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Original Article

RELIABILITY AND OPTIMIZATION OF THE MANUFACTURING OF STEEL FLANGES, BY USING MECHANICAL METHOD, STATISTICAL METHOD, FIREFLY ALGORITHM

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ABSTRACT

This paper presents the reliability calculation and the optimization of the manufacturing process of steel flanges, by using three methods: the first is the mechanical method based on feedback and the analysis of failure modes. The second one is the statistical method for determining the mathematical model of the reliability factors. The last one is the optimization method by the Firefly algorithm.

On the mechanical method we used the feedback experience to define all the elements related to reliability, and the identification of failure modes, the target of the statistical analysis method is to value the results of the mechanical, we used the optimization method through the Firefly algorithm to calculate the values of the reliability factors for the two steel flanges, by concluding on the most reliable and optimal manufacturing process.

KEYWORDS: Reliability, Regression, Algorithm, Optimization & Firefly

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INTRODUCTION

We have started this study with an objective, even the reclamation of our customer for the new structure, the Quadra-sector flange (figure 2), and after making the results of the stress marked by a good result of the stress of the new Quadra sector flange, we should communicate to our client the reliability of this structure.

With the three methods the mechanical, statistical and the firefly algorithm, we must justify that the new Quadra-sector flange is reliable as the ring flange (figure 1), which we have an experience of manufacturing and we have also the satisfaction of our client for this one.

The new Quadra sector flange and the ring flange realized in the same workstations, but the process is different between the two structures, on welding and machining, because we should weld the four sectors for the new Quadra-sector flange, but for the ring flange we had one element without welding, the welding of sector provides us a benefit in raw materials, it gives us a benefit of purchasing of this new Quadra sector [5].

Our objective is to assume that the new Quadr-sector flange is reliable and the optimal structure, according to the difference in the process of manufacturing and the benefit of raw materials, and to prove that our new Quadra-sector flange is also reliable and the new optimal structure.

we support our study of the two flanges using the three methods, mechanical, statistical and the fire fly algorithm, in goal to communicate the reliability and optimization of those structures, especially the new Quadras-sector flange.

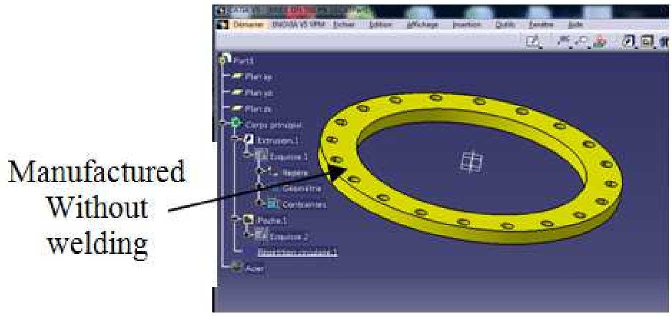

Figure 1: Ring Flange Structure

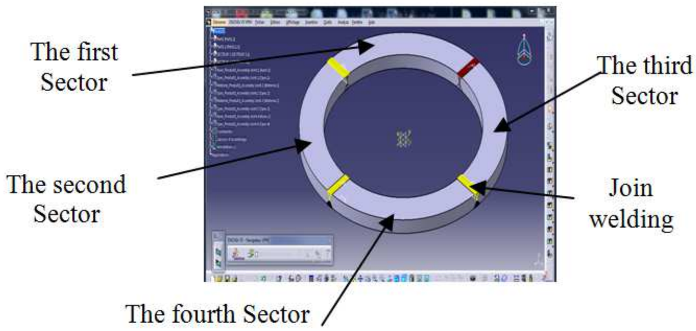

Figure 2: Quadr-Sector Flange Structure

MATERIALS AND METHODS

The first step we followed is the identification of all the reliability factors, those are parameters regarding the operating environment of the structure, which can be factors related to reliability, while starting with an identification process, we used the mechanical method of experience feedback for line of production of flange structures, over a period of one year.

The second step is the analysis of the results factors of experience feedback, we analysed the failure modes, their effects; as a target of this method, we evaluated the factors related to the reliability of this flange structure, for both models; at the same time, we got the failure modes that we can have to avoid in order to have a more reliable structure.

