AN ALGORITHMIC APPROACH FOR THE DISTRIBUTION OF THE BLADES OF A GAS TURBINE ROTOR

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ABSTRACT:*Our study focuses on the critical steps of balancing and maintaining the turbine rotor in electricity production companies. We aim to develop a MATLAB program for blade distribution to optimize the turbine's performance. We conducted practical tests using the BLADIS software from a major company in the field and compared it with the test data from our program. We performed three blade distribution experiments using the initial static moment values of each blade, which the MEI Company's (Sonelgaz-M'sila) electronic balance provided. Our main objective is to propose a new algorithm for turbine rotor blade distribution using a MATLAB subroutine that remains applicable during maintenance operations, including punctual blade changes. This proposed algorithm will help improve the turbine rotor's efficiency and performance. Electricity production companies to maintain their turbines and optimize energy output can use our study's findings and algorithm. By implementing our proposed algorithm, companies can save costs and increase their energy efficiency, making them more competitive in the market.*

KEYWORDS: *Blade, Distribution, Static balancing, Gas turbine, MATLAB*

1 INTRODUCTION

Turbines have very important roles in industry, particularly in the production of electrical energy. This can be achieved through the use of gas turbines or steam turbines. However, it is essential to have a planned program of periodic inspections, repair, and replacement of defective parts to ensure maximum machine reliability. Imbalances are often the cause of annoying vibrations and noises in rotating machines. During an imbalance, the main axis of inertia or the center of gravity of the rotating part of the machine is outside its axis of rotation. Balancing is the process of adding or removing masses to move the center of gravity or principal axis of inertia so that both axes match the axis of rotation [1-3]. The process of balancing a rotating machine involves controlling the weight distribution of a rotor, so that it rotates in its bearings without creating uncompensated centrifugal forces. Corrective rotor balancing solutions are made by adding material (balancing mass) or removing material [4-6]. Recent work has also focused on blade arrangement optimization methods.

Chuanzhi Sun et al [7] . Used a blade sorting method based on the cloud adaptive genetic algorithm (CAGA) to optimize the unbalanced of asymmetric rotor of an aero-engine. Wonjoon Choi et al. [8] proposed heuristic methods for balancing blades based on the number partitioning algorithm. Thompson et al. [9] used the simulated annealing algorithm to solve the large-scale combinatorial optimization problem of seeking the best layout through blade exchange. Rahimi M. [10] used the genetic algorithm for solving an optimization problem to find the worst-case response of a bladed-disk assembly. Li Y. [11] put forward the genetic particle swarm algorithm to optimize the blade arrangement sequence. Pan et al. [12] improved the genetic algorithm based on the genetic algorithm and proposed an improved genetic algorithm to solve the assembly sort optimization problem. Amroune et al. [13] proposed that balancing operation consists of improving the distribution of the rotor masses so that the free centrifugal forces around the rotor axis, imposed by the manufacturer, do not exceed the tolerances allowed by the standards.

In addition to balancing, maintenance is another crucial aspect of turbine operation. Maintenance activities for a turbine rotor should be carried out periodically to ensure its continued optimal performance. These activities can include inspection, cleaning, lubrication, and replacement of damaged parts. The maintenance schedule of a turbine should be planned to avoid unplanned shutdowns and extend the lifespan of the turbine.

To achieve effective maintenance, various techniques and tools can be used. Vibration analysis is a non-destructive testing technique used to detect the presence of a problem in a rotating machine. It involves measuring the vibration levels of the machine and analyzing them to identify any abnormalities. Once an issue is detected, further inspections can be carried out to identify the root cause of the problem and determine the best course of action to rectify it.

In addition to vibration analysis, other techniques such as ultrasonic testing, magnetic particle inspection, and X-ray inspection can be used to detect defects in turbine rotors. These techniques are non-destructive and can identify defects without disassembling the rotor.

