A MECHANICAL METHOD TO EXTRACT THE CORE AND WIRE LOSSES ON A SYNCHRONOUS GENERATOR

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***Abstract* –This paper presents a new method to extract the core and wire losses of a synchronous generator with permanents magnets. This method does not require the use of an auxiliary coil to include the wattmeter and instead of that, a dynamometer and a tachometer were used. Open and short circuit tests were performed on the generator, allowing the core and wire losses extractions. The open test was made using the hydraulic installation's power generator through a Pelton turbine of 320mm, targeting to extract the core losses (Foucault, hysteresis, ventilation and friction losses). Based on the experimental results, it was possible to observe a quadratic variation of core loss as a function of rotation, according the literature. The short circuit test was conducted with a low rotation and a high torque, and for that it was necessary the use of a rotation reducer. In that way, the friction and ventilation losses could be disregarded resulting only in the wire losses.**

***Keywords* – Core and wire losses, synchronous generator, method**

INTRODUCTION

The synchronous machine used in this work is composed with permanent magnets on the rotor and windings in stator. The main advantage of this configuration is the absence of the exciter current, making it more economical than the machines constituted with the field winding. But, the absence field winding prevents the regulation of output voltage of the generator.

The transfer of rotor power to the stator, in case of synchronous machine, suffers energy loss due to heat dissipation in the ferromagnetic material core and wires. Through the open circuit it is possible to obtaining the core losses, hysteresis e Foucault [1-3], and the short circuit test defines the wire losses [4].

The hysteresis and Foucault losses are independent of the load and are practically constant for the same generated voltage and RPM [5]. However, the wire losses are a function of the current load requests, which is dependent on the operating condition of the generator[5].

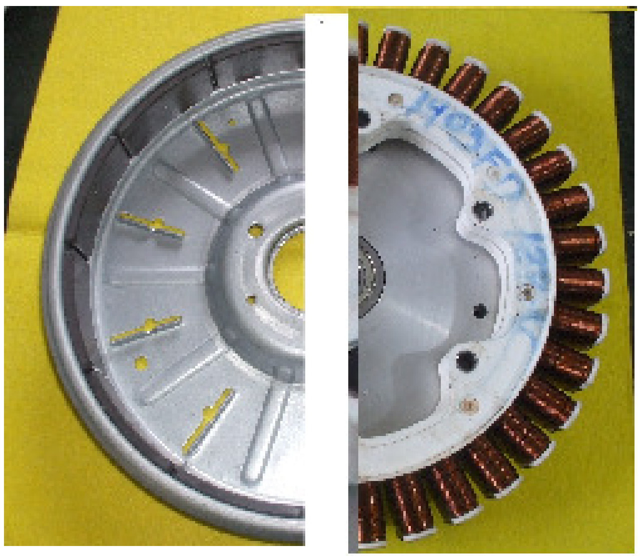
However in case of synchronous generators not is possible to make the electrical measure the power generated and losses, separately, it is possible to measure only the useful power.

In order to meet these losses, despising friction and ventilation, has been proposed a new experimental procedure without the use of the wattmeter. This new procedure provides, through mechanical action, to determine the equivalent circuit parameters of this synchronous machine.

I. EXPERIMENTAL SETUP

A. GENERATOR

This motor comprises a rotor consisting of 12 Magnets, and each of these magnets has 2 pairs of magnetic poles; three-phase stator with 36 coils and 12 per phase. With this combination, each revolution of the rotor can form twenty four cycles of a sinusoidal voltage. This type of engine was chosen because it is not necessary to multiply the rotation. Figure 1 presents the rotor and the stator of the wash machine.



(a) (b)

Fig. 1 – (a) Rotor and the (b) estator of the cloth wash machine.

The Figure 2 presents the generator already mounted. The three phases will generate an electrical open when the shaft is driven by a source of mechanical energy.

