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ANALYSIS OF BLADE DISTRIBUTION FOR LESS STATIC UNBALANCE

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Abstract. *During the research and development project: "Analysis of two possible cold source: one pumping river water and the other one from a cooling tower", working in the reblading of several stages of the low pressure turbine was necessary. This project presents the methodology used to find different ways to distribute the turbine blades with the purpose of obtaining the minimum static moment possible.*

Keywords: *imbalance, static, blades, turbines, balancing*

1. INTRODUCTION

Steam turbines are turbomachinery used for power generation. These consist of a rotor shaft in which several wheels composed of blades of different sizes are mounted.

The steam that is generated in a boiler is directed towards the turbine. In the first place, the steam goes through a ring of nozzles where its velocity rises at the expense of an enthalpy jump. Then the steam with high speed, following its established path, meets the turbine blades, these blades have a certain shape and dimensions that allows the absorption of the energy flow and the transformation into mechanical energy on the shaft of the turbine. Mechanical energy which produces the movement of the axis, giving movement to a generator that gives us electric energy.

Figure 1. Picture of turbine from a low shaft pressure

The generation of electrical energy is a process in which there are several energy losses for different reasons, either because of the mechanical functioning of the different parts and systems or by its principle of operation at the thermodynamically speaking.

In addition to energy losses, there are several phenomena that influence the deterioration of the machine, which must be treated so that they do not end up putting the turbine out of service or shortening its lifespan. One of the most frequent damaging phenomena is the imbalance of the rotor.

2. IMBALANCE

In a rotating part, such as the turbine rotor, each point of its mass is subjected to the action of a radial force tending to separate that point from the axis of rotation. If the mass of the rotor is evenly distributed around the axis, that rotor is said to be balanced, and its rotation will not produce vibrations. On the other hand, if there is a certain amount of leftover mass, ie mass distributed in a heterogeneous way, they will generate a centrifugal force that must be supported by the supports.

There is static imbalance when the leftover mass generates a displacement of the center of gravity with respect to the axis of rotation. This causes the axis of rotation and the inertia axis to separate, in parallel, a distance that depends on the force generated by the imbalance.

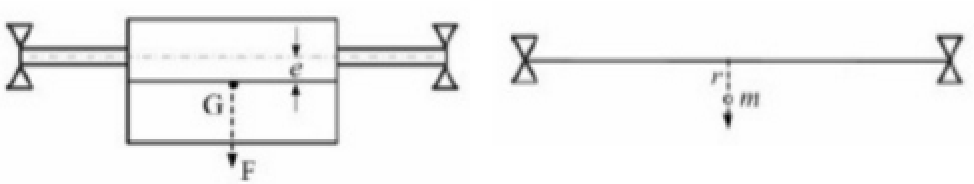

Figure 2. Displacement of the center of gravity on an axis due to unbalance

To compensate for the static imbalance a mass is placed on each side and in the opposite direction to the imbalances, or also a mass that compensates the resulting imbalance could be used instead.

A machine can be statically balanced but still exhibit dynamic imbalance. The latter only occurs when the rotor is in rotation, meaning it could not be detected if the rotor was simply supported without movement. In order to detect this kind of imbalance it is essential to measure on a balancing machine or with the machine running on site. The dynamic imbalance is generated by the difference of weights on the rotor axis, in the case of turbines it is generally due to the difference of weights between the different stages, which when rotating produce centrifugal forces in different directions.

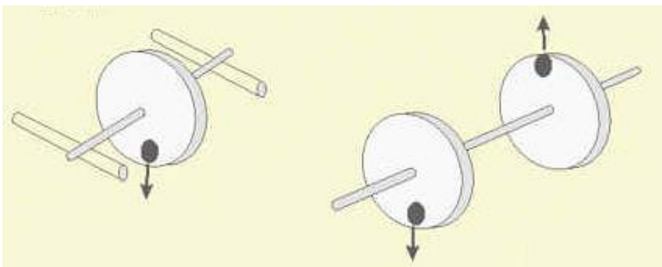

Figure 3. Static imbalance (left) and dynamic imbalance (right)

2.1 Consequences of imbalance

The unbalance of a rotor causes the application of variable centrifugal forces at the frequency of the rotation's rhythm in the bearings. The forces caused by the imbalance are proportional to the square of the speed in RPM, considering that the rotor of a generation turbine rotates to 3000 RPM, it is shown that the forces will have a considerable magnitude. If the force is important they generate strong vibrations in the equipment that are transmitted to the bearings. This can significantly reduce bearing lifespan and reduce the rotor's clearances with the stator (housing).