In objective to determinate the mathematical model for each type of metallic flange, we benefit from the mechanical method and the results of the mechanical method, we decided to use the results of the mechanical method of the statistical method.

Both the statistical and mechanical methods, can only give the mathematical parameter and the analysis of factors related to reliability, hence, we decided with our laboratory of mathematics applied to use the algorithm firefly, by using the firefly we can have the values of reliability of the two flange structures, then the most optimized flange structure.

Before moving to use methods, we introduce below the structure's environment. The structure is metallic, in contact with the connected pipe environment, the fluid is the element that flows through the pipes (figure 3), and the two environments are as follows:

We present in the next table the elements of the external environment:

Table 1: Elements of External Environment

Environment	Nbr	Designation Elements
External	1	Ms: Mechanical forces, which are the results of the external environment efforts (N)
	2	At: Operating temperature, it's the temperature of the external environment (°C)
	3	Grm: The grade of structural materials manufacturing, it is the grade of the structural metal raw materials.
	4	Cs: Conditions of storage and transportation of metallic structures.
	5	F: The fluid, which is in most cases steam or water, which flows through the piping.
	6	mt : The melting temperature of the filler metal, using during welding. (°C)

We present in the next table the elements of the internal environment:

Table 2: Elements of Internal Environment

Environment	Nbr	Designation Elements
Internal	1	OP: Operating pressure.
	2	Gw: Geometry of the weld bead (m^2)
	3	Sts: Surface treatment against corrosion. (g/m^2)
	4	Sc: Stress concentration. (N/m^2)
	5	Sc: Security Constraint (N/m^2)
	6	Tmp: Thickness of the manufacturing plate. (mm)
	7	Gs: Geometry of the structure. (m^2)
	8	Ws: Weight of the structure. (kg)
	9	Qwe : Quality of the welding electrode for the elements of the structure

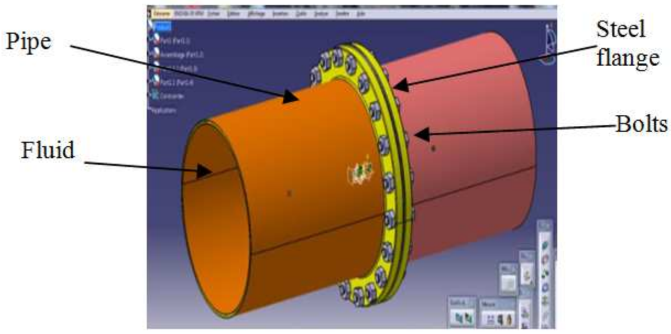

Figure 3: Piping with Steel Flanges

The reliability of the structures depends on many factors, because the structure is on the interaction medium between many elements, the list of these elements is not limited, and we focused on the elements that had direct contact with steel flanges.

We will address the reliability analysis mentioned above, to identify all the factors related to the reliability using each method.

Mechanical Method

We present in the following method, the identification of factors related to the reliability of the metal flanges, through our experience feedback based on one-year of manufacturing of flanges in our factories, we analysed each element defined in the environment, the importance to our metallic structure, thereafter, we had all important elements evaluated as factors related to the reliability analysis of the flange structure.

Factors Related to the Reliability Analysis

The analysis through our experience feedback method provide us the elements that we characterized as factors related to the reliability of the two metallic flanges, the ring and the Quadr-sector flanges, we can see the analysis results in the following table:

Table 3: Reliability Factors of the Flange Structure

nbr	sym	Designation	Environment
6	mt	The melting temperature of the filler metal.(°C)	External
1	Op	Operating pressure.(br)	Internal
2	Gw	Geometry of the weld bead. (m²)	Internal
6	Tmp	Thickness of the manufacturing plate. (mm)	Internal
7	Gs	Geometry of the structure.(m²)	Internal
6	Ws	Weight of the structure.(Kg)	Internal

As we can see in the table that 99% of the elements characterized as factors related to the analysis of reliability, using the experience feedback method, are the internal environment elements.

Analysis of the Failure Modes

The analysis of the failure mode method gives us the determination of the effects of the failure modes.