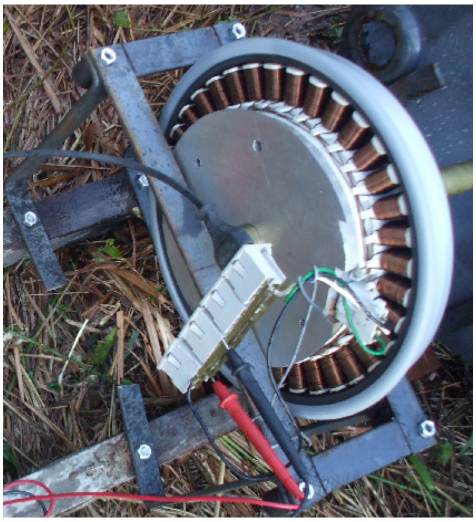


Fig. 2 – The generator already mounted.

B. TURBINE

The turbine will be the source of mechanical energy for the generator and for this a Pelton Turbine will be used. The shell model was based on literature [6]. The radius of this wheel after placement of the shells was with 0.16 meters. The Figure 3 shows that turbine assembled and ready to use.

Fig. 3 – The Pelton turbine that will be used in this work.

II. RESULTS AND DISCUSSION

A. Test Setup

1) Energy Water:

A waterfall of 22m, piped with fire hoses of 2.5 inches was used. Were used 25 hoses to total of 375m. It was used one 10mm nozzle. The figure 4 shows the layout of this hydraulic system.

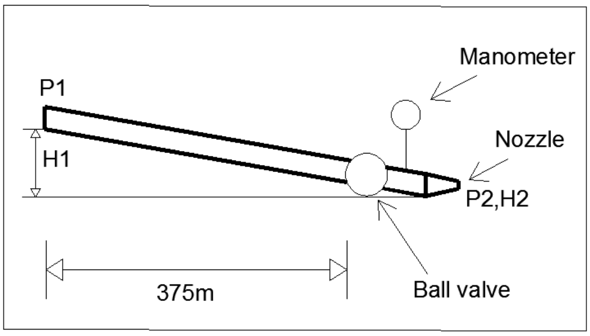


Fig 4. Layout of this hydraulic system used in the no load test.

The manometer registers a manometric height of 18m, which means a loss of 4 meter for this flow. The figure 5 shows the manometer with this reading.

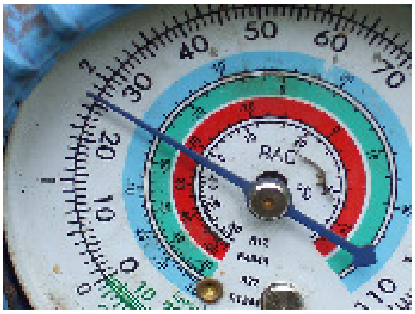


Fig. 5 – Manometric height measurement device attached before the nozzle.

For this configuration, the measured flow was 1.43l/s. For 7.8e-5m2 of cross-sectional area of the nozzle, the jet velocity was calculated from the equation (1).

$$V = \frac{Q}{S} = \frac{1,43}{7,8 * 10^{-5}} = 18,2 m/s \quad (1)$$

Using Bernoulli's equation (2) [6], which assumes a hole in the botton of the pipe instalation, with height h_1, h_2 e pressure p_1 e p_2. As shown in Figure 4.

$$\frac{1}{2}\rho v_1^2 + \rho g h_1 + P_1 = \frac{1}{2}\rho v_2^2 + \rho g h_1 + P_2 \quad (2)$$

For this case:

$$\frac{1}{2}\rho v_1^2 = \rho g h_2 \quad (3)$$

(3) therefore,

$$h_2 = \frac{1}{2}\frac{v_1^2}{g} = \frac{18,2^2}{2 * 9,8} = 16,73 m \quad (4)$$