Shutdowns due to maintenance or failure of the turbine result in less energy generated and therefore higher costs, which is can be seen as economic losses. All these explain the importance of balancing correctly and in the most accurate way possible.

2.2 Balancing methods

At the moment the market offers equipments in which the customer only has to place the different blades that conformed to the turbine. The machine returns a diagram which indicates the position where to place each blade together with the value of the counterweight to be added at a certain angle. We must take into account that the turbines to be balanced can contain a minimum of 100 blades, and the number of blades can be even or odd.

Figure 4. Commercial balancing equipment, brand SCHENCK

Figure 5. Balancing a turbine blade

There are different methods of balancing proposed by the manufacturers of balancing machines. All methods currently used are based on obtaining the moment of inertia of each blade, order them from lowest to highest and then place them around the axis in different ways, with the aim that the resulting static moment is as small as possible. The main layouts of blades used are explained below:

- The first layout has the following logic: The first blade of the list is placed in a position, the second diametrically opposed to this, the third next to the first, the fourth next to the second and so on.
- The second layout: First fill the odd positions of the wheel by running it in one direction; then the even positions are completed with the remaining blades, in the opposite direction.
- The third layout: The odd positions of the wheel are filled so that each consecutive blade in the list is diametrically opposite. Then, even pairs are filled with the same logic and in the opposite direction.
- The fourth layout: The method is very similar to the one used in the previous arrangement, with the difference that the consecutive blades in the list are 90° apart of each other, instead of 180°.
- The fifth layout: The consecutive blades in the list are 90° apart from each other, running the wheel in one direction for both odd and even blades.
- The sixth layout: Repeating the arrangement logic of the fourth layout, but in this case the blades are 120 ° apart between each other.

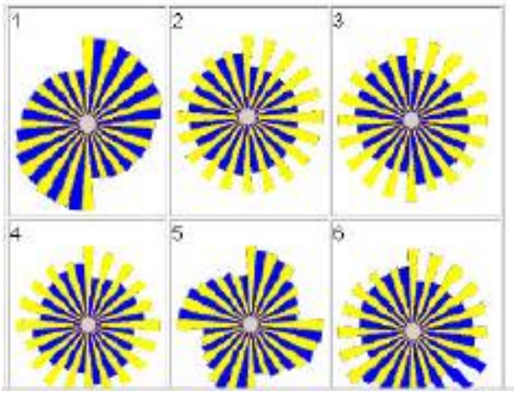

Figure 6. Balancing methods proposed by manufacturers

3. WORK DEVELOPMENT

By knowing the importance of the imbalance, we propose in this work to find a more efficient method to balance the turbine blades, a simpler and faster calculation method which gives the smallest static moment possible.

Prior to defining a method to position the blades, it was necessary to calculate the static moment of each one. With two balances placed in each on the extremes of the blade we obtain the extreme weights, which represents the reactions P1 and P2 (as we can see in the figure 7). Having said that our input data becomes the total weight and the longitude of the blade, as well as the distance between supports. Also it is verified that the sum of both forces are equal to the blade weight. With this information and by the application of the formula sum forces equal to cero in balanced objects, we obtained the distance to the gravity center for each of the analyzed blades. With the blade position in the wheel, we calculate the vector sum of the static moments to obtain the residual static moment. With it, we determine the weight and the angle of balance counterweight.