After analysis of all the failure modes, their effects, we have the occasion to present the most critical and degrading failure modes; the list of these failure modes is as follows:

Failure in Erection of Piping with Flanges

- Bad state of the pipes and wires.
- The propagation of surface cracks on the flange structure.
- Wrong adjustment of the joint welding equipment of the weld bead.
- Welding in an inadequate area, presence of dust…
- Bad tightening of bolts, poor application of a tightening torque.
- Abnormal pressure.

Failure in Manufacturing and Process of Control

- Lack of dimensional control of the flange structure.
- Lack of grade and plate control of the raw material of the flange structure.
- Lack of aspect and plate quality control of the raw material of the flange structure.
- Lack of dimensional geometry control of the flange structure.
- Lack of hole geometry control of the flange structure.
- The machining of inconvenient thickness flange.

The different steps are going to allow the manufacturers of these types of structures to avoid these failure modes, with implementation of the prevention programs to eliminate a maximum of these failure modes, need to reinforce their improvement process of manufacturing, in order to have a good quality control during manufacturing of the metal flange structure and a qualified team in the erection of piping with flanges.

The mechanical method allowed us to group the factors related to reliability, we also evaluated their failure modes, we analyse in the following method done statistically, to quantify and identify, what are the elements that related to the reliability of the flange structure, by using the statistic method?

STATISTICAL METHOD

Objective of the Statistical Method

The objective of using the statistical method is to select statistical the factors related to the reliability of the structure, quantify analytic the mathematical model of the reliability of the flange structure, this method done for the first time on these metallic structures, then we can evaluate and compare the results of statistical method with the results of the mechanical method.

We started with the methodology of the statistical method, step by step to find the mathematical model for the two flanges.

Database of the Statistical Method

To answer this question of the statistical analysis of the factors related to the reliability of the structures, we analysed our manufacturing of the metallic flange structures in our production plant, process of manufacturing realised on the machine shops and metal workshops, in which the flange structure followed a many production's step.

We collected all the parameters related to geometry, the strength of the structure, the fluidity, to the welding of the structure, the manufacturing time of the flange structure, and other elements for the 36 flanges manufactured on different diameter, with a pressure from 10 bar to 16 bar.

The collect of information done through the observation of production workstations, and the timing of production workstations, we also used the standards and security norms related to structure, namely the pressure, the security constraints, the Young module.

Alimentation of Database

We used in the statistical method all the data collected, through the method of observation of the workstations established in one year of manufacturing of the metallic flanges structure for 36 flanges, we joined our data bases of the two metallic structure to qualify the parameters that have a significant weight, in the reliability analysis and the reliability calculation of these two metallic flange structure.

The use of the statistical method performed us to write the mathematical model for the two different flange structures, this model is, the better results of the statistical analysis, and this mathematical model used in the analysis of the algorithmic optimization method.

Algorithmic Optimization Method

The Necessity of the Algorithmic Method

Our analysis of important factors and parameters related to the reliability is an essential method, but it is preliminary in the evaluation of the most reliable metallic flange model and the most optimized manufacturing process.

The mechanical method and the statistical method allowed us to have mathematical model, by using the linear function regression, which groups all the reliability factors of the two metallic structures.

Our objective is the evaluation of the reliability of the two metallic structures (the ring and the quadr-sector flanges) and also the evaluation of the most optimized manufacturing process.

The analytical calculation of the regression function will be too long, according to all the parameters that we have as reliability factors, and in regards to the complexity of the regression function. So to find the reliability factors, we used our mathematical model of the two structures by using the algorithmic method[1].

Firefly Algorithm Method

The firefly is one of the most impressive performances swarm intelligence algorithms in solving optimization problems which were based on the flashing patterns and behaviour of fireflies.

Fireflies are insects characterized by their amazing flashing light produced by a process of bioluminescence. The main role of such flashes can be reduced to the following two tasks: Firstly, to attract mating partners and secondly to remind potential predators of the bitter taste of fireflies. The movement of a firefly I is attracted to another more attractive (brighter) firefly J[9,10,11].

Method of Calculation Reliability Factors

To find the reliability factors, we worked in collaboration with our numerical laboratory (LGS), we provide them our data bases, the parameters of reliability and the mathematical models of each flange.