In conclusion, balancing and maintenance are crucial aspects of turbine operation, and both require a planned program of periodic inspections, repair, and replacement of defective parts. Balancing is necessary to ensure that the rotor rotates in its bearings without creating uncompensated centrifugal forces. Maintenance activities such as inspection, cleaning, lubrication, and replacement of damaged parts are essential to ensure the continued optimal performance of a turbine. The use of non-destructive testing techniques such as vibration analysis, ultrasonic testing, magnetic particle inspection, and X-ray inspection can help to detect defects in turbine rotors without disassembling them. By implementing effective balancing and maintenance practices, companies can ensure maximum machine reliability and prolong the lifespan of their turbines.

2 STATIC ROTOR BALANCING ASSUMPTION

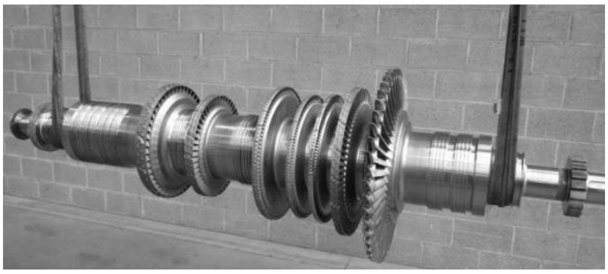
In physics, a solid is in static equilibrium in a Galilean frame if the resultant of the forces is zero (translational equilibrium) and the resultant of the moments of the forces with respect to any point is zero (rotational equilibrium).

2.1 Fundamental principle of statics

For a system of several solids, it is necessary to write the preceding conditions for each of the solids. This is a consequence of the "fundamental principle of statics" which states that "the sum and momentum of all forces acting on it is zero". Logically, and if we had good mathematical knowledge, we would have to start by studying statics to deduce the static balancing formulas of our work. The theory of balancing technique is based on general physical principles. The following paragraphs present the most important equations and explanations for balancing.

2.2 Balancing of several masses rotating in the same plane

To demonstrate the relation which makes it possible to calculate the unbalance and the angle of correction. We will consider four masses of magnitude m1, m2, m3 and m4 which are distant with respect to the center of rotation at a distance r1, r2, r3 and r4 at an angle α1, α2, α3 and α4 (angle αi means the position of the mass with respect to the rotating reference mark). As shown in fig.1.



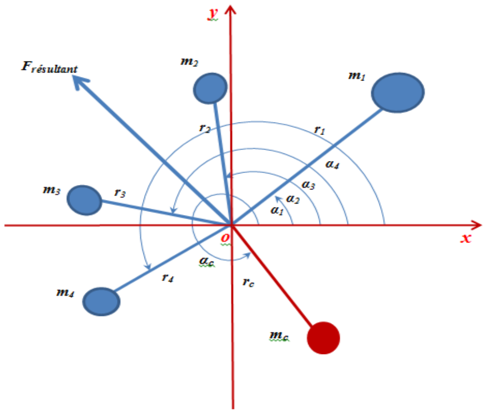


Fig.1 Description of the unbalance of a disc-shaped rotor in the same plane

The simplest case is represented by a disc-shaped rotor mounted perpendicular to the axis of the shaft. If the rotor rotates with a continuous angular velocity of ω rad/s, each elementary mass mi generates on its radius $\vec{r}$i a centrifugal force $\vec{Fi}$.

$$\vec{F_i} = m_i.\vec{r_i}.\omega^2 \qquad (1)$$

The opposite force of the same intensity, the force of inertia of mass, is called centrifugal force, its expression is:

$$\vec{F_c} = m_c.\vec{r_c}.\omega^2 \qquad (2)$$

The vector sum of the centrifugal forces of all the elements is the centrifugal force acting on the bearings, and it is expressed by:

$$\vec{F} = m_1.\vec{r_1}.\omega^2 + m_2.\vec{r_2}.\omega^2 + m_3.\vec{r_3}.\omega^2 + m_4.\vec{r_4}.\omega^2$$

(3)

So:

$$\vec{F_r} = \sum_{i=k}^{n} m_i.\vec{r_i}.\omega^2$$

(4)

Two possibilities may arise:

$\vec{F_r} = 0$: No centrifugal force is exerted, the rotor is then unbalanced, it is a perfectly balanced rotor.

