Active Noise Control Proposal for Rotating Machines

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ABSTRACT

Rotating machines are absolutely used in many engineering tasks, such as “Energy transmission” given by compressors, turbines, pumps. However, these machines produce high decibels of noise, for this reason is necessary to attenuate noise by many mechanisms as passive criterion, but that can not get good response under low frequencies domain or under disturbances.
Therefore, in this research is proposed an active mechanism supported by “Least Mean Square” (LMS) strategies to get noise attenuation in 3-dimension space, furthermore a “Vibration Control Analysis” by sensors based in nanostructures.

Keywords: Active Noise Control (ANC), nanostructures.

1. INTRODUCTION

The join between rotor’s motor with different machines like “rotating machines” generates specific problems as noise and vibration. It is accepted to work among 30dB to 40dB. Nevertheless, rotating machines furthermore connector devices with engines or source movement are noisier than this allowed range of noise; for this reason, it is applied many mechanisms according to attenuate noise values that usually are around 80dB

One successful criterion is given through using noise and vibration materials. Notwithstanding, it can get good results under high frequency, as for example sound or vibration around 5kHz can need passive materials with thickness a bit more than 6 cm, but in low frequency like 50 Hz, the thickness passive material can be near 7 meters. Therefore, in this work is proposed to not work only by passive or active noise cancellation, it means to analyze also the source of sound: “vibrations” obtained because of “rotational movement transmission” inside motors or machines that need movement transmission.

Otherwise, in this work it was achieved noise cancellation by ANC strategies based in LMS correlated with vibration analysis from movement’s source. In order to sense vibration [12], it was designed sensor based in Anodic Aluminum Oxide (AAO) by anodization and electropolishing because of getting nanoholes over aluminum surface and configuring as transistor model. For this reason, vibration signal was obtained and correlated with sound signal in the main noise cancellation algorithm due to achieve noise attenuation around 10 dB.

2. ACTIVE NOISE CONTROL (ANC)

In general description, a mathematical model to represent pressure effect as noise can be summarized by equation 1, which is a Feynman form for 3-dimension wave equation to describe energy transmitted as pressure in air changes over space. Its solution is usually a harmonic function, that proportionate much information to analyze sound, also the anti-noise signal expected in order to achieve noise attenuation. For this reason, in equation 1, P represent pressure level source in air as dependence of position r and time t, and q means pressure level in air as consequence of changes in source p, by this way is theoretically represented noisy (pressure level change in air) in 3D space.

$$\frac{1}{C^2}\frac{d^2(P(x,t))}{dt^2} - \nabla^2\big(P(x,t)\big) = q(x,t) \qquad (1)$$

However, in this research is proposed nanostructure effects according to enhance adaptive coefficients calculation, which have information of the system to get noise attenuation. Therefore, it was analyzed sensors/actuators based in nanostructures, that have transistor behavior. It means as described by equation 2. For which, Ic represents “collector current”, Vb, Ve are electrical voltage to activate transistor, furthermore Rb and Re are their electrical resistances.

$$I_c = \frac{V_b - V_c}{R_b} + \frac{V_e}{R_e} \qquad (2)$$

That can help to explain nanostructure behavior as sensor/actuator based in transistors as it described through equation 3[17], for that I_D is equivalent to electrical collector current, V_{GS}, V_{th}, V_{DS}, are the voltage to warrant transistor behavior for a group nanostructures with geometrical parameters correlated with electrical parameters(that depends of material sample which support of the sensor designed) as given by “μ, C and L” in order to get that the sample composed by nanostructures as described with equation 3, [17].

$$|I_D = \mu \frac{C}{L^2}(V_{GS} - V_{th})V_{DS} \quad (3)$$

That means that samples based in nanostructures can be a good support to elaborate sensors which can get faster response time and robustness under different mechanical disturbances. For this reason, in this work it is proposed to integrate vibrations analysis, based nanostructure sensors (due to high geometrical order of them give good stability in physical and optical variables of them), with active noise control algorithm applied to rotating machines owing to noise cancellation needs high precision during adaptive algorithm strategies to send antinoise signal. Noise produced in big frequency domain is coupled with environment noise around its source even though it is produced in general owing to its vibration (characteristic behavior of rotating machines like turbines, compressors and pumps).