This result indicates a manometric loss in the nozzle of 1,27m. Thus, the nozzle performance can be calculated as follows:

$$\eta = \frac{16,73}{18} = 0,93 \quad ou \quad 93\% \quad (5)$$

The energy as a function of the mass of a water column can be given by:

$$E = mgh \quad (6)$$

Dividing this expression by the time, result:

$$P = \frac{mgh}{t}, \quad with \quad \frac{m}{t} = \rho Q,$$

Therefore:

$$P = \rho Q g h \quad (7)$$

The water power coming out of the nozzle can be calculated by replacing the data in equation (8).

$$P = 1{,}43 * 9{,}8 * 16{,}73 = 234{,}45\,Watts \quad (8)$$

The water jet transfers hydraulic energy to the turbine, the turbine converts this energy into mechanical. The maximum performance occurs when the tangential speed of the turbine, in the case of the Pelton turbine, reaches the 0,455 of the jet velocity [6]. As the jet velocity is 18.2 m / s. The tangential velocity will be:

$$V_t = 0{,}455 * 18{,}2 = 8{,}28\, m / s \quad (9)$$

The tubina radius used in the test was 0.16 m. Thus one can calculate the RPM for maximum power:

$$N = \frac{V_t * 60}{2\pi R} = \frac{8{,}28 * 60}{2\pi * 0{,}16} = 494{,}2\,RPM \quad (10)$$

Table I - Open circuit test results.

Pot antes Do bocal	Pot do jat	Pot mec	RPM	Pu
H 18m	H16,73 m			
252W	234,45	160,16	524	76,45
	0,93	0,68		0,32
252W	234,45	168	505	78,9
	0,93	0,716		0,34
252W	234,45	161,7	465	81,7
	0,93	0,68		0,35

B. Open circuit test procedure

On open circuit test extract the mechanical power input that is based on the Foucault losses, hysteresis, ventilation and friction. The Fig.5 shows the equivalent circuit of the open circuit test used in this work. This test is easer than the short circuit test due to the star engine model, because in this case we only need to divide the voltage generated by √ 3, and at the same time it is possible to measure the force applied to the turbine housing in balance, on an arm of 79mm.

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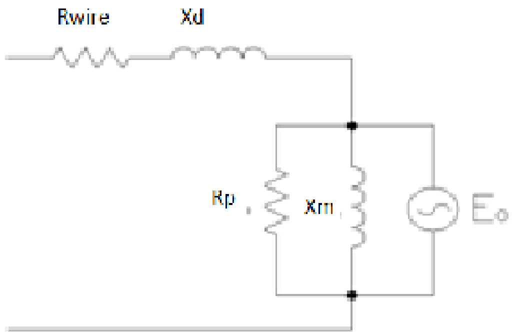

Fig. 5 - Electrical circuit diagram of the open circuit test used in one phase of the generator.

Where Eo is the generated voltage that is in function of the rotation, Rp is the resistance that represents the core loosed power (including Foucault and hysteresis). Rp was obtained with the aid of a digital dynamometer (included in the carcass swing of the generator) and rotation meter.

$$P = C\omega = F * b * \omega = F * b * 2\pi * N / 60 \quad (11)$$

Where:
C is the conjugate [Nm]
F is the force [N]
b is the arm where the force is applied [m]
N is the rotation [RPM]

The Figure 6 below presents a photography indicating the point of the carcass where the force was measured. In this same figure, it is possible to observed a reflector inserted on the rotor to assist in the optical measurement of rotations. To prevent that the carcass could stay in balance during the measurement, the pivot rotor has been extended for placement of a bearing.