$\vec{F_r} \neq 0$: The rotor is subject to an imbalance.

The question now is how to express the unbalance in the best way. We can imagine the residual centrifugal force as coming from an unbalance $m_c.r_c$ where U (eq.5) and then simplify the influence of the regime on both sides (eq.6):

$$\sum_{i=k}^{n} m_i.\vec{r_i}.\omega^2 = m_c.\vec{r_c}.\omega^2 \qquad (5)$$

$$\sum_{i=k}^{n} m_i.\vec{r_i}. = \vec{U}$$

(6)

To solve equations mathematically, divide each force into its x and y components:

$$\sum_{i=k}^{n} m_i.r_i.\cos\alpha_i = U.\cos\alpha \qquad (7)$$

$$\sum_{i=k}^{n} m_i.r_i.\sin\alpha_i = U.\sin\alpha \qquad (8)$$

The addition of the Root-square of the two equations above (eq.7) and (eq.8) gives:

$$U = \sqrt{\left(\sum_{i=k}^{n} m_i.r_i.\cos\alpha_i\right)^2 + \left(\sum_{i=k}^{n} m_i.r_i.\sin\alpha_i\right).^2}$$

(9)

Dividing (equ.8) near (equ.7):

$$tan\,\alpha_c = \frac{\sum_{i=k}^{n} m_i.r_i.\sin\alpha_i}{\sum_{i=k}^{n} m_i.r_i.\cos\alpha_i} \qquad (10)$$

We used the analytical method to deduce the correction mass (argument) and its angle (phase):

- Argument = U
- $\text{Phase}(\alpha_c) = \arctan.\frac{\sum_{i=k}^{n} m_i.r_i.\sin\alpha_i}{\sum_{i=k}^{n} m_i.r_i.\cos\alpha_i}$

a)

b)

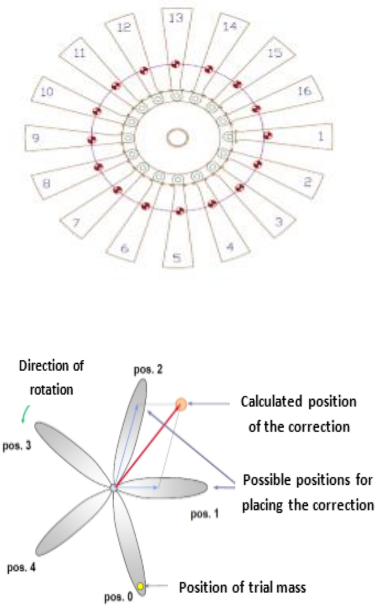


Fig.2 a) The distribution of the blades of a Turbine stage, b) Determining the position of the correction mass

These calculations can be represented graphically, as shown in Fig.4. Find out the centrifugal force (or the product of the mass and the radius of rotation) exerted by each mass on the rotating shaft. Plot a vector table with the centrifugal forces obtained (or the product of the masses and their radius of rotation), such that the ab represents the centrifugal force exerted by the moment m1.r1 in magnitude and direction at some appropriate balance.

Similarly, the attraction be, bc, cd, and de to represent the moments of other masses m1r1 m2r2, m3r3 and m4r4. Now, according to the polygon law of forces, the closing lateral ae represents the resultant force in the greatness and meaning.

The balancing force is, then, equal to the resultant force, but in the opposite direction. It has been found outside the magnitude of the balancing mass (m) at a given radius of rotation (r), such that: mcrc. Resultant of m1.r1 of m2; r2 r3 of m3 and r4 of m4.

In general for the solution, the vector m1r1 m2r2, m3r3 and m4r4, the m2 of r2, the graph m3 the r3 and r4 of m4, etc., are added. If they close in a loop, the system is balanced.

