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STUDY OF ROUGHNESS IN A TESLA TURBINE

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Abstract. *The main objective of the project proposed in this course is the study of microscopic effects on a Tesla turbine's discs. This will be done by means of a small-scale model of a Tesla turbine which will be built. Of special consideration is the discs' roughness, which is responsible for adherence of the working fluid. The study employs as a basis for its approach the concepts learned in Fluid Mechanics, with the Boundary Limit Theory as a primary focus as this is relevant to the type and quality of the disc surfaces used. In this way it was possible to analyze factors that are intrinsically linked to Mechanics of Solids, such as surface roughness. The methodology used first involved computer software to model the Tesla turbine, then experimental tests were conducted to better understand how fluids behaved as results were compared from the four different sets of rotors. The torque output of each disc type was then determined using the ideal surface roughness of a disc as the baseline. The project's secondary objective was to increase the efficiency of the Tesla turbine by mitigating losses, such that the electricity generated can potentially be used in remote areas.*

Keywords: *Tesla turbine, Roughness, Energy.*

1. INTRODUCTION

Currently, the demand for clean energy generation from renewable sources is growing continuously making use of the application of the various known technologies, aiming for sustainability. Reflecting this demand is to optimize existing systems, especially those with low energy utilization, in order to use the concept elaborated in an in-depth re-study for possible improvements. One way to meet the need of power generation in low power cycles is the use of multi-disc turbines that are gaining space because they are simple construction equipment. Its efficiency is considered low compared to other turbines and is highly linked to the type of configuration and geometry adopted. The Tesla turbine is composed of a set of discs separated by spacers and mounted parallel to an axis. (TESLA, 1913) This assembly is covered by a housing having a fluid inlet nozzle that directs it tangentially to the discs generating rotation on the shaft, i.e., kinetic energy.

In its creation and initial study, the roughness factor was not taken into account even though it was developed in previous years. The deployment of skills to define the spacing and quantity of disks for this model of turbine was only

possible after the aerodynamic limit layer concept was studied (PRANDTL, 1904). This phenomenon results in the analysis of the ideal roughness of the discs in order to make them more efficient.

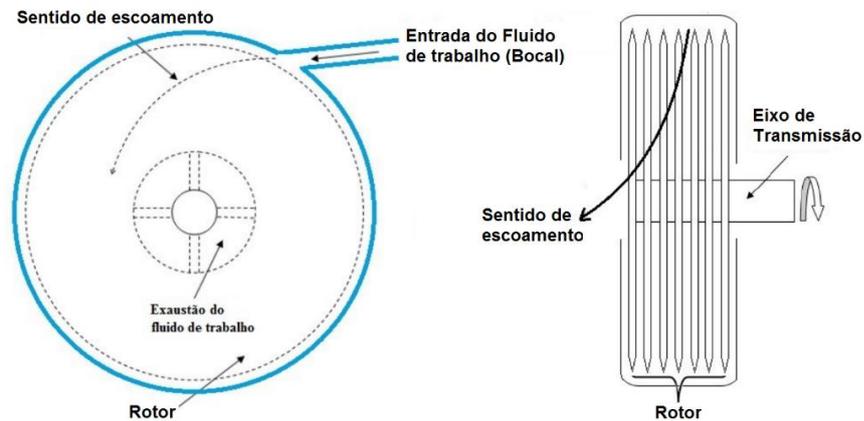


Figure 01 – Principle of operation of a Tesla Turbine (Neckel, 2013)

The objective of this work is to reproduce a compact model of the Tesla turbine to study the surface roughness in the discs, feeding it through the compression of the atmospheric air by means of a commercial compressor (compressed air line). This fluid was used to analyze the microscopic phenomena that occur in the same (shock wave, fluid-disk contact, etc.) that are not possible to the naked eye, and through the study of roughness on the surface of the discs determine the torque gain.

2. EXPERIMENTAL PROCEDURE

In the experiments the influence of the roughness on the surface of the discs of the Tesla turbine was evaluated. The turbine used in the tests consisted of: a casing made of aluminum, with a housing machined to allow the coupling of a nozzle for entering the working fluid; sides made of 20mm thick polycarbonate sheets; SAE 1020T carbon steel shaft; armored ball bearings; and 7 (seven) SAE 1020L carbon steel discs separated by aluminum spacers.