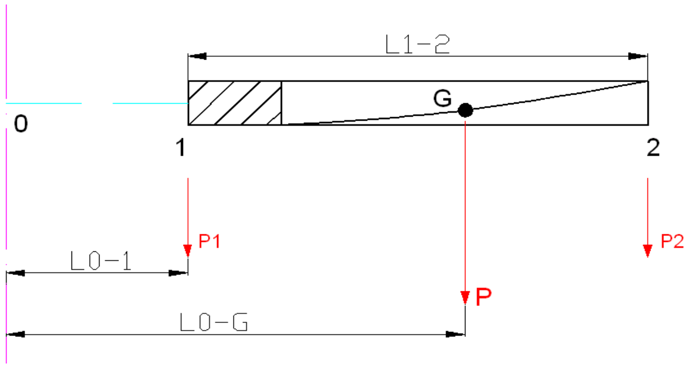

Figure 7. Simplification of studied blade

Everything that has been calculated was made with an Excel® spreadsheet, in which the following information is represented:

- Number of blades.
- Blade position.
- P1 (Load in the position 1).
- P2 (Load in the position 2).
- L1-G (distance according to sketch).
- L0-G (distance according to sketch).
- Sp = Static Moment.
- SPx = Static Moment in the axis “X”.
- SPy = Static Moment in the axis “Y”.

Once we obtain all these results, we continued to analyze the blades positions and the combination which gives the lowest static residual moment will be the ideal case. To achieve this development, we carried out in Excel a Visualbasic program, which allows simulating the different blades positions, getting the resulting static moment for each case. This program calculated all the possible combinations, looking for the most favorable. We must take care that the quantity of possible combinations to calculate for a wheel of 8 blades is 5040, increasing exponentially with the quantity blades. Such is this, that for 100 blades, the processing time amounts to hundreds of millions of years.

By analyzing this situation, we observed that many of these combinations presented repeat themselves. To understand this, we must imagine a wheel full of blades with four positions each one at 90° from each other. The blades could be numbered so that the combination 1 - 2 - 3 - 4 is the first one. Then, successive combinations will be made, until at a certain point the program will make the combination 4 - 1 - 2 - 3 and calculate the result of the moment just as with previous combinations. These two mentioned combinations will be identical in module but out of phase at an angle. Since it is a combinatorial of elements arranged radially, the two mentioned correspond to the same distribution but rotated.

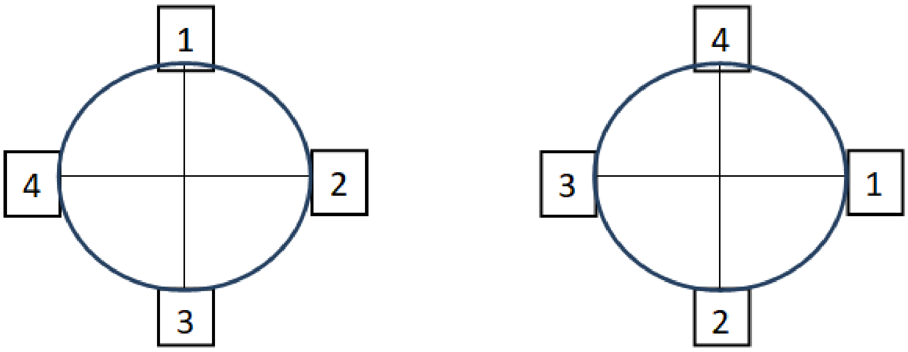

Figure 8. For a four bladed wheel, two positions with the same combination

This represents an unnecessary calculation that the program was making. To avoid the excess of time the programming was changed to maintain one of the fixed blades, in this case the first one, and to perform the combinatorial of the rest of the blades. For the example of the 4 blades the combinations to be made will be:

- 1 – 2 – 3 – 4
- 1 – 2 – 4 – 3
- 1 – 4 – 2 – 3
- 1 – 4 – 3 – 2

By doing so, of the 16 possible combinations that result from combining 4 elements, it is only necessary to take the first 4. This avoids performing repeated combinatories and reducing the processing time of the program. Although it was possible to reduce the calculation time, it was still excessively high. Understanding that the processing times are linked to a technological problem related to the processing capacity of the current computers, the possibility of calculation by this method was discarded.

The alternative calculation method is to take the difference of static moment between pairs of blades and place those pairs in different positions around the wheel. The process consists in taking the ordered list based on the individual static moments of the blades and looking for the minimum differences between consecutive blades. Then these pairs of blades are taken and placed around the axis following the same logic presented by the manufacturers of the balancing machines. Finally, the residual moments of these dispositions are calculated, always looking for the lowest result.