1. Adaptive FXLMS algorithm

Noise Cancellation can be achieved by error analysis such as given through following equation 4 with recurrence behavior because to describe error adaptation as algorithm, in which W represents the weight at instance “n”, μ means weight coefficient, X is the input signal (not filtered yet) furthermore “E” is the error.

$$W(n+1) = W(n) + \mu X(n)E(n) \quad (4)$$

That equation is known as “Least Mean Square (LMS) algorithm”. That is described in following flowchart, in which it is looked for correct calculation of “weights matrix”, for this reason, it was proposed that though interruptions to get every component of the weight matrix; as a summary of an “online identification of physical parameters” as it was proposed by [2], [16] when identification is part inside of the main control algorithm. Therefore, in the algorithm described by the flowchart of figure 1, the proposal is to get continuous inspection in order to get noise cancellation when any kind of noise disturb the system

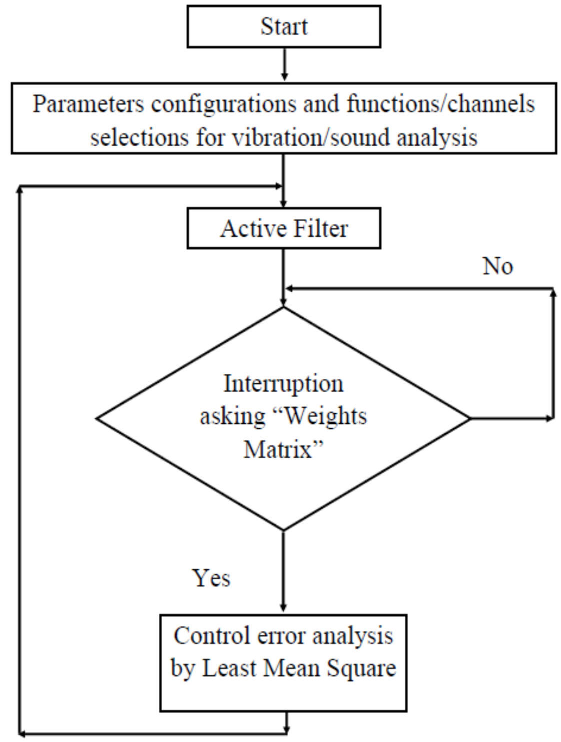

Figure 1. Algorithm description flowchart.

Notwithstanding, in order to enhance active noise cancellation, it is suggested to analyze vibration of the main source of sound, that is achieved by vibration sensor; therefore, sound noisy information can be correlated with vibration signal to focus the antinoise signal necessary to attenuate the noise.

3. EXPERIMENTAL ANALYSIS

It was necessary elaborate samples based in Anodic Aluminum Oxide (AAO) owing to study transistor properties to capture vibration, as it is depicted in figure 2, in which is shown a vibration sensor (left side) proposed by ARDUINO company, also it is shown the sample based in AAO, that was more robust to capture vibration as electrical voltage transduction in linear approximation range of work that was enough to get comparisons for rotating machines speeds between 100RPM to 1200RPM.

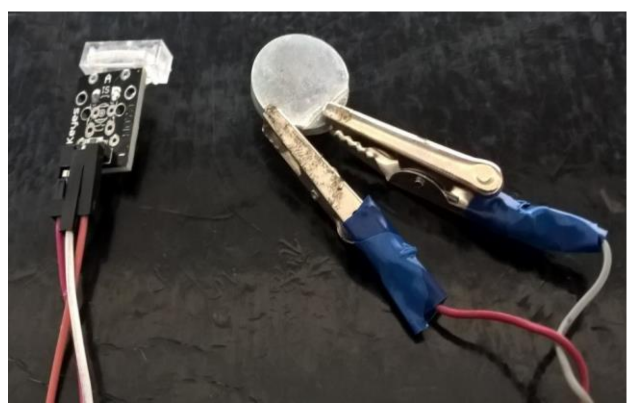

Figure 2. Vibrations sensors

Nevertheless, it was necessary to verify whether it was achieved nanostructure devices inside the sample surface.
Therefore, it was used a scanning electron microscopy (SEM) of Pontificia Universidad Católica del Perú and shown nanoholes or nanopores depicted in figure 4, from which can be seen holes with diameters in nanoscale.

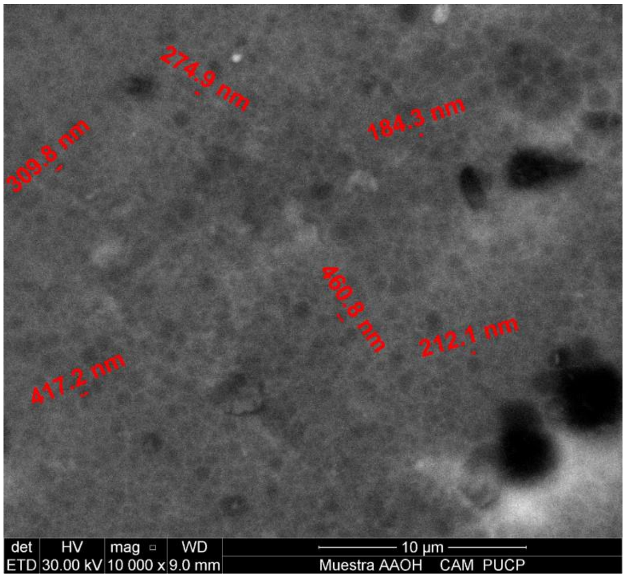

Figure 3 AAO Surface over the sample.