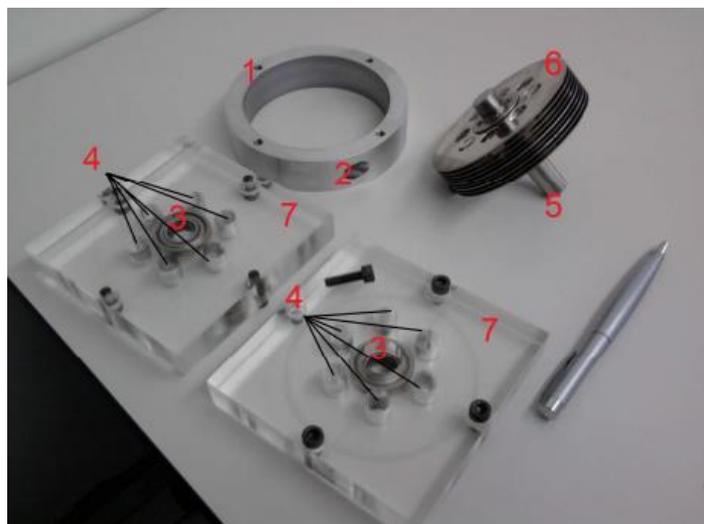


Figure 2: Tesla turbine disassembled. (1) Housing; (2) Fluid inlet; (3) Bearings; (4) Fluid outputs; (5) Shaft; (6) Discs; (7) Sides.

In the beginning would be used disks of computer's HD's due to its low weight and excellent balance when compared to the other low alloy steels. However during the evolution of this study, it was verified that the sensitivity of this material resulted in the deformation of the discs.



Figure 3: Evolution in roughness tests and materials: (1) Hard Disk; (2) Tests with different roughness; (3) Steel disk without deformations, adopted for this study; (4) Aluminum disc with loss of external diameter; (5) Blasted aluminum disc with deformations; (6) Aluminum disc with double thickness.

Considering these facts, SAE 1020T carbon steel discs (3) were used with the surface roughness made in a penetration electro-erosion. It was used 4 (four) sets with 7 (seven) discs and through the erosion obtained the roughness: $1,02\mu\text{m}$, $8,75\mu\text{m}$, $9,54\mu\text{m}$ and $16,01\mu\text{m}$ and to standardize the methodology, a rugosimeter to measure the micro geometric deformation of the discs, thus ensuring that it can be reproduced again.

2.1 Torque Testing as a Function of Fluid Pressure

The turbine supply hose was parameterized at a constant pressure of 5 bar. In addition, pressure pliers were used to fasten the shaft so as to create a horizontal lever between the axis of the turbine and the balance, such as a bridge, thus a level was used to mitigate slopes and reach the horizontal plane.

The balance was then zeroed with all loads added thereto and the rod was measured, in this case 0.22 m, then the pressure was fully released from the hose for 10 seconds, thus providing a constant and hysteresis free load. This measurement was performed 10 times for each set of disks.

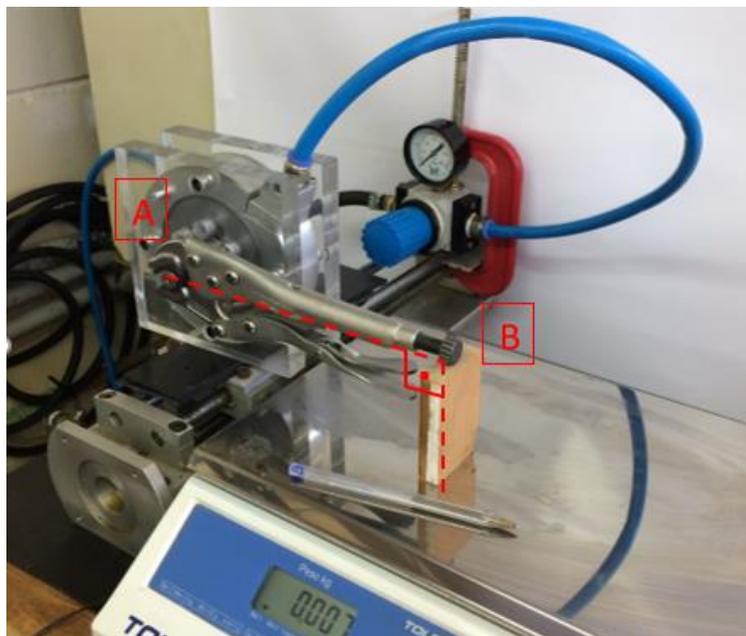


Figure 4: A- B plane illustration.