Our software automatically runs the previously proposed alternative, obtaining the most convenient arrangement in terms of balancing.

4. RESULTS

The result of this project is the development of a new method of ordering blades for the static balancing of turbines. In this development not only a new grouping of blades is proposed, but also new geometric dispositions, to those already implemented today. The following item shows an example for an 8-blade wheel, where the results obtained can be seen and compared.

5. EXAMPLE

The following eight blades are used in this example:

Table 1. Data of eight random blades including their weight, reactions and static moments of inertia.

#	Weight [Gr]	P1 [Gr]	P2 [gr]	Sp [Gr mm]
1	5000	3000	2000	4217500
2	5004.7	3009	1996	4218056
3	4998.5	3001	1998	4215335
4	5011.3	3009	2003	4225820
5	5012.3	3008	2005	4227683
6	4989.3	2998	1992	4206003
7	5018.8	3009	2009	4234486
8	5005.8	3009	1997	4219200

Each blade has an assigned reaction at the tip ends, according to a randomized distribution, resulting in a total weight and a determined moment of inertia. Then they are ordered from smallest to largest according to their static moment, using this list they are placed on the wheel according to the methods proposed by the manufacturers. Once the blades are placed the counterweight necessary to balance is calculated for each method used.

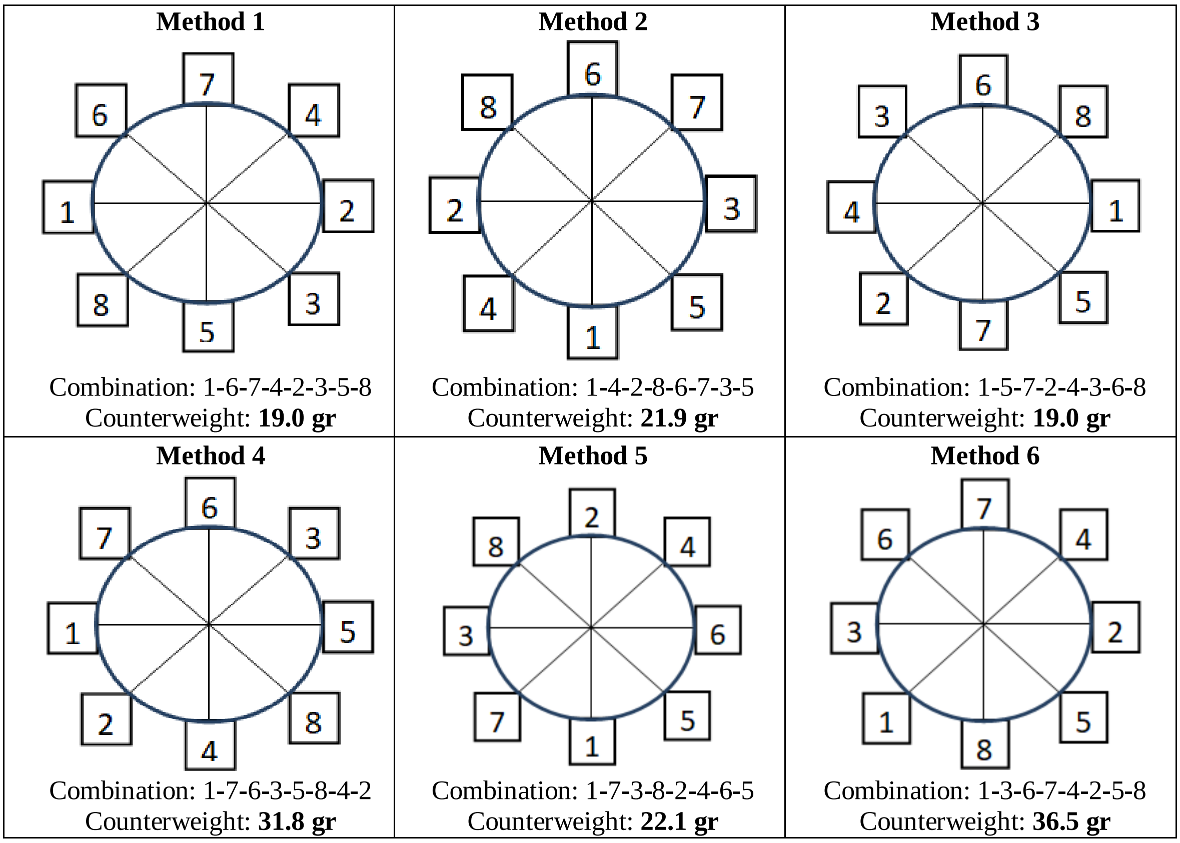

Figure 9. Results with manufacturer methods

On the other hand, the individual static moments of each blade are ordered, the differences between consecutive pairs are calculated and the pairs of blades with less difference are formed.