Otherwise, the closing vector will give the correction mass. Its direction identifies the angular position of the counter-mass relative to the other mass. Angular positions are measured counter-clockwise from the reference line along the x-axis.

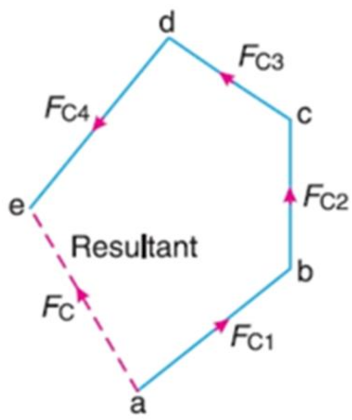


Fig.4
Balancing vector diagram of several of the mass rotating in the same plane.

3 EXPERIMENTAL PROCEDURES

Preparation and realization of a static balancing of a rotor must be mounted on the bearings then driven, and equipped with an angular reference.

The distribution of the blades of a turbomachine rotor, measurement of the static moments, classification of the blades according to a determined selection criterion depending on the static moments previously measured and finally, distribution of the blades on the disc by numbering of the blades in order of the results. Fitting the fins according to a distribution makes it possible to bring the residual unbalance of the entirely blade disc within the admissible tolerance.

In order to minimize the unbalance and therefore make it close to the admissible unbalance of the rotor, the static moments are measured thanks to the connection between the PC and the electronic balance of a very high precision.

Development of a blade distribution program

The main objective of our work is to solve the unbalancing problem of a free rotor using the MATLAB computer code (finding the mass correction), following the preselected algorithms:

3.1 Blade Dispatch Program Flowchart

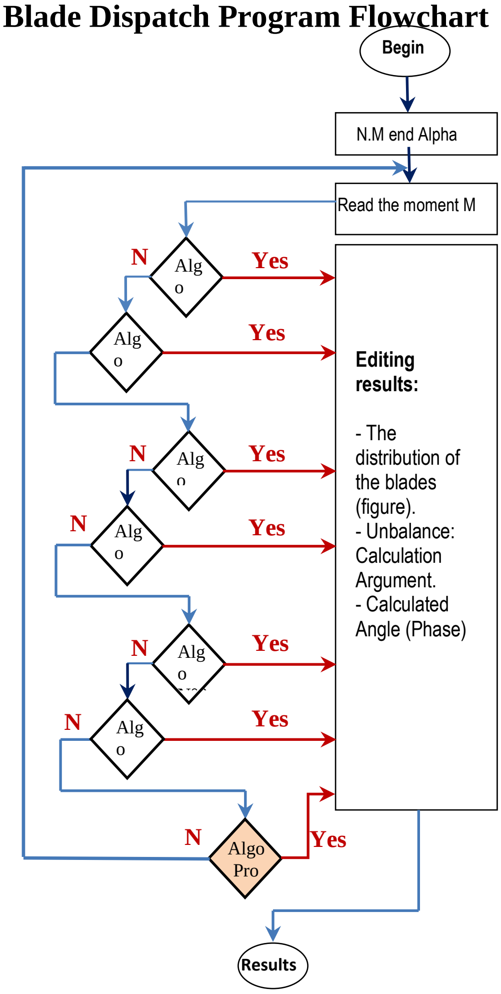


Fig. 5 Application Flowchart

3.2 Algorithms of distribution of blades subroutine MATLAB

Distribution algorithm N°03: Two decreasing and alternating sectors and heavy blades and light blades (fig.6.).