In figure 4 is depicted an extension view of figure 4, because of to check nanoholes obtained after electropolishing and anodization process made to get them.

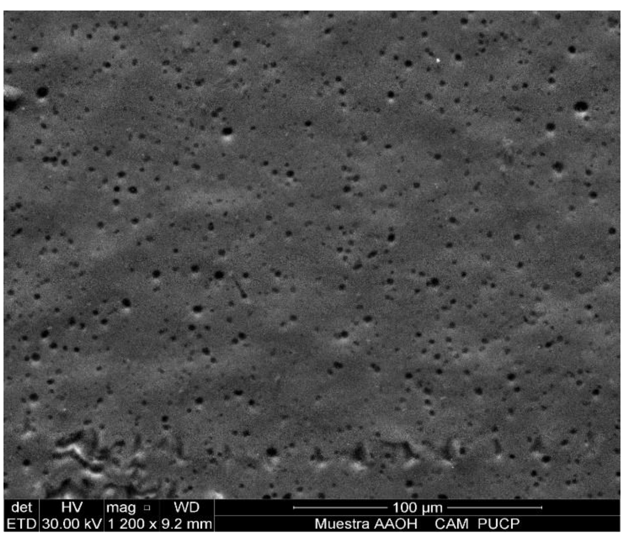

Figure 4. Extension view of figure 3.

In this context, it is summarized physical variables from every nanohole through "Tensor analysis calculation" as given from equation 5, it because to work with a mathematical support to store information of every instant needed to capture sound and vibration signal. For which ¯A, A mean the vector and scalar fields correlated through their derivative changes ¯X , X as described for every components "i and j'.

$$\bar{A} = \frac{d\bar{x}_i}{dx_1} A_j \tag{5}$$

Otherwise, equation 6 joins every sensor information for quantity of captured data "n", that sensors information can be correlated later by a LMS algorithm (such as vibration and sound).

$$\begin{pmatrix} \bar{A}_1 \\ \bar{A}_2 \\ \bar{A}_3 \\ \vdots \\ \bar{A}_n \end{pmatrix} = \begin{pmatrix} \frac{\mathrm{d}\,\overline{x_1}}{d\,x_1} & \frac{\mathrm{d}\,\overline{x_1}}{d\,x_2} & \cdots & \frac{\mathrm{d}\,\overline{x_1}}{d\,x_n} \\ \frac{\mathrm{d}\,\overline{x_2}}{d\,x_1} & \frac{\mathrm{d}\,\overline{x_2}}{d\,x_2} & \cdots & \frac{\mathrm{d}\,\overline{x_2}}{d\,x_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{\mathrm{d}\,\overline{x_n}}{d\,x_1} & \frac{\mathrm{d}\,\overline{x_n}}{d\,x_2} & \cdots & \frac{\mathrm{d}\,\overline{x_n}}{d\,x_n} \end{pmatrix} \begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_n \end{pmatrix} \tag{6}$$

For which, as consequence error analysis as proposed through equation 7 can be achieved, where $\bar{E}$ is matrix error, $\bar{D}$ is the matrix of desired signal and $\bar{\gamma}$ is the matrix of the effect of antinoise signal produced by LMS as consequence to correlate it is changes "S".

$$\bar{E} = \bar{D} - \frac{d\bar{s}_i}{ds_1} \gamma_j \tag{7}$$

That means, in general expression as described by equation 8,

$$\begin{pmatrix} \bar{E}_1 \\ \bar{E}_2 \\ \bar{E}_3 \\ \vdots \\ \bar{E}_n \end{pmatrix} = \begin{pmatrix} \bar{D}_1 \\ \bar{D}_2 \\ \bar{D}_3 \\ \vdots \\ \bar{D}_n \end{pmatrix} - \begin{pmatrix} \frac{\mathrm{d}\,\overline{s_1}}{d\,s_1} & \frac{\mathrm{d}\,\overline{s_1}}{d\,s_2} & \cdots & \frac{\mathrm{d}\,\overline{x_1}}{d\,s_n} \\ \frac{\mathrm{d}\,\overline{s_2}}{d\,s_1} & \frac{\mathrm{d}\,\overline{s_2}}{d\,s_2} & \cdots & \frac{\mathrm{d}\,\overline{s_2}}{d\,s_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{\mathrm{d}\,\overline{s_n}}{d\,s_1} & \frac{\mathrm{d}\,\overline{s_n}}{d\,s_2} & \cdots & \frac{\mathrm{d}\,\overline{s_n}}{d\,s_n} \end{pmatrix} \begin{pmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \vdots \\ \gamma_n \end{pmatrix} \tag{8}$$

Therefore, the antinoise signal effect over the noisy signal "X" as dependence of weights matrix "W" is represented by equation 9.

$$\bar{\gamma} = W_i^T X_i \tag{9}$$

So, it is necessary a setup configuration for experiments as described in figure 5. For which, is represented as engine the rotating machines, the microphone, the vibration sensor, loudspeaker, controller and computer system.