Como trata-se de um teste estático, pois os discos da turbina permanecem estagnados por conta da alavanca apoiada na balança, não foi necessário usar dispositivos para fixar a turbina, balança ou qualquer aparato. O paralelismo considerado para os cálculos de momento torçor nesse estudo, foi a parte superior da balança em função da cota do centro do eixo à ponta do alicate em contato com o calço de apoio (Plano A – B) como ilustrado na figura anterior.

2.2 Mathematical equations

ANOVA hypothesis ANOVA: $H_0 = \mu_1 = \mu_2 = \mu_3 = \mu_4$

H_1 there is at least 1 difference.

Significance level adopted: $\alpha = 0,05 \rightarrow \text{patern}$

$$SQE = \sum_{j=1}^K \left[\left(\frac{(\sum_{i=1}^n x_{i,j})^2}{n} \right) \right] - \left(\frac{(\sum_{s=1}^n \sum_{i=1}^n x_{i,j})^2}{n} \right) \quad (1)$$

$$\frac{0,17994^2}{10} + \frac{0,2167^2}{10} + \frac{0,21892^2}{10} + \frac{0,20196^2}{10} = 0,016708$$

$$SQE = 1 - 2 = 9,64.10^{-5}$$

$$SQR = (\sum_{j=1}^n \sum_{i=1}^n x_{i,j})^2 - \sum_{j=1}^K \left[\frac{(\sum_{i=1}^n x_{i,j})^2}{n} \right] \quad (2)$$

$$SQR = 0,01892^2 + 0,01804^2 \dots 0,02046^2 = 3-1 = 9,2.10^{-6}$$

$$GLE = K - 1 = 4 - 1 = 3 \quad (3)$$

$$GLR - N - K = 40 - 4 = 36 \quad (4)$$

$$QME = \frac{SQE}{GLE} = 3,213.10^{-3} \quad (5)$$

$$QMR = \frac{SQR}{GLR} = 2,555.10^{-7} \quad (6)$$

$$F = \frac{QME}{QMR} = 12,56 \quad (7)$$

Table 1: ANOVA statistic

FV⁽¹⁾	Q⁽²⁾	GL⁽³⁾	QM⁽⁴⁾	F⁽⁵⁾
Entre	9,64.10 ⁻³	3	3,21.10 ⁻⁶	12,56
Dentro (Resíduo)	9,2.10 ⁻⁶	36	2,555.10 ⁻⁷	
Total	1,056.10 ⁻⁴	39		

⁽¹⁾source variation; ⁽²⁾sum of squares; ⁽³⁾freedon degree; ⁽⁴⁾square average; ⁽⁵⁾F factor

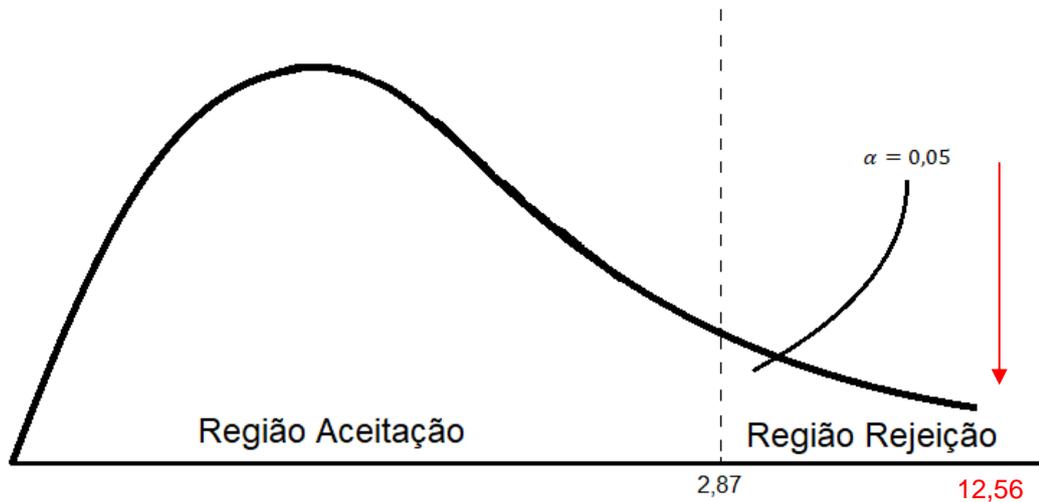


Figure 5: In table F (5%) = 3.36 > 2.87

TUKEY test

H_0 , is rejected because there is at least 1 difference. This makes it necessary to perform the Tukey test.

