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Theoretical and Experimental Research Performed on the Tesla Turbine – Part II

The paper presents research made to highlight the dynamical behavior of a Tesla turbine actuated with compressed air. Since the noise and vibration level of industrial equipment is an important concern of nowadays industry, we focused on established the relation existing between the angular speed and the vibration amplitude. The turbine, designed and manufactured specially for this experiment, is simple and consists of a casing and 16 circular disks mounted on the shaft. Due to the inexistence of unbalanced components, a low vibration level is presumed; experiments confirmed this hypothesis.

***Keywords**: Tesla, turbine, compressed air, vibration level*

1. Pressure versus Frequency of rotation

The bladeless centripetal flow turbine patented by Nikola Tesla uses the boundary layer effect and not a fluid impinging upon the blades as in a conventional turbine. This device makes use of fluids as motive agents converting pressure in rotation, but it can be used for the propulsion or compression of fluids as well. Its application is limited, being mainly used to pump fluids that are abrasive or viscous, contain solids, or are otherwise difficult to handle with other pumps [1].

As a main disadvantage, the discs warping/deformation can be mentioned. However, this has been partially solved by involving new materials such as carbon fiber [2], [3]. If not suppressed, the phenomenon of deforming discs can induce significant vibration in the system, which annuls the advantage of having just balanced components.

First, the dependency of the frequency of rotation of the pressure is analyzed. Experiments are performed on a stand, presented in Fig. 1, composed by:

- the Tesla turbine designed by the authors;
- a Metabo compressor;
- a PCE – DT62 tachometer.

The compressor is used to assure the motive agent (compressed air) in a pressure range of 0.5 ÷ 5 MPa. The compressor is equipped with a pressure regulator and a manometer to indicate the actual pressure.

The frequency of rotation is measured with the tachometer. The non-contact measurements of the tachometer are taken by using a piece of reflective tape that is stuck to the rotating component [4].

The measurement procedure for one pressure level is as follows:

1. Setting the pressure to the desired level;
2. Air admission in the turbine chassis;
3. Angular frequency stabilization;
4. Simultaneous measurement of pressure and frequency of rotation;

The procedure is iteratively applied for all pressure levels of interest.

Turbine

Compressor

Tachometer

Figure 1. Experimental stand

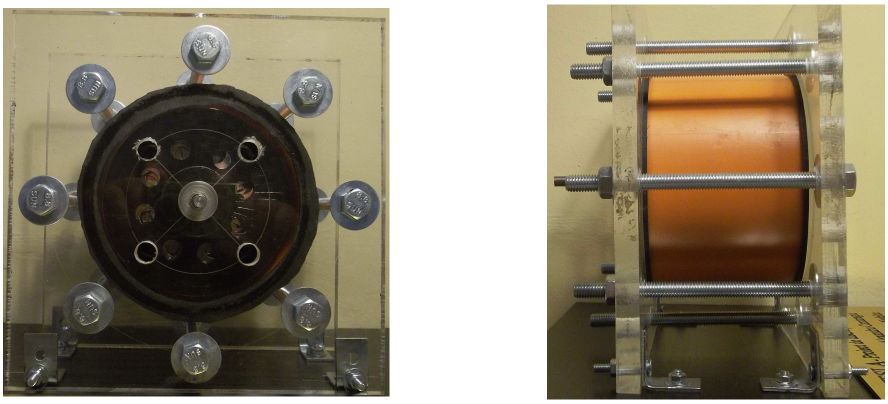

Figure 2. The Tesla turbine

Figure 2 presents the analyzed Tesla turbine [5]; one can remark in the left image the 4 evacuation holes.

In the table 1 the measured frequency of rotation values are provided, for the individual cases when the pressure was set between 0.5 and 5 bar, with a step of 0.5 bar. For each pressure level 10 measurements were performed. The average value is determined in consequence; these values are also presented in table 1. Figure 3 shows dependence of the frequency of rotation as a pressure function.

