direction-CCW		4					□Δ
physical characteristic	length		3			Δ		□
	width		3			Δ		□
	height		3			Δ		□
	dry weight		3			Δ		□
maintenance	mean time to repair		3			□		Δ
	total maintenance man houre		3			□		Δ
life cycle cost	initial costs, purchase price (pump, system, pipe, auxiliary services)		4				Δ	□
	installation and commissioning cost (including training)		3			Δ		□
	operation costs (labor cost of normal system supervision)		4				□	Δ
	maintenance and repair costs (routine and predicted repairs)		4				Δ	□
	down time costs(loss of production)		3					
	enviromental costs(contamination from pumped liquid and auxiliary equipment)		4					
	decommissioning/disposal costs (including restoration of the local environment and disposal of auxiliary services).		2					
reliability	mean time between removals		5					Δ□
	mean time between failure(MTBF)		5					Δ□
regulation	endurance characteristic	100 hours or 600 cycle at high temp.(+120° C)	4					Δ□
		300 hours or 1800 cycle at room temprature	4					Δ□
		20 hours or 120 cycle at low temprature(-54 °C)	3					Δ□
	fire resistance	at 1090 °C for 5 minutes	5					Δ□
	fuel pump capable of operated for 5 hours at design maximume engine performance at 30,000 feet.		4					Δ□
	fuel pump cavitation, 47 hours at intermediate rated speed and maximume requiered flow and pressure(ARP 492)		5					Δ□
	low lubricity , resistance to deterioration, 100 hours, (ARP 1797)		5					Δ□
	accelerated aging, minimum temp. 71°C, minimume 168 hours		3					Δ□
	vibration-MIL- STD- 810		4					Δ□
	fuel type	primary fuel: MIL-T-5624, Grade JP4	4					Δ□
		alternate fuel	3					Δ□
	enviroment condition	humidity resistance- 95% or higher humidity	4					Δ□
		maximume and minimume fue inlet press.8-50 psia	3					Δ□
		minimume & maximume temp. (-54°C to 90°)	4					Δ□

Customer rating: A pump Δ, B pump □ (1 = worse, 5 = better)