Table 2. Pairs of blades according to difference of static moments.

#	Sx	Dif.	Pair
6	4,206,002.6		3
3	4,215,334.8	9332.2	3
1	4,217,500.0	2165.25	1
2	4,218,056.5	556.45	1
8	4,219,200.3	1143.85	4
4	4,225,819.6	6619.25	2
5	4,227,683.1	1863.5	2
7	4,234,485.8	6802.75	4

With the paired blades, the following combination made around the wheel, according to the first proposed method (method 1 seen previously):

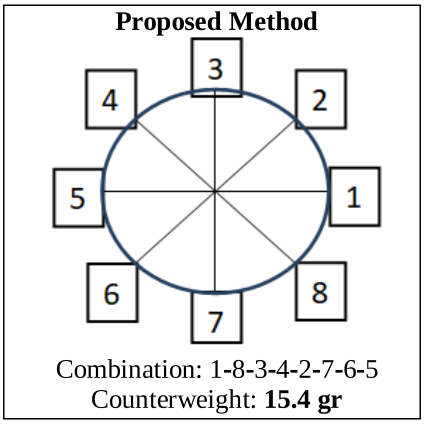

Figure 10. Results using proposed method

It can already be observed that this last result is the best from all the methods proposed. Nevertheless, in the future it can be analysed new combinations with pairs of blades that offer better results.

Finally, the possible 5040 combinations of arrangements for 8 blades located radially are calculated, obtaining all the possible counterweight values. The combinations that gave the optimum results could be found. It is worth saying that this is what was sought at the beginning of the research, reaching to the conclusion that for more than 100 blades computing times would take millions of years (using the available technology).

In order to simplify the visualization of the obtained results, below is the graph titled "comparison of methods". In this graph it can be seen the 5040 possible combinations on the horizontal axis, ordered from lower to greater according to the balancing weight required for said combination. On the other hand, in the vertical axis the balance weight that corresponds to each combination can be visualized. The relationship between these 2 axes, for all combinatorics, can be observed with blue series. It is important to note three zones of the curve obtained: a central zone where the curve is approximately a straight line and the extreme zones where the first derivative of the curve takes high values.