Table 1. Frequency of rotation measurements using the PCE – DT62 tachometer

Pressure	Frequency of rotation										
p	n1	n2	n3	n4	n5	n6	n7	n8	n9	n10	Average
[bar]	[rpm]	[rpm]	[rpm]	[rpm]	[rpm]	[rpm]	[rpm]	[rpm]	[rpm]	[rpm]	[rpm]
0.5	606	580	589	567	574	591	582	579	573	607	585
1	2193	2216	2223	2205	2204	2182	2192	2208	2181	2178	2198
1.5	3654	3648	3639	3628	3640	3627	3631	3632	3644	3622	3636
2	4182	4144	4136	4137	4161	4154	4154	4134	4155	4180	4154
2.5	5948	5966	5964	5936	5939	5958	5939	5968	5950	5947	5952
3	6610	6629	6586	6603	6613	6633	6632	6595	6624	6622	6615
3.5	7515	7524	7500	7525	7529	7535	7530	7508	7513	7531	7521
4	8553	8557	8540	8569	8567	8532	8553	8558	8551	8541	8552
4.5	8933	8924	8929	8937	8938	8931	8913	8912	8910	8904	8923
5	9086	9125	9076	9096	9081	9099	9097	9090	9091	9118	9096

By applying polynomial interpolation to the measured points a mathematical relation expressing the frequency of rotation "n" dependency of pressure "p" is achieved. This relation, a second order algebraic equation, is presented below.

$$\mathbf{n} = -259.89 \times \mathbf{p}^2 + 3356.9 \times \mathbf{p} - 1006.9 \qquad (1)$$

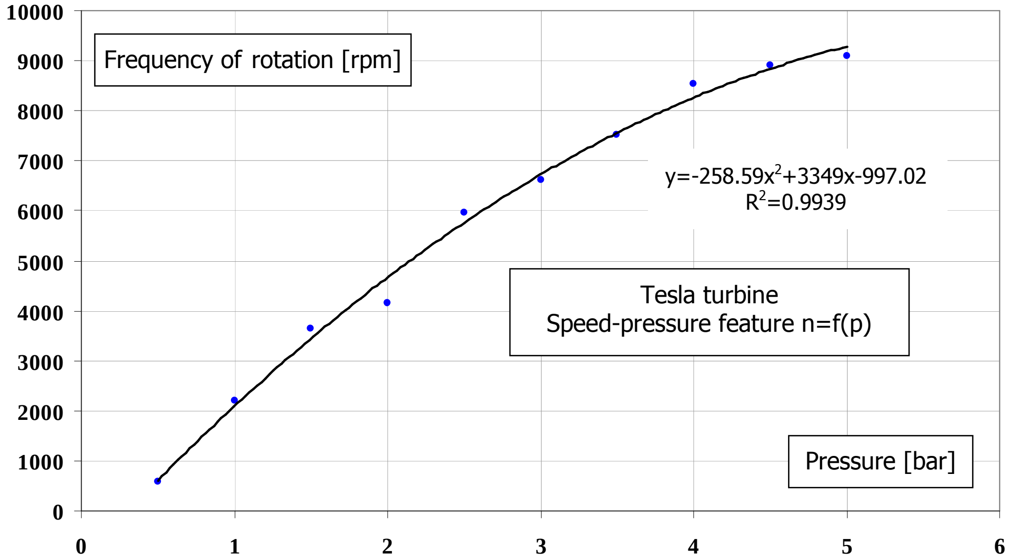

Figure 3. Frequency of rotation vs. pressure graph

Relation (1) shows that increasing the pressure an increased frequency of rotation is obtained; however, for high pressure values the frequency of rotation growth rate decrease.

2. Analysis of the dynamic regime

An interesting aspect of the use of Tesla turbines is the dynamic regime. To make investigations about this aspect an experimental setup was designed, aiming to find the correlation between frequency of rotation and the level of vibration resulted in the casing. Since the frequency of rotation was measured again with the PCE – DT62 tachometer, for measuring the vibration features as natural frequencies and amplitudes NI equipment was used [4], composed by:

- laptop Toshiba Satellite A20 – 16G;
- NI cDAQ-9172 compact chassis;
- NI NI 9234 module;
- Kistler accelerometer 8772A5 10G.

In addition, a virtual instrument in the LabVIEW environment was designed [6], in order to assure accurate evaluated frequency values. These values are obtained by applying an algorithm that evaluates the natural frequencies after an iteratively signal length crop [7]. In Figure 4 the first natural frequency is represented as an overlapped spectrum, the value being indicated at the intersection of the horizontal and vertical cursor lines in the zoomed picture. Having a look on the mentioned figure, one can remark the high accuracy achieved by reading the frequency; at least two digits after the unit are involved in the frequency value.