Fig. 7 Technical competitive comparison

Whats (REQUIREMENT) / How			importance	Boost pump			filter		main gear pump					relief valve		vibration	rotation direction
				flow rate	pressure rate	efficiency	filter O.D. pressure	max press. drop	flow rate	pressure rate	efficiency	force on gear shaft	force on bearing	cracking pressure	fully open flow		
primary	secondary	tertiary															
performance	Pump Characteristic	min fuel flow @ max. speed and max pressure	5	Θ	Θ	O			Θ	Θ	Θ			O	Θ		
		min fuel flow @ max. speed and min pressure	4	Θ	Θ	O			Θ	Θ	Θ			O	▲		
		min fuel flow @ idlle speed and max pressure	4	Θ	Θ	O			Θ	Θ	Θ			▲			
		min fuel flow @ idlle speed and min pressure	4	Θ	Θ	O			Θ	Θ	Θ			▲			
		min fuel flow @ min. speed and max pressure	5	Θ	Θ	O		▲	Θ	Θ	Θ			▲			
	max torque		4	▲	O	▲				▲		Θ	O				
	max power		3	▲	O	▲			Θ	Θ	O	O					
	rotation direction-CCW		4														Θ
physical characteristic	length		3	▲					▲	▲							
	width		3	▲						▲							
	height		3	▲						▲							
	dry weight		3						▲								
maintenance	mean time to repair		3		▲	▲		▲			▲	▲	▲	▲			
	total maintenance man houre		3									▲	▲				
life cycle cost	initial costs, purchase price (pump, system, pipe, auxiliary services)		4	▲	O	Θ	O	▲	O	O	Θ	▲	O	O	O	Θ	▲
	installation and commissioning cost (including training)		3		▲	O		▲	▲	▲		▲				▲	▲
	operation costs (labor cost of normal system supervision)		4	▲	▲	▲				▲	O					▲	
	maintenance and repair costs (routine and predicted repairs)		4		O	O	▲	▲	▲	▲	O	O	O	▲	▲	O	
	down time costs(loss of production)		3			▲					▲						
	enviromental costs(contamination from pumped liquid and auxiliary equipment)		4			O					▲					▲	
	decommissioning/disposal costs (including restoration of the local environment and disposal of auxiliary services).		2									O	O				
reliability	mean time between removals		5		▲	O	O	O			▲	O	▲	Θ		Θ	
	mean time between failure(MTBF)		5		▲	O	O	O				O	▲	Θ		Θ	
regulation	endurance characteristic	100 hours or 600 cycle at high temp.(+120° C)	4	▲	O	Θ			Θ	Θ	Θ	▲	▲	▲	▲	O	
		300 hours or 1800 cycle at room temprature	4	▲	▲	Θ			Θ	Θ	O	▲	▲	▲	▲	O	
		20 hours or 120 cycle at low temprature(-54 °C)	3	▲	O	Θ			Θ	Θ	Θ	▲	▲	▲	▲	O	
	fire resistance	at 1090 °C for 5 minutes	5	▲		O			▲		▲						
	fuel pump capable of operated for 5 hours at design maximume engine performance at 30,000 feet,		4	▲	O	Θ			O	O					▲		
	fuel pump cavitation, 47 hours at intermediate rated speed and maximume requiered flow and pressure(ARP 492)		5	▲	▲	O	▲	▲	O	O		O	O		▲	O	
	low lubricity , resistance to deterioration, 100 hours, (ARP 1797)		5	O	▲	O	▲		▲		Θ	O	O	▲		▲	
	accelerated aging, minimum temp. 71°C, minimume 168 hours		3	▲		▲			▲					▲			
	vibration-MIL- STD- 810		4		▲		▲					Θ		O		O	
	fuel type	primary fuel: MIL-T-5624, Grade JP4	4	▲	▲	▲	▲	▲	▲	▲	▲				▲		
		alternate fuel	3	▲	▲	▲	▲	▲	▲	▲	▲				▲		
	enviroment condition	humidity resistance- 95% or higher humidity	4	▲	▲	▲	▲										
		maximume and minimume fue inlet press.8-50 psia	3		O	▲	Θ	▲	▲	O	O			▲			
		minimume & maximume temp. (-54°C to 90°)	4		▲						▲		▲				
organizational difficulty				5	6	7	4	4	7	8	9	8	8	7	8	8	2
absolute importance				276	338	379	98	64	399	403	427	177	103	183	92	214	43

Fig. 8 Phase 1 of QFD chart

Part Design Parameters (HOW) / Design requirement	customer targets	importance	impeller propertice		main pump																			inlet area	pump rpm	filter propertice				relief valve propertice		
					gear propertice														bearing propertice											
			tip clearance impeller/housing	impeller angle	pitch	width	teeth number	pressure angle	pitch diameter	root diameter	clearance gears(ξ)	gear core hardness	gear case hardness	tip clearance gear/body	geometry total runout	tooth profile tolerance	diffrential pressure	inlet pressure	bearing O.D.	bearing I.D.	surface roughness			filter spring siffness	spring seat area	element mesh number	element mesh size	relief valve spring stiffness	sealing surface roughness	valve cross area
design difficulty			8	6	5	4	1	4	6	6	7	9		8			5	5	6	6	6	3	3	5	5	5	5	5	8	5
parameter values			0.008-0.015 in	(-) Degree	(-) 1/in	(-) in	(-)	20 degree	(-)in	(-) in	(-)	(-) HRC	(-) HRC	(-) in	(-) in	(-) in	(-) psid	(-) psig	(-) in	(-) in	(-) µ.in	(-) squre.in	(-) rpm	(-) lb/in	(-) squre.in	(-)	(-) in	(-) lb/in	(-) µ.in	(-) squre.in