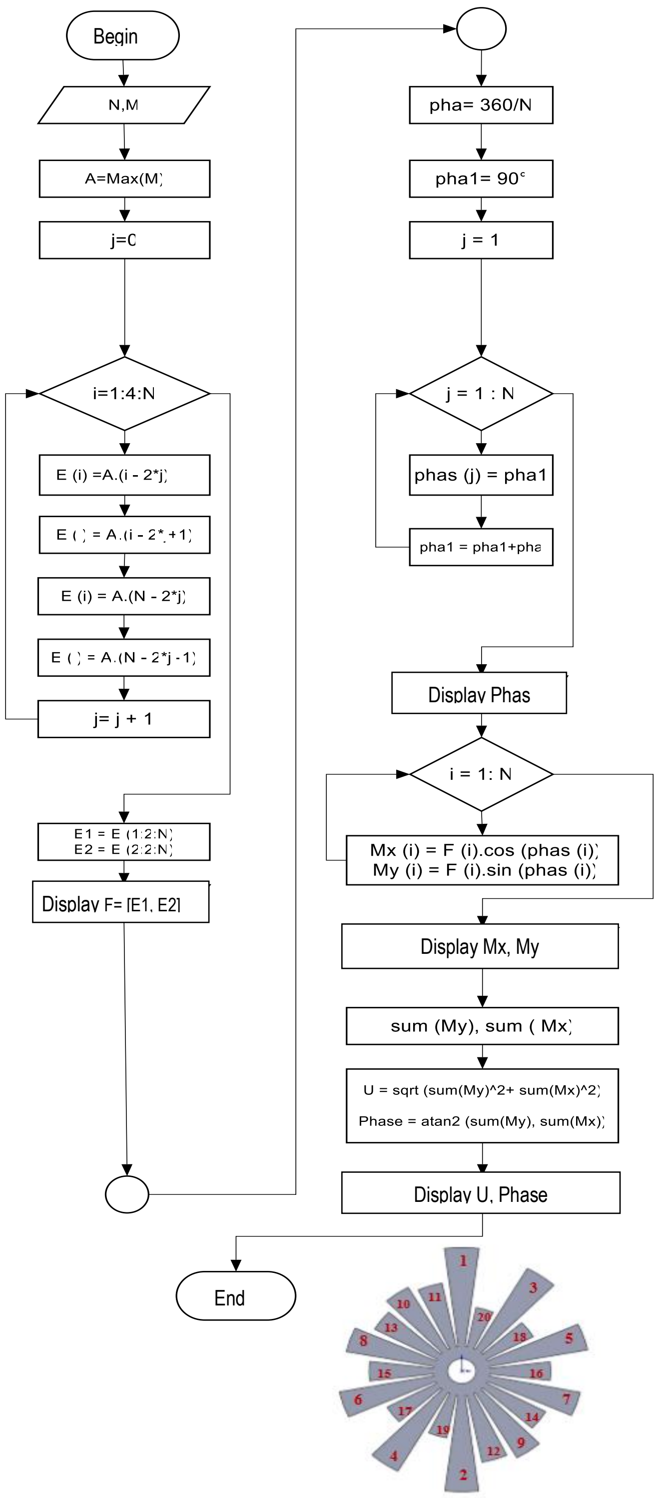


Fig. 6 Flowchart represents the blade N°03

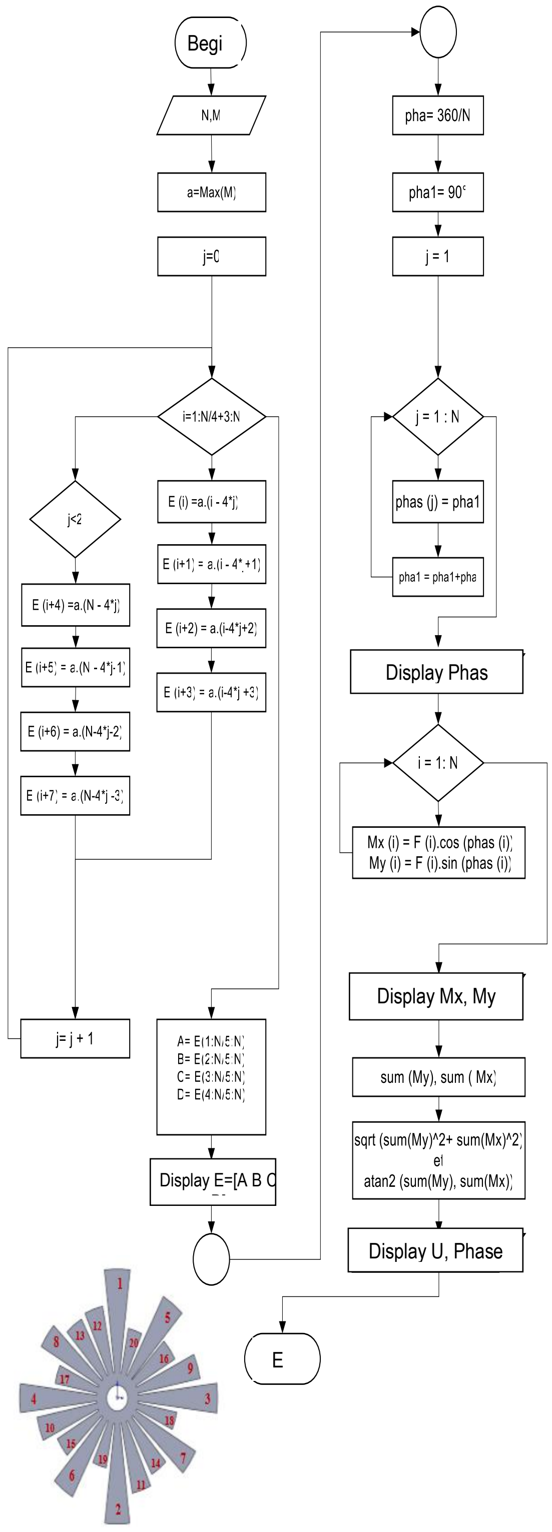


Fig.7. Flowchart represents the blade distribution algorithm N°04

Algorithm of distribution N°04: Four sectors decreasing by alternating heavy blades and light blades (fig.7.).

Proposed distribution algorithm: Four heavy descending sectors (fig.8.).