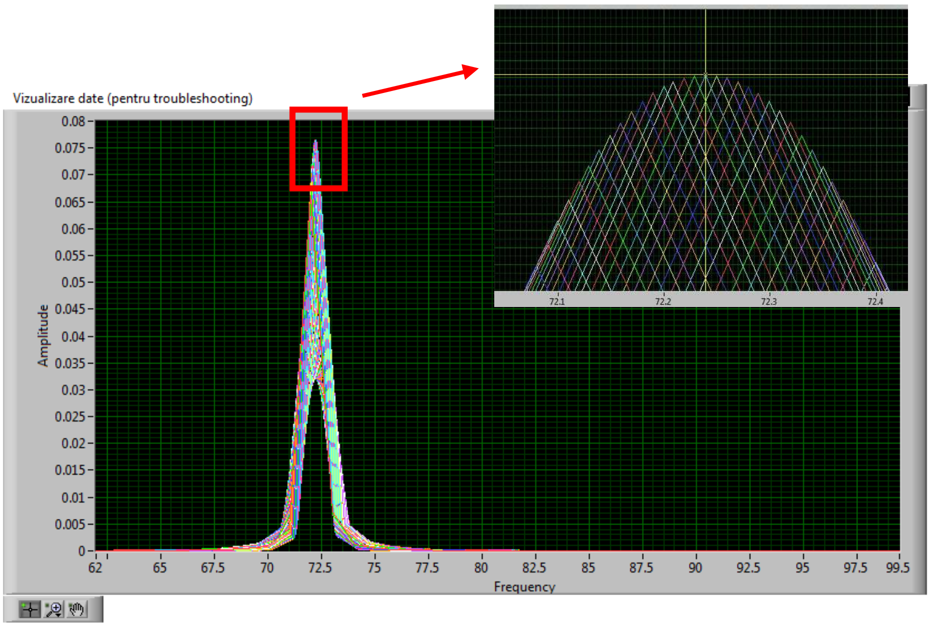

Figure 4. First natural frequency achieved by involving the pre-processing algorithm for the input pressure of around 2 bars

The natural frequency of the superior modes is shown in the spectrum depicted in Figure 5. It is obvious that the values are multiples of the fundamental frequency. A more detailed picture about frequency evolution is obtained if more measurement points are used.

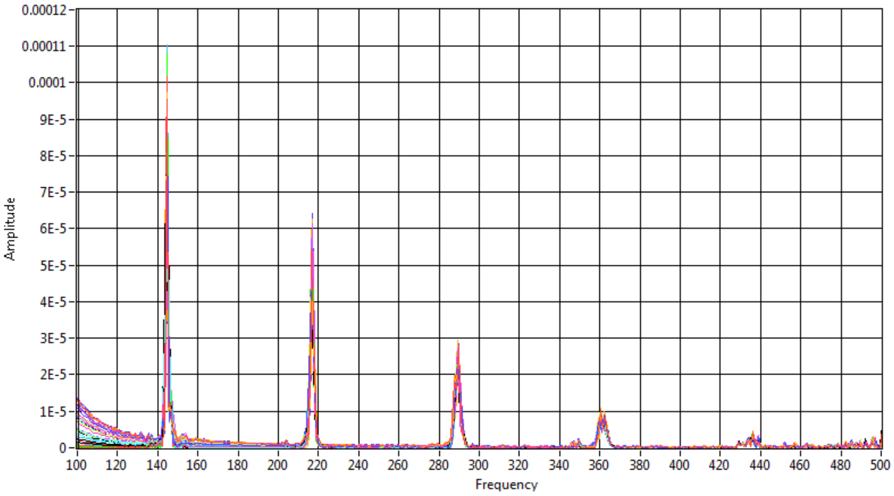

Figure 5. Frequency spectrum depicting the superior vibration modes

In the tables 2 and 3 are provided results of two test stages. In both of them the input air pressure was decreased from around 5 bars and the frequency of rotation was measured via the PCE – DT62 tachometer. At the same time the vibration signal of the turbine housing was acquired using the above described equipment. For the signals the power spectral density PSD was calculated applying the iterative truncation algorithm, and the overlapped spectra represented for all measurement cases. Afterwards, the fundamental frequencies and the corresponding amplitude were extracted.