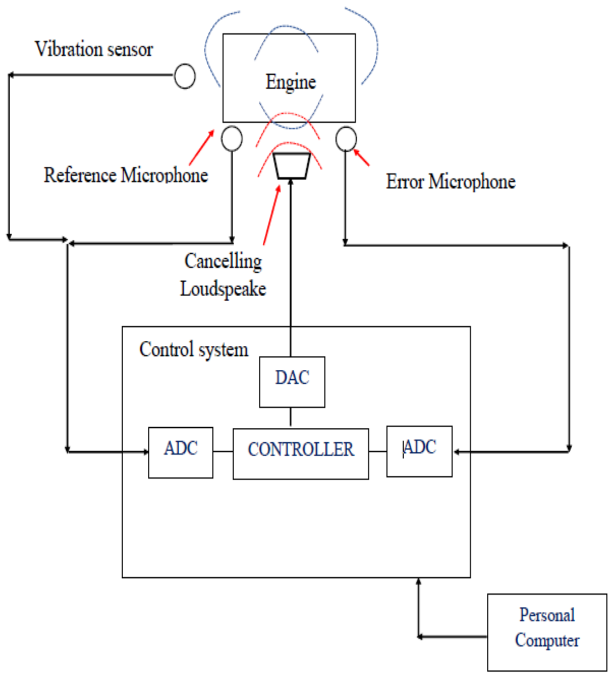

Figure 5. Setup configuration.

For which, finally, it is proposed ANC through vibration and sound analysis, furthermore an enhancement given by sensors/actuators based in nanostructures [2], [10], [16]. In figure 6 is shown a noisy signal achieved in voltage (blue color curve) which equivalence in dB was 72, also its noise cancellation based in vibration measured by nanostructure sensor and correlated with ANC (red color curve) that equivalence in dB was 63. This decibels values were calculated by SPL from voltage values described in figure 6.

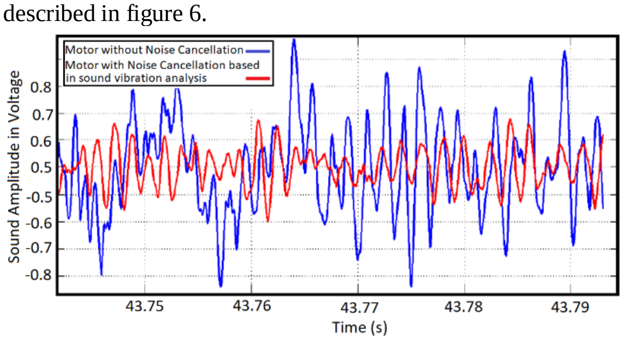

Figure 6. Experimental test in time domain for a DC motor joined to an Active Magnetic Bearing System.

Finally, it was analyzed frequency domain range of work, in order to compare vibration and sound correlation as consequence to look for both variables cancellation, as it was looked for in decibels. For this reason, in figure 7 is depicted vibration signal (blue color curve), sound signal (red color curve), from both is possible to verify that sound signal get more decibels than vibration signal (but not in resonance point) due to reflection and refraction wave effects.

Furthermore, it is shown in figure 7 ANC effect (green color curve) that is more intense in power spectral density than ANC correlated with vibration signals cancellation (yellow color curve) which is a very good advantage shown in this work, also around resonance values.

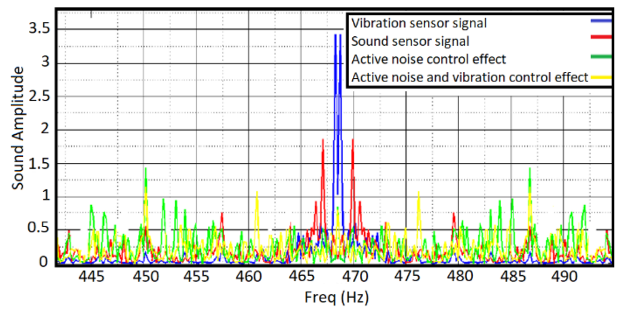

Figure 7. Frequency domain experimental comparisons.

4.CONCLUSIONS

It was obtained noise control and attenuation through noise and vibration from rotor machines systems, it because source produced was correlated with noise in order to optimize control noise cancellation.
It was improved adaptive coefficients achieved by Active Noise Control algorithm designed, as a consequence to use sensors/actuators based in nanostructures.

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