Therefore, if:

$$d.m.s = q \cdot \sqrt{\frac{QMR}{n}} = 6,15 \cdot 10^{-4} \quad (8)$$

$$|XA - XB| \geq dms \rightarrow \mu_A \neq \mu_B$$

$$|XA - XB| < dms \rightarrow \mu_A = \mu_B$$

At where:

d.m.s: Minimum significant difference;

q: Found in factor table Q for 5%, K, GLR;

n: Number of repetitions.

Table 2: Comparisons of Measures

Comparações	$ XA - XB $	Dms	Conclusão
Torque 1 e Torque 2	$3,67 \cdot 10^{-3}$	$6,15 \cdot 10^{-4}$	$\mu_{\text{torque 1}} \neq \mu_{\text{torque 2}}$
Torque 1 e Torque 3	$3,89 \cdot 10^{-3}$	$6,15 \cdot 10^{-4}$	$\mu_{\text{torque 1}} \neq \mu_{\text{torque 3}}$
Torque 1 e Torque 4	$2,202 \cdot 10^{-3}$	$6,15 \cdot 10^{-4}$	$\mu_{\text{torque 1}} \neq \mu_{\text{torque 4}}$
Torque 2 e Torque 3	$2,22 \cdot 10^{-4}$	$6,15 \cdot 10^{-4}$	$\mu_{\text{torque 2}} \neq \mu_{\text{torque 3}}$
Torque 2 e Torque 4	$1,472 \cdot 10^{-3}$	$6,15 \cdot 10^{-4}$	$\mu_{\text{torque 2}} \neq \mu_{\text{torque 4}}$
Torque 3 e Torque 4	$1,696 \cdot 10^{-3}$	$6,15 \cdot 10^{-4}$	$\mu_{\text{torque 3}} \neq \mu_{\text{torque 4}}$

Through the ANOVA hypothesis, it was found that there is at least one difference between the means, discarding the hypothesis that all the roughness are equal. Using the TUKEY test, it was possible to compare the measurements with each other, in the test, it was found that only the mean torques in the roughness 8.75 μm and 9.54 μm are significantly the same, reiterating this hypothesis that at least there is a difference between the stockings