Fig. 9 Design parameters of phase 2

Design requirement (primary)	(secondary / tertiary)	customer targets	importance	impeller propertice: tip clearance impeller/housing	impeller propertice: impeller angle	main pump – gear propertice: pitch	width	teeth number	pressure angle	pitch diameter	root diameter	**clearance gears(ξ)**	gear core hardness	gear case hardness	**tip clearance gear/body**	geometry total runout	tooth profile tolerance	diffrential pressure	inlet pressure	bearing propertice: bearing O.D.	bearing I.D.	surface roughness	inlet area	pump rpm	filter propertice: filter spring siffness	spring seat area	element mesh number	element mesh size	relief valve propertice: relief valve spring stiffness	sealing surface roughness	valve cross area
Boost pump	flow rate	12150(pph)	5	Θ	Θ														O				Θ	Θ							
	pressure rate	60(psi)	4	Θ	Θ														O				▲	Θ							
	efficiency	0.92	4	Θ	Θ																		▲	O							
filter	O.D. pressure	15(psid)	5																						Θ	Θ					
	max. pressure drop	10(psid)	4																								Θ	Θ			
main gear pump	**flow rate**	10130(pph)	5			Θ	Θ	Θ	Θ	O	▲	▲			Θ			O	O					Θ						O	
	pressure rate	1200(psi)	5			O	Θ	O	O	O	Θ	O	O	O	O			Θ	O					Θ						O	
	efficiency	0.87	4				O		O			Θ			Θ			Θ	Θ			O		Θ						O	
	force on gear shaft	(-) lb	4	O	▲		O		O	▲		O	Θ	Θ	O	O	▲							▲							
	force on bearing	(-) lb	4				▲							O		▲		▲		Θ	Θ	▲		▲							
relief valve	cracking pressure	1200(psid)	5											▲				O											Θ	Θ	Θ
	fully open flow	1200(pph)	5																												Θ
vibration		(-)g(ft/s^2)	5		O		O	Θ	▲			Θ	Θ	Θ	▲	Θ	Θ	▲				▲		O							
rotation direction		CCW	2		Θ																										
design difficulty				8	6	5	4	1	4	6	6	7	9		8			5	5	6	6	6	3	3	5	5	5	5	5	8	5
parameter values				0.008-0.015 in	(-) Degree	(-) 1/in	(-) in	(-)	20 degree	(-)in	(-) in	(-)	(-) HRC	(-) HRC	(-) in	(-) in	(-) in	(-) psid	(-) psig	(-) in	(-) in	(-) μ.in	(-) squre.in	(-) rpm	(-) lb/in	(-) squre.in	(-)	(-) in	(-) lb/in	(-) μ.in	(-) squre.in
absolute importance				129	154	60	133	105	85	34	50	**163**	96	113	**113**	61	49	105	93	36	36	21	53	242	45	45	36	36	45	87	90

Fig. 10 Phase 2 of QFD chart

Part Design requirement / Manufacture Design Parameter (HOW)	CNC Milling – 5 Axis: Cutting Speed	CNC Milling – 5 Axis: Feeding Speed	Gear Manufacture – Hob Machine Parameters: Special class tolerance	axial feeding(in/wrev)	Radial feeding(in)	cutting speed(in/min)	Gear Manufacture: case depth hardening (μ.in)	Spring parameter: spring material type and grade	residual stress in the spring	Hot Set Process Parameter: clamping stress	clamping temprature	clamping time	Turning: Cutting Speed	Turning: Feeding Speed
difficulty	8	6	9	7	8	8	9	7	6	8	6	5	6	6
parameter values	NA	NA	μ.in	in/wrev	in	in/min	μ.in	NA	NA	NA	NA	NA	NA	NA

Fig. 11 Design parameters in manufacturing (phase 3)

IV. ANALYSIS

In QFD table-phase 3, the parameter "special class tolerance" that used in hob machinery, has most important percentage (14.7%).

The manufacture design parameter has impact on part design requirement with equal importance coefficient as:

- Clearance gears (ξ): importance factor=5x9=45
- Tip clearance gear /body: importance factor=5x9=45
- Geometry total run out: importance factor=5x9=45
- Tooth profile tolerance: importance factor=5x9=45

All four part design requirements belong to design requirements of pump wheel gear since the impact of each mentioned points on customer needs in phase 1 is widespread so, one point with simple analysis is selected for analysis.

Refer to phase 2 of QFD absolute importance of four part design requirements mentioned in previous stage shows that two parameters clearance gear and tip clearance gear /body have most absolute importance equal to 113. These two parameters effect different design requirements that most important of them are brought in Table I, regarding amount of impressionable.

As a result, vibration and main gear pump –flow rate have most effective. Refer to phase 1 QFD amount of effectiveness of mentioned parameters on customer needs shows that flow rate has absolute importance 399 and vibration has absolute importance 214. Consequently, tip clearance of gear/body has most effectiveness on engineering parameters in phase 1 QFD. Now it is stated the impact of parameter special class tolerance of phase 3 QFD on main gear pump – flow rate of phase 1 QFD and also customer requirements. Before that, a definition of hob tool is expressed.