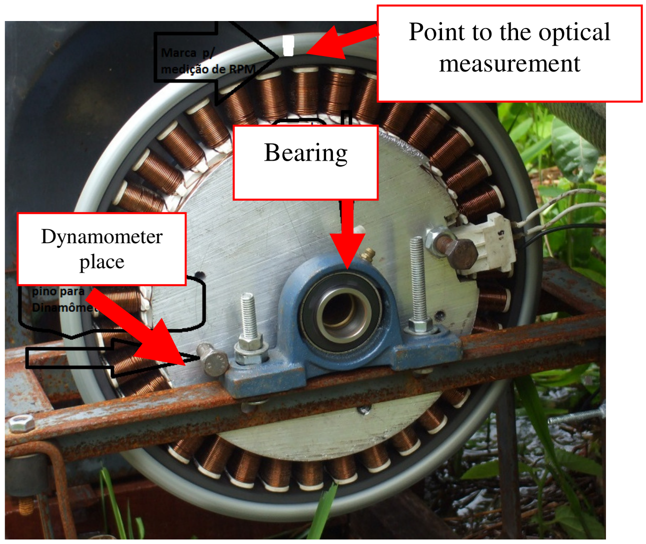

Fig. 6 –photography of the generator indicating were the measured was realized.

The mechanical power per phase can be extracted by the equation (12).

$$P_{mecF} = F * b * 2\pi * N/(3*180) \quad (12)$$

As a consequence the electrical power can be extracted considering 10% less than the mechanical power, due to the friction and ventilation, resulting in the equation (13):

$$P_{EF} = P_{mecF} * 0{,}9 \quad (13)$$

Finally, the losses resistance can be extracted through equation (14), and the result can be seen on Table II.

$$Rp = \frac{V_F^{\ 2}}{P_{EF}} \quad (14)$$

Table II - Open circuit test results.

F(kg)	N	C(Nm)	PmecF	PEF	Rp	VF
1,36	325,3	1,05	11,95	10,76	262,1	53,11
1,69	427	1,30	19,50	17,55	346,1	77,94
1,86	618,4	1,44	31,08	27,97	369,0	101,61
2,09	731	1,61	41,28	37,15	388,0	120,08

It is known from the literature that the iron losses for a given type of core can be extracted through equation (15) presented below:

$$P_{FE} = K_H * f + K_F * f^2 \quad (15)$$

Considering that K_H is the hysteresis losses constant and the K_F is the Foucault losses constant, keeping a constant flux, since it is generated by permanent magnets. Basing on that, through the Fig. 7, it is possible to observe that the iron losses curves as a function of revolution per minute shows a behavior of a second-degree equation.

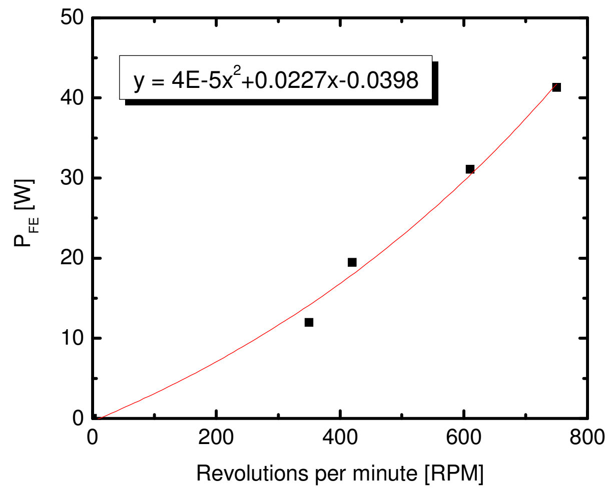

Fig. 7 – Curve of the P_{FE} as a function of the RPM.

C. Short circuit test procedure

The short test uses the same principle of the open circuit test, where the power is still measured by using mechanical power (W_1). As a very high torque is required, we built a reducer to be driven by an electric motor with high torque and low speed lift of approximately 500W. Fig. 8 shows the arrangement of the short circuit test procedure.