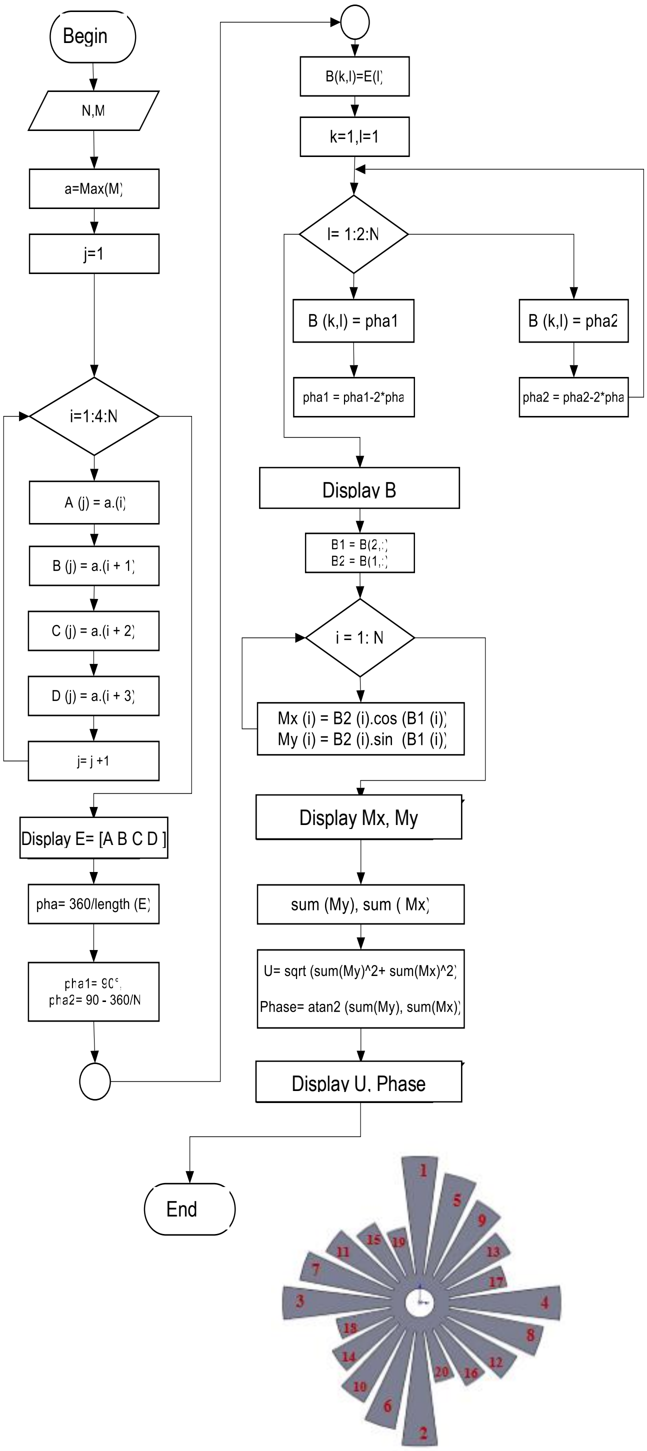


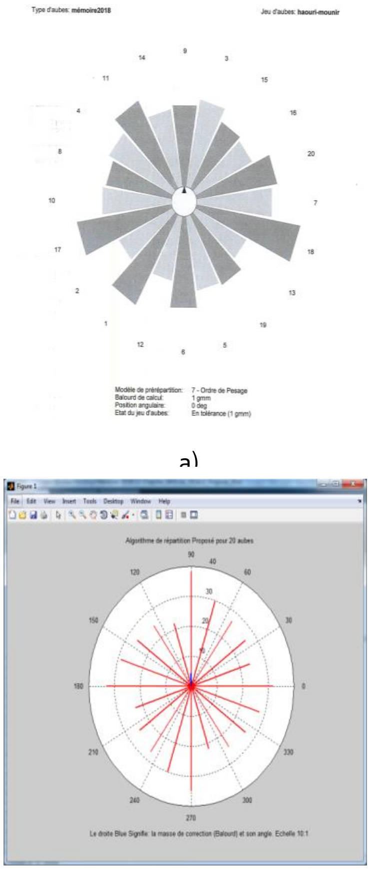
Fig.8 Flowchart represents the proposed blade distribution algorithm

4 RESULTS AND DISCUSSION

Table.1 Results of the different algorithms for the distribution of 20 blades

Number of blades		Algo N°01	Algo N°02	Algo N°03	Algo N°04	Algo N°05	Algo N°06	Present Algo	Bladis
20	Uc g.mm	0.43	1.02	0.35	0.354	3.89	0.53	0.42	1
	αc deg	52	50.6	90	86	26.5	70.5	92	0 (90°)

From reading the previous table, we observe that the masses of the corrections obtained belong to the Unbalance range mentioned in the BLADIS report. So the best permutation between the algorithms is algorithm N°03 and the proposed algorithm (fig.9.).



a)

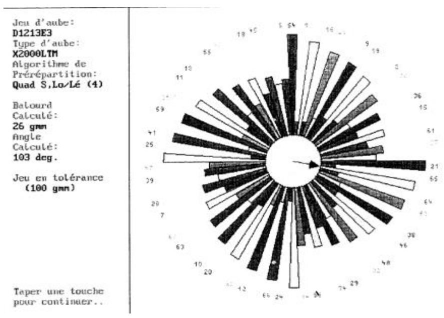
b)

Fig. 9 The images recorded: a) during machine results b) during simulations

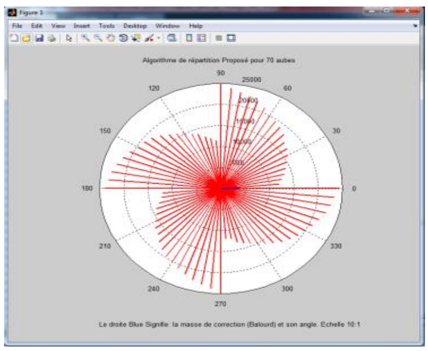
Table .2 Results of the different algorithms for the distribution of 70 blades