A. Hob

Hob is a tool that often used for produce gear profile. The production of gear is done with continues index process by rotating piece and hob together with a fixed ratio and at the same time, the hob being driven into pieces [6].

Hob tooth creates progressively and each tooth is in a different position. Hobs are made in 5 different classes. 3 classes have profile grinding and 2 classes do not have profile grinding [7].

Hob that has profile grinding:

- AA: very high accuracy
- A: high accuracy
- B: standard
- Hob that does not have profile grinding:
- C: high accuracy
- D: standard

Part Design requirement / Manufacture Design Parameter (HOW)			customer targets	importance	CNC Milling – 5 Axis – Cutting Speed	CNC Milling – 5 Axis – Feeding Speed	Gear Manufacture – Hob Machine Parameters – Special class tolerance	Gear Manufacture – Hob Machine Parameters – axial feeding(in/wrev)	Gear Manufacture – Hob Machine Parameters – Radial feeding(in)	Gear Manufacture – Hob Machine Parameters – cutting speed(in/min)	Gear Manufacture – case depth hardening (μ.in)	Spring parameter – spring material type and grade	Spring parameter – residual stress in the spring	Spring parameter – Hot Set Process Parameter – clamping stress	Spring parameter – Hot Set Process Parameter – clamping temprature	Spring parameter – Hot Set Process Parameter – clamping time	Turning – Cutting Speed	Turning – Feeding Speed
primary	secondary	tertiary																
impeller propertice	tip clearance impeller/housing		0.008-0.015	5	Θ	Θ												
	impeller angle		(-) Degree	5	Θ	Θ												
main pump	gear propertice	pitch	(-) 1/in	4					▲	▲								
		teeth number	(-)	4						▲								
		pressure angle	20 degree	5			▲	▲	▲	O								
		pitch diameter	(-)in	4			O	▲	▲	▲								
		root diameter	(-) in	3			▲	O	O	▲								
		clearance gears(ξ)	(-)	5			Θ	Θ	O	O								
		gear case hardness	(-) lb	4							Θ							
		tip clearance gear/body	(-) in	5			Θ	Θ	▲	O								
		geometry total runout	(-) in	5			Θ	Θ	O	O								
		tooth profile tolerance	(-) in	5			Θ	Θ	Θ	O								
	bearing propertice	bearing O.D.	(-) in	3													▲	▲
		bearing I.D.	(-) in	3													▲	▲
		surface roughness	(-) μ.in	5													Θ	Θ
filter propertice	filter spring siffness		(-) lb/in	4								Θ	Θ	Θ	Θ	Θ		
relief valve propertice	relief valve spring stiffness		(-) lb/in	4								Θ	Θ	Θ	Θ	Θ		
	sealing surface roughness		(-) μ.in	5													Θ	Θ
	valve cross area		(-) squre.in	3													▲	▲
difficulty					8	6	9	7	8	8	9	7	6	8	6	5	6	6
parameter values					NA	NA	μ.in	in/wrev	in	in/min	μ.in	NA	NA	NA	NA	NA	NA	NA
absolute importance					90	90	200	198	102	91	36	72	72	72	72	72	102	99
absolute weight					6.6	6.6	14.6	14.5	7.5	6.652	2.6	5.3	5.3	5.3	5.263	5.3	7.5	7.2

Fig. 12 Phase 3 of QFD chart

TABLE I
IMPACT OF GAINED DESIGN PARAMETERS TO ENGINEERING PARAMETERS

-		Tip clearance gear/ body	Clearance gear
Main gear pump	Flow rate	Importance factor=45	-
	efficiency	Importance factor=36	Importance factor=36
vibration		-	Importance factor=45

The selection of Class accuracy depends on the piece that is built by its tolerance. For example, if hob diametric pitch is 3-3.999, hob accuracy as Table II.

TABLE II
HOB ACCURACY FOR DIAMETRIC PITCH 3-3.999 [7]

Hob special class tolerance	AA	A	B
Hob diameter runout	2	4	6
Outside diameter runout	5	15	25
Lead variation tooth to tooth	4	4	6
Pressure angle or tooth profile	2	3	5
Tooth thickness(minus only	15	15	15

Assume that change hob tolerance class makes change outside diameter of gear about "α", then tip clearance gear/body (radial clearance) is changed about "α/2".