2.3 Figures and tables

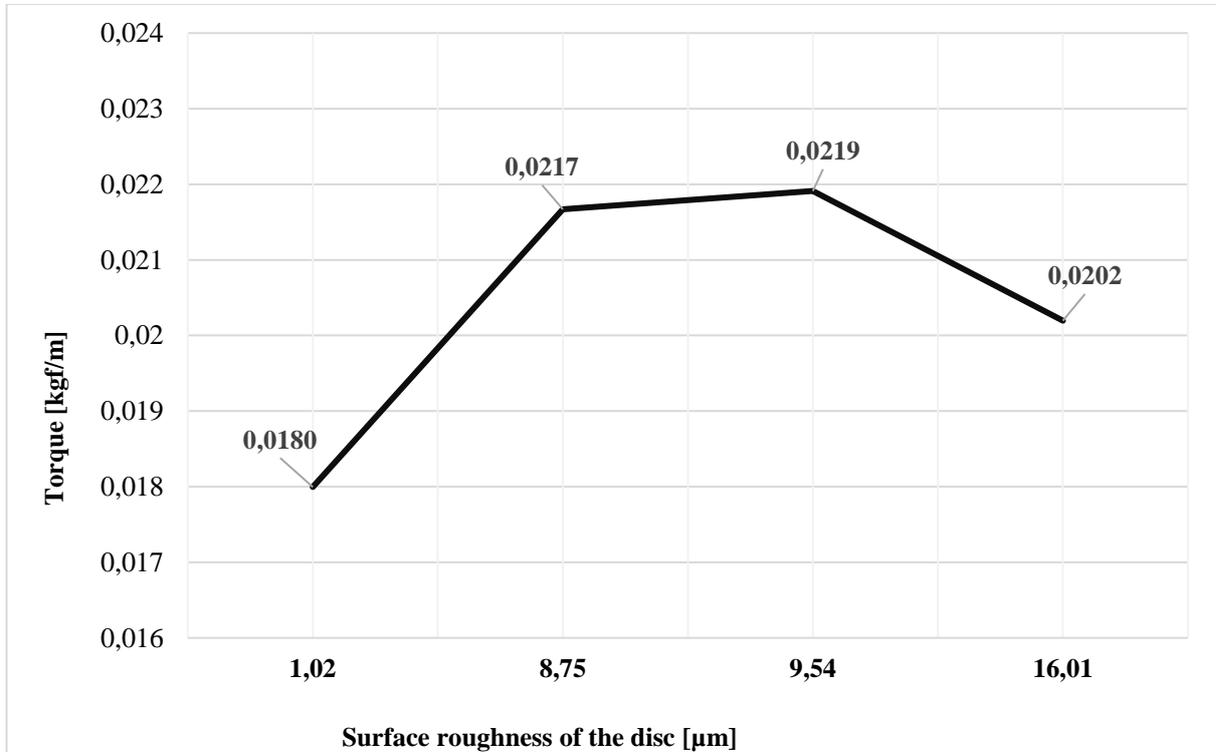


Figura 6: Torque extracted in function of the roughness

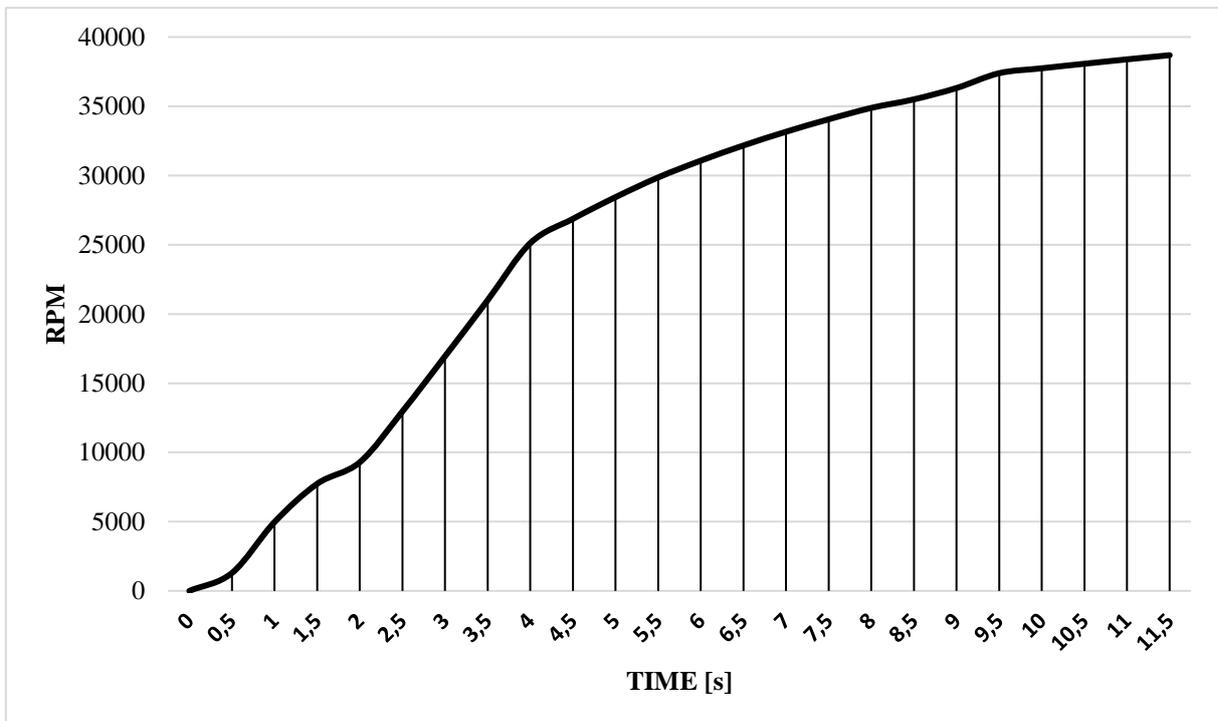


Figure 7: Rotation as a function of time

3. CONCLUSION

It was observed that the increase of roughness in the turbine discs generated greater torque in the shaft, however, between $9.54\mu\text{m}$ and $16.01\mu\text{m}$ the turbine efficiency decreased due to the fluid detaching from the disk surface. It was also verified that, through statistical analysis, the mean roughness values of $8.75\mu\text{m}$ and $9.54\mu\text{m}$ are significantly the same, concluding that if the discs maintain the roughness tolerance of 10% for more or less, they will obtain the same torque on the shaft. Microscopic analysis through shilieren photography proves the phenomena described above and ANOVA hypotheses and Tukey's test reiterates this fact.

4. ACKNOWLEDGEMENTS

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