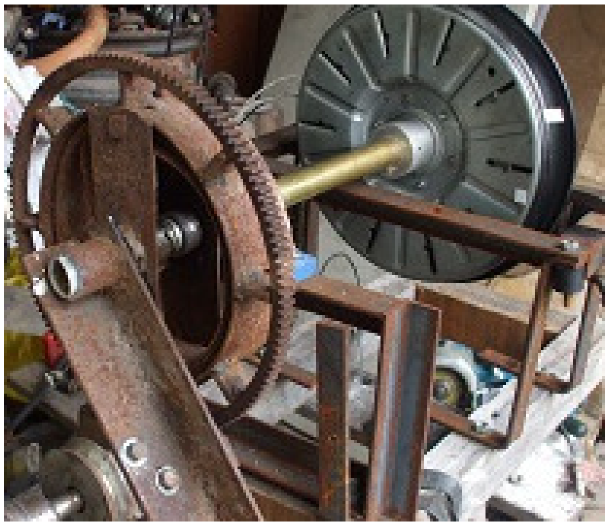

Fig. 8- Photography of the experimental setup of the short circuit test realized on the generator.

As the rotation is very low friction and ventilation losses aren't expected. We distributed in the rotor four reflectors to measure the revolutions per minute (N), multiplying the torque in that way. The three outputs of the generator were short-circuited and the current (Icc) was measured with clamp meter, not to unbalance phases. The table III shows the test results.

Table III - Short circuit test results.

N (RPM)	P (W)	Rcc (Ω)	Zf (Ω)	Xd (Ω)	C (Nm)	Icc (A)	F (Kgf)	Eo (V)	Vf (V)	Ld (H)
43	9,4	4,5	5,07	2,32	6,50	1,4	8,4	12,7	7,35	0,50
54	12,3	4,6	5,64	3,19	6,70	1,6	8,7	15,9	9,19	0,55
78	17,6	4,6	6,71	4,88	6,78	1,9	8,7	22,7	13,16	0,59
90	20,1	4,4	7,05	5,51	6,73	2,1	8,7	26,1	15,09	0,58
117	23,4	4,4	8,52	7,27	6,03	2,3	7,8	33,9	19,59	0,59
138	25,2	4,3	9,63	8,58	5,49	2,4	7,1	40,0	23,12	0,59

The line voltage Eo was extracted before the short be done. Through this value it was possible to extract the phase voltage (V_F) and finally calculated the phase impedance (Z_F). This impedance includes the dispersion (X_d) and the wire resistance (Rwire).

$$Rwire = \frac{P}{Icc^2} \quad (16)$$

$$X_d = \sqrt{Z_F^{\ 2} - Rwire^2} \quad (17)$$

The figure 9 shows the power and the torque as a function of the rotation. Despite the fall in torque with the increase in the rotation, the power continues to increase due to the increase of the rotation as equation (11).

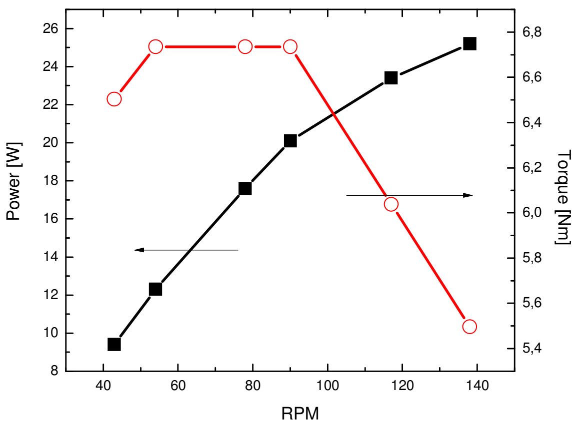

Figure 9 Power and the torque as a function of the rotation.

III. CONCLUSION

This paper presents a mechanical method for the extraction of electrical parameters of the equivalent circuit of a synchronous generator that uses permanent magnets. With the knowledge of the equivalent circuit parameters is possible to predict the synchronous generator performance when operating under load. In a hydraulic system, where the flow and the height of the water column are limiting factors, the knowledge about the core and wire losses is of fundamental importance. Only in this way, it is possible to calculate the optimum rotation of the generator and the turbine diameter, as a function of battery voltage, to obtain the maximum performance from the system. Therefore, the use of the proposed method in this paper facilitates the design of the turbine without the use of rotation speed reduction drive systems, reducing losses and the cost of installation.

IV. REFERENCES

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