Pump capacity in equal condition depends on radial clearance between pump body and tooth head and also inclusion fluid film, if it does not fit, leakage of fluid occurs from high pressure zone to low pressure. For gear with common size, the radial clearance range is variable from 0.8 μ.in to 8 μ.in [8]. In Fig. 13, it is seen the impact of radial clearance on gear pump volumetric efficiency.

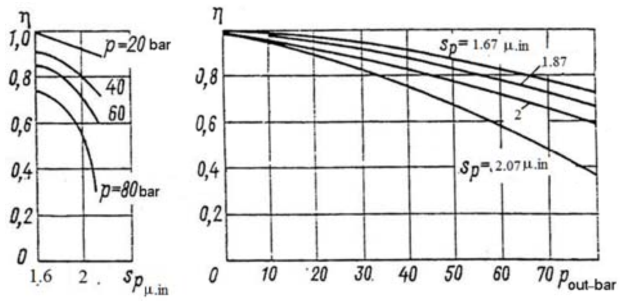

Fig. 13 The impact of radial clearance on gear pump volumetric efficiency [8]

According to Fig. 13, change of tip clearance about "α/2" makes efficiency change about "ß". Because the volumetric efficiency of gear pump is related directly to pump flow rate, so flow rate varies in ratio "ß" as per (1).

$$\eta = Q_{ef} / Q_i \rightarrow Q_{ef} = \eta \times Q_i \quad (1)$$

Q_{ef}: Effective flow rate of pump; Q_i: Nominal flow rate of pump; η: Pump efficiency.

As observed in phase 1, QFD table, engineering parameter "main gear pump-flow rate" affects different requirements, by considering the importance of requirement the most effectiveness as:

- Min fuel flow at max. Speed and max. Pressure → importance factor: 5x9=45
- Min fuel flow at min. Speed and max. pressure → importance factor: 5x9=45

The point is that what to be noted most is that the gear pump internal leakage sequence of radial clearance can be occurred further at low speed. The internal leakage sequence of radial clearance to total internal leakage is minimal by increase in pump speed. Due to radial clearance, the change in effective flow rate of pump has most effectiveness on requirement "min fuel flow at min. speed and max pressure".

V. CONCLUSION

As shown, QFD model facilitates translation of total and vague requirements into technical measurable requirements. Consequently, the existence of such structure leads to manage complexity in systems so, QFD is a tool for transition customer needs to technical design parameters which increases customer satisfaction and also decreases of problems in initial stage of design phase. QFD in itself does not engineering's problems; it is a forum for gathering and organizing all the data related to a design. The reason of usage QFD in aero industry is its ability to integrate physically besides the integration among customer needs, design requirements, parts characteristics, process key activities, and production requirements. In recent case study which shows the QFD matrix as a powerful tool representing the relationship between customer needs and design parameter's pump. The matrix is for negotiation between requirements in a way that it decreases no certainty in product design. The traditional method of a QFD developed in mentioned research. At first stage customer needs identified so, it compliances between customer need and product's one made. Then in following step by determining technical parameters in order to meet the needs, they were entered into QFD chart. Then the relationship between the parameters set in quality house's roof. According to calculations' results that given in last chart, absolute weights are as Table III.

TABLE III
ABSOLUTE WEIGHT

Turning		Feeding Speed	7.2
		Cutting Speed	7.5
Spring Parameter	Hot Set Process Parameter	Clamping Time	5.3
		Clamping Temp	5.3
		CLAMPING stress	5.3
		Residual Stress in the Spring	5.3
		Spring Material Type and Grade	5.3
Gear Manufacture		case depth hardening(μ.in)	2.6
	Hob Machine Parameters	Cutting Speed(in/min)	6.7
		Radial Feeding(in)	7.5
		Axial Feeding(in/wrew)	14.3
		Special Class Tolerance Values in μ.in	14.7
CNC Milling	5 axis	Feeding Speed	6.6
		Cutting Speed(in/min)	6.6

The calculations for technical parameters represents that the most percentage is related to special class tolerance used in machinery in 14.7; it means that the mentioned parameter has most importance regarding to customer requirements.

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