Our target from the algorithmic method is the evaluation of the reliability factors, by using the analysis program of the function, and defining the constraints of the parameters related to this function.

We have chosen the Firefly algorithm, as a new one characterized quickly compilation, the ability of analysis for these types of functions[6,7,8].

RESULTS AND DISCUSSIONS

Results of the Statistical and Mechanical Methods

Coefficients of the Ring Flange

After using the data bases, in the statistical method, by the alimentation of the data base elements for the ring flange, we present the following table.

In the table we see the factors related to the reliability of the ring flange structure:

Table 4: Reliability Coefficients of the Ring Flange

Model	Non Standardized Coefficients		Standardized Coefficients
	A	Standard Error(Ɛ)	Bêta
Constant	-1,530	0,732	
Pressure	0,000	0,002	0,061
Flow temperature	0,004	0,004	0,186
Inside diameter	0,000	0,000	-3,144
Outside diameter	0,000	0,000	-4,817
Thickness	-0,002	0,001	-2,195
Number of holes	0,001	0,001	0,483
Diameter of the holes	-0,002	0,002	-1,109
Weight	0,000	0,000	4,336
Security Constraint.	0,011	0,006	6,383

In the table of reliability coefficients, we have the important parameters of modelling, which are designated by the element *A*. The elimination of this element *A* is interpreted by the no-consideration as a reliability factor, a real modelling takes into consideration the standard ErrorƐ, both elements *A* and standard ErrorƐ are sufficient for the writing of mathematical model of multi-variable linear regression.

Our analysis of the table of coefficients focalises on the interpretation below, which allowed us to identify the factors related to the reliability are appointed reliability coefficients of the metallic flange structure which are:

- **Ft**: Flow temperature.
- **T**: Thickness.
- **Nh**: Number of holes.

- **Dh**: Diameter of holes.
- **Sc**: Security Constraint.

Mathematical Model of the Reliability of the Ring Flange

The mathematical model designed in the analysis of reliability, through the objective function, to find the optimum of the functions under the effect of well-defined constraints.

The mathematical model is a function grouped all important factors results of the reliability, and this model helps us to find after as a result the optimum of a function.

We have written the mathematical model with the reliability function $f(X_i)$, by using the following linear regression function:

$$f(X_i)Rf = a_0 + \sum_{i=1}^{n} a_i X_i + \boldsymbol{\varepsilon}$$

Where:

$f(X_i)Rf$: Reliability function of the structure ring flange.

a_0 : The original constant of the reliability function

X_i : Reliability coefficient factor

a_i : The A value of the reliability coefficient factor

$\boldsymbol{\varepsilon}$: The standard error of the reliability coefficient factor

By using the values of the table of the reliability coefficient factor, the reliability function $f(X_i)$ of the ring flange is written as follows:

$\mathbf{f(X_i)}\boldsymbol{Rf}$ = -1.530 + 4x10^{-3}**Ft** -2x10^{-3} **T**+10^{-3}**Nh** - 2x10^{-3}**Dh**+11x10^{-2} **Sc** +14x10^{-2}.

Finally, we have only the following coefficients:

Ft: the fluid, which is in most cases steam or water, which flows on the pipe.

T: Thickness of the manufacturing plate

Nh and Dh : the number of holes and the Diameter of hols are two parameters of Geometry surface(Gs),

Sc: Security Constraint depend of the material of flanges.

Coefficients of the Quadra-Sector Flange

After using the database, in the statistical method, by the alimentation of the data base elements for the Quadra-sector flange, we present the following table.

In this table we present the factors related to the reliability of the Quadra-sector flange structure:

Table 5: Reliability Coefficients of the Quadra-Sector Flange

Model	Non Standardized Coefficients		Standardized Coefficients
	A	Standard Error(Ɛ)	Bêta
Constant	-20,097	10,510	
Pressure	0,001	0,030	0,017
Flow temperature	0,116	0,054	0,369
Inside diameter	-0,002	0,005	-4,392
Outside diameter	-0,001	0,005	-1,166
Thickness	-0,030	0,017	-2,107
Number of holes	0,000	0,011	-0,006
Diameter of the holes	-0,007	0,028	-0,274
Weight	0,003	0,002	2,730
Security Constraint	0,128	0,081	5,194

The factors related to the reliability are appointed reliability coefficients of the metallic Quadra-sector flange, which are:

- **P**: Pressure
- **Ft**: flow time
- **Id**: Internal diameter
- **Od**: Outside diameter
- **T**: Thickness
- **Dh**: Diameter of the holes
- **W**: Weight
- **Sc**: Security Constraint.