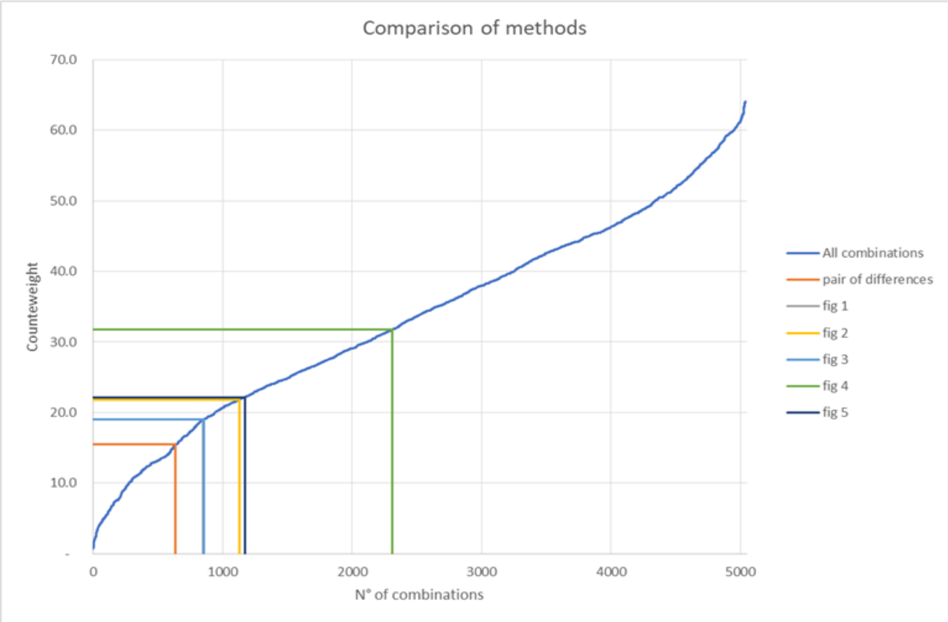

Figure 11. Graph comparing all methods tested

This substantial change in the first derivative, at the ends of the curve, is due to the small number of combinations for which the minimum and the maximum counterweights are obtained. The above can be displayed through the next histogram. In which the number of cases is displayed in the horizontal axis and the ranges of counterweights in the vertical axis.

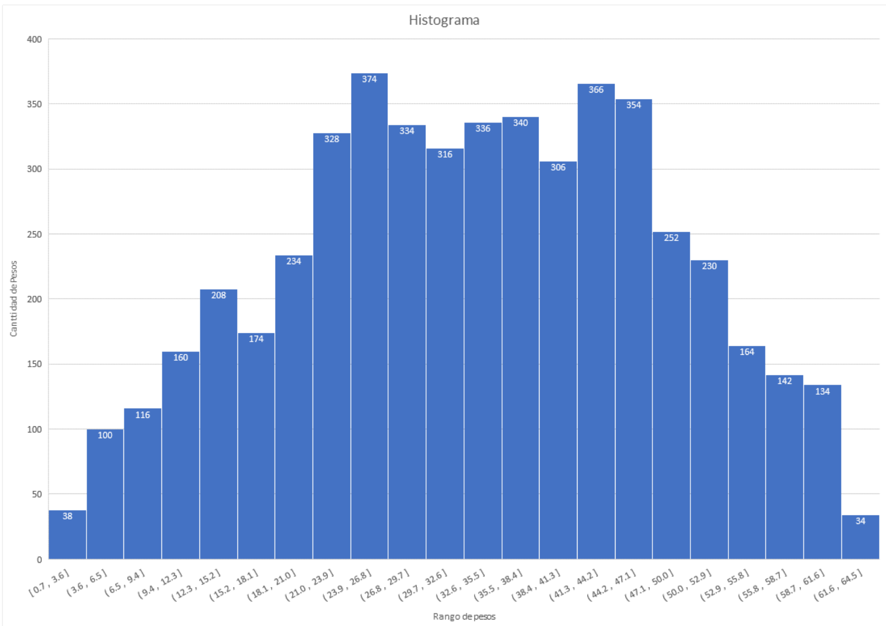

Figure 11. Histogram of results

Finally, it is possible to quantify the improvement achieved by the method proposed in figure 10, displaying the indicated reference in red. This reference corresponds to the counterweight obtained by the use of pairs of blades and the rest of the references, indicated in other colours, correspond to the 6 methods previously proposed. It should be noted that the best balance obtained corresponds to a counterweight of 0.7 gr, which is obtained only for 2 combinations. While this is the best possible result, in practice it is not of interest to find it since vibration regulations, such as ISO 1940, indicate an acceptance range which does not require optimum balancing for approval.

6. CONCLUSIONS

There is no single arrangement that satisfies any randomly dispersed blade sample. To choose the combination that provides the smallest residual moment such that the static balance weight is negligible, or as small as possible, all the possible combinations should be calculated.

During the development of this work it was seen that this is impossible given the technology that we have today, since it takes years of processing to arrive at the final result.

It is for this reason that an alternative method to the known one was presented, which results in residual static moments of similar magnitude to those obtained with the already known method. The new method could be an alternative to take into account when doing the balancing of a turbine.

Bearing in mind that the balancing results in vibrations in the rotor supports, they are accepted according to the criteria of the normative used. One of the regulations used is ISO 1940, which like all regulations related to the study of vibrations offer a range of acceptance; not being necessary the finding of ideal point of balance.

Another result of this research to point out is the development of a software for academics uses, which calculates the necessary counterweight for balancing using the new proposed method.

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8. RESPONSIBILITY NOTICE

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