Table 2. Frequency-amplitude pairs achieved by vibration measurements – test 1

Measured frequency of rotation	Frequency	Estimated frequency of rotation	Difference	Amplitude
n_{tacho} [rpm]	f [Hz]	n_{estim} [rpm]	ERR [rpm]	a [g]
6000	101.1190	6067	67	0.30110
5500	90.0080	5400	-100	0.20490
5000	80.8300	4850	-150	0.12040
4500	72.2289	4334	-166	0.07655
4000	64.0496	3843	-157	0.04271
3500	56.3135	3379	-121	0.02810
3000	47.4878	2849	-151	0.00926
2500	40.5788	2435	-65	0.00229

Table 3. Frequency-amplitude pairs achieved by vibration measurements – test 2

Measured frequency of rotation	Frequency	Estimated frequency of rotation	Difference	Amplitude
n_{tacho} [rpm]	f [Hz]	n_{estim} [rpm]	ERR [rpm]	a [g]
5700	93.0486	5583	-117	0.42882
5000	81.5067	4890	-110	0.22296
4500	74.5099	4471	-29	0.17317
4000	64.8713	3892	-108	0.06760
3500	56.2213	3373	-127	0.06360
3000	47.7851	2867	-133	0.05110
2500	39.4533	2367	-133	0.01270

Figure 6 gives a visual representation of the values indicated in tables 2 and 3. First it has to be remarked that the measured frequency of rotation and the estimated one present low differences, defined by the concordance of the acquisition moment in time. Then, analyzing the dependency of the amplitude on the values of frequency clearly results that the higher the frequency, the higher the amplitude is. This should point out the future investigation directions regarding the Tesla turbine, namely the diminishing of vibration amplitudes especially for higher pressure (i.e. frequency of rotation).

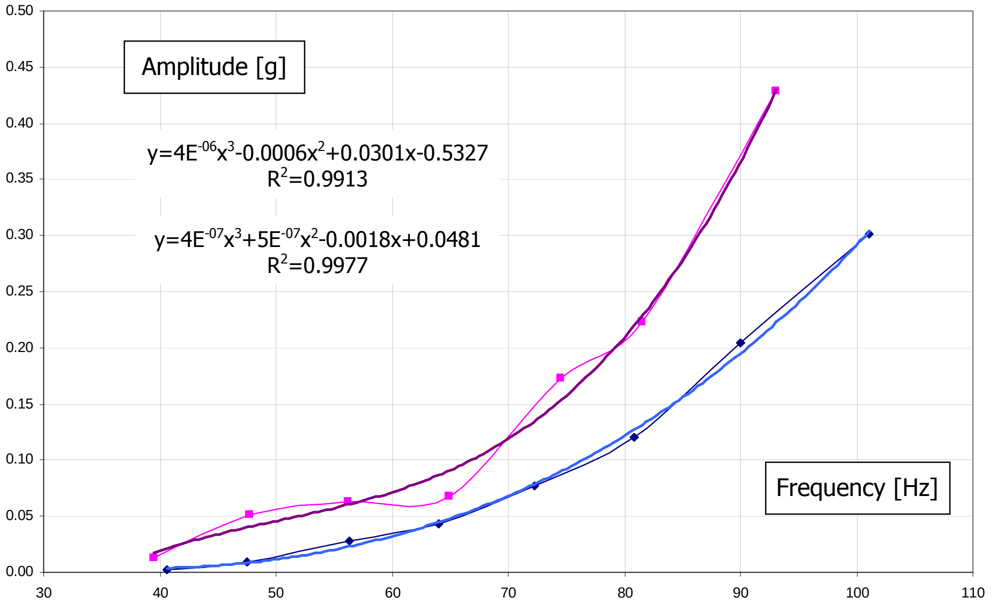

Figure 6. Fundamental frequency-amplitude pairs for different input pressures

In the authors' opinion, two possible ways to reduce vibration amplitudes are feasible: (*) to increase the rigidity of the turbine blades and/or casing; (**) to optimize the direction and shape of the air admission and evacuation shaft.

3. Conclusions

The researches presented in this paper shown that the Tesla turbine has a simple structure, being therefore robust and reliable even in unfriendly environment. Herein compressed air was used as the driving agent, but also water or exhausted gases can be used as well.

As a main disadvantage of the turbine the vibration phenomena can be nominated; it occurs especially by high frequencies of rotation. It was shown that, by increasing the pressure, the frequency increases. However, the dependency was proved as non-linear; a variation of pressure at higher values has a lower effect on the frequency increase compared with a similar variation at low pressure.

Regarding the vibration amplitudes of the casing, these increase by pressure (i.e. frequency) increase. Diminishing the amplitudes is possible by adjusting the driving agent direction, in fact the angle under which the gas is injected in the turbine housing. Another way to reduce the vibration amplitudes is the casing stiffening. As future work, we will analyze the dynamic behavior of all turbine components, by measurements and simulation, in order to propose reliable solutions for the vibration control.

Acknowledgement

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