Mathematical Model of the Reliability of the Quadra-Sector Flange

We written the mathematical model of the reliability function $f(X_i)$, by using the following linear regression function:

$$f(X_i)Qsf = \mathbf{a_0} + \sum_{\mathbf{i=1}}^{\mathbf{n}} a_i X_i + \boldsymbol{\varepsilon}$$

Where:

$\mathbf{f(X_i)}\boldsymbol{Qsf}$**:** Reliability function of the structure Quadra-sector flange.

$\mathbf{a_0}$ **:** Original constant of the reliability function

$\mathbf{X_i}$ **:** Reliability coefficient factor

$\mathbf{a_i}$ **:** Value A of the reliability coefficient factor

$\boldsymbol{\varepsilon}$ **:** Standard error of the reliability coefficient factor

By using the values of the table of the reliability coefficient factor, the reliability function Y2 of the Quadra-sector flange is written as follows:

$\mathbf{f}(\mathbf{X_i})Qsf$ = -20.097+10^{-3} **P** +116x10^{-3}**Ft**-2x10^{-3}**Id** -10^{-3} **Od** -30x10^{-2} **T**-7x10^{-3}**Dh**+3x10^{-3}**W**+128x10^{-3}**Sc**+222 x 10^{-3}

Finally, we have only the following coefficients:

P: Pressure (operating pressure).

Ft: the fluid, which is in most cases steam or water, which flows on pipe.

T: Thickness of the manufacturing plate

Id and Ed, Dh: Internal and external diameter, Dimeter of hols, all are parameters of the Geometry surface (Gs)

W: Weight of the structure

Sc: Security Constraint depend of the material of flanges.

Results the Firefly Algorithmic Optimization

The writing, the programming and the compilation of the algorithm Firefly, was based on the results of the two methods, the mechanical and the statistical methods, we used the mathematical model for each flange structure [5].

The numerical analysis laboratory used the factors and parameters of our reliability analysis of the two flanges, the objective is to compile the algorithm and to visualize the results after many iterations.

After 1000 iterations, we got the result of the ring flange, the homogenous flange, without welding, cut and processed according to the normal manufacturing process, the result is the reliability factor value: 1.850.

With the same method we got the result of the Quadra-sector flange, the flange welded into four sectors, cut and processed according to a new manufacturing process, the result is the reliability factor value: 1.789

The following table presents the results of the algorithmic optimization method [2, 3,4].

Table 6: Reliability Factor

Type of Flange	Reliability Factor	Manufacturing Process
Ring flange	1.850	Standard Process
Quadra-sector flange	1.789	New Process

After the analysis and the algorithmic method firefly of the two flanges models, we observe that the value of the reliability factor of the two flanges had the approximate value with a negligible value of 0.061 between two factors.

CONCLUSIONS

The using of the mechanical, statistical and algorithmic optimization methods, help us to prove that reliability of the Quadra-sector flange is approximately the same of the reliability of the ring flange structure, then the manufacturing process of the new Quadra-sector flange is the optimal one, because we use a less material to manufacture the flange [5], we have ensured the satisfaction of the customer by the reliability factor and the comparison of the results of the two metallic flanges.

The manufacturing process of these two rings and Quadra-sector flanges is different, this different located on the steps of their cutting and welding. The manufacturing of the new Quadr-sector flange gives us a better benefit on raw material, also the optimal time and process of manufacturing, but the production of the ring flange provides scrap material and a long process of manufacturing[5].

This study of the ring and Quadra-sector flanges, was very important to prove the difference and the benefit to our customer, and the use of the three methods are appropriate with the two models of flanges, the three methods also are complementary to achieve the results.

For this new manufacturing process, we have a new Quadra-sector flange, optimized physically in raw materials, proved by the using the mechanical and statistical methods, the firefly algorithmic optimization method.

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