Number of blades		**Algo N°01**	**Algo N°02**	**Algo N°03**	**Algo N°04**	**Algo N°05**	**Algo N°06**	**Present Algo**	**Blades**
70	Uc g.mm	508	564	53.5	19	349	116	16	26
	αc deg	7	-78	82.5	-14	46	53	-13	103 (-13)

According to the reading of the preceding table, the algorithms N°01, N°02, N°05 and N°06 out of tolerance while the masses of the corrections of the two algorithms N° 04 and proposed obtained belong to the Unbalance range mentioned in the P.V. So the best permutation between the algorithms is the algorithm N°04 and proposed (see fig.10.), This makes it possible to obtain the best possible blading for a stage



a)



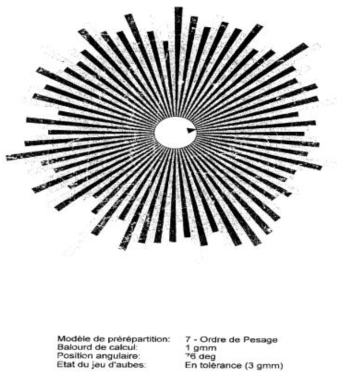
b)

Fig.10 Images recorded: a) during result with BLADIS b) during MATLAB simulations

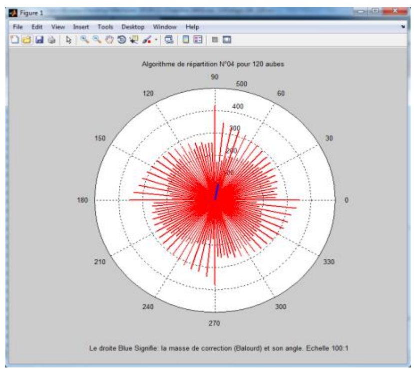
Table .3 Results of the different algorithms for the distribution of 120 blades

Number of blades		**Algo N°01**	**Algo N°02**	**Algo N°03**	**Algo N°04**	**Algo N°05**	**Algo N°06**	**Present Algo**	**Blades**
120	Uc g.mm	69.5	178	43.6	0,73	78.4	58	0.69	1
	αc deg	42	31	76.9	79	67.6	63.5	38.7	76 (14°)

According to the reading of the previous table, we observe that all the algorithms are out of tolerance except the correction mass of algorithm N°04 obtained belongs to the unbalance range mentioned in the P.V. So the best permutation between the algorithms is l algorithm N°04 (see fig.11.).



a)



b)

Fig.11 Images recorded: a) during result with BLADIS b) during MATLAB simulations

5 ASSEMBLY OF THE BLADES OF A GAS TURBINE

The figures below represent an assembly of the blades on a following rotor disc by best distribution

Fig.12 a) Distribution of the blades on the disk by numbering of the blades in order of the results, b) View of a rotor disk during assembly of the blades in order of the results of the static distribution

6 CONCLUSION

Through this study which allowed us to carry out experimental tests which aim to optimize a distribution of the blades of a stage of the rotors of the turbines in order to reduce the mass of correction (unbalance). We then made the choice of the different predetermined distribution algorithms with our proposed algorithm contribution. Then, we analyzed the possibilities of blade distribution with a MATLAB code.

Three experiments have been designed to illustrate the usefulness of analytical equations. Modeling equations were performed in the MATLAB program for a one-stage rotor bancing that would facilitate the conversion of the measured imbalance into the experimental results.

The results obtained using the MATLAB program show that the recorded unbalance of a rotor stage is within tolerance even in the case of a large number of blades. A distribution that has been optimized may display an imbalance exceeding the tolerance limits so this is very often necessary to change the position of a large number of blades with the permutations of the algorithms. It can be concluded that the developed program and the proposed algorithm give results similar to the BLADIS distribution program. It remains to point out that it is possible to make an extension in our program to ensure the direct link between the electronic scale and the PC. This connection has not been established and it will be the subject of a final master's study project for future promotions.

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