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Experimental Modal Analysis of Electrical Submersible Pump Using 3D Scanning Laser Doppler Vibrometer

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Abstract: This paper presents a study of the dynamic properties of a nine-stage electrical submersible pump. The dynamic properties were estimated by means of the experimental modal analysis technique using a 3D scanning laser Doppler vibrometer (3D SLDV) to determine the vibratory responses. Initially, by starting from the numerical model and experimental modal analysis of an aluminum plate, it was possible to see good consistency between the numerical and experimental results. Based on this methodology it is intended to demonstrate conformity of the experimental results obtained for the pump.

Keywords: Experimental Modal Analysis, 3D Scanning Laser Doppler Vibrometer, Electrical Submersible Pump.

INTRODUCTION

In the field of petroleum production, the electrical submersible pumping (ESP) is one of the most used artificial elevation methods in the industry (Foresti, 2014). Through this method a multistage submersible centrifugal pump, in addition to other necessary equipment that makes up the method, is used to pump the fluid from the reservoir to the surface for further processing. Figure 1 shows a schematic of this artificial elevation method with its main equipments, on the left side and illustrates also an electrical submersible pump with some of the its main internal components, on the right side (Baker Hughes, 2009).

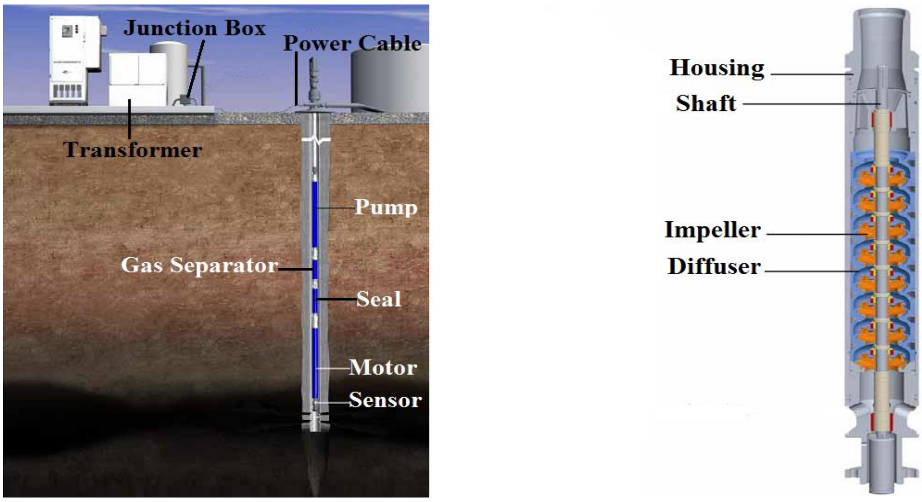


Figure 1 – ESP system equipments and pump components.

Regardless of the mechanical system, it is desirable to perform a numerical, analytical or experimental study of its dynamic behavior in order to obtain a mathematical model that describes it in terms of its matrices of physical properties, mass matrix, stiffness and damping or in terms of its dynamic properties; that is, their natural frequencies, damping rates and modes of vibration (Ewins, 2000). Once in possession of these properties it is possible to predict the dynamic behavior of the system under certain operating conditions. In this way, it is possible to act on the system or its components by applying substructuration techniques, determining its dynamic response under a given load, among others. It is through the technique known as experimental modal analysis that the dynamic properties of a structure can be extracted (Maia et. al, 1997). Within the context of instrumentation for modal test, the laser Doppler vibrometer is one of the equipment that has been applied to measure the vibratory response of the test structure as can be seen in the works of Ewins et al. (2014), Mendes Souza (2014), Braga (2014). Figure 2 exibt the 3D SLDV used in the present work to read the vibratory responses. It consists of a modern non-contact measuring system that measures the vibration velocities of a point on the surface of the test object in the three orthogonal directions; i.e., components in-plane and out-plane.

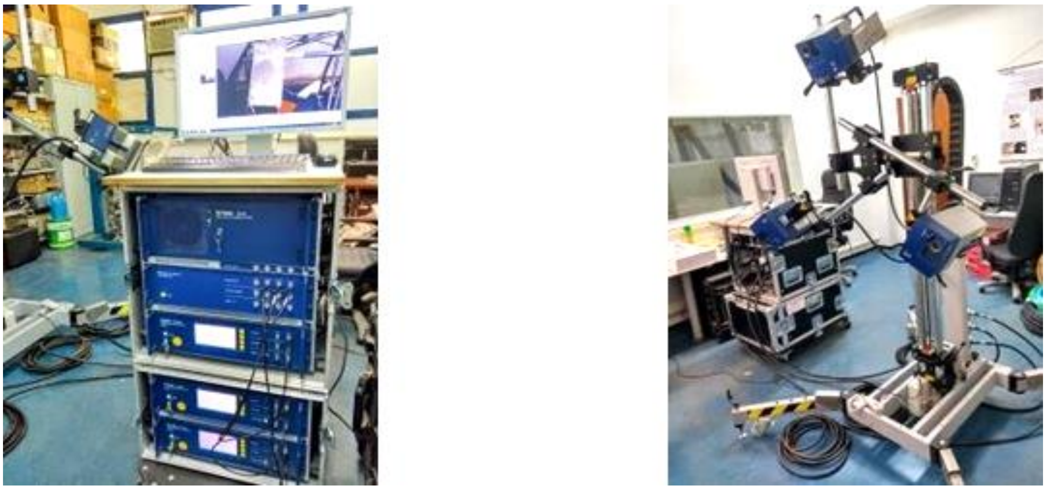


Figure 2 – Signal acquisition and processing system, on the left and laser scan heads, on the right.

Basically, the execution of the modal test consists of exciting the test object with an impact hammer or electrodynamic shaker. Usually the object is suspended by very flexible springs but can be simulated in the grounded condition. Into analyzer the excitation (input) and vibration response (output) analog signals are digitized and transformed to the frequency domain by the fast Fourier transform algorithm, a process known as sampling. After sampling, the frequency response functions (FRFs) of the system are estimated, functions that express the ratio between input and output of the system. The FRFs contain the system dynamics information and are the input data for the modal parameter identification algorithms. This work intends to identify the flexural modes of a submersible centrifugal pump model, out of operation, such a pump model will operate in the experimental bench of BCS mounted in the Dynamic Testing Laboratory (Labedin), located at UNICAMP.

EXPERIMENTAL PROCEDURES

To certify the operation of the test equipments, and especially the quality of the measurements of the vibrometer, it was appropriate to divide the experiment in two measurement steps. In first step the experimental modal analysis of an aluminum plate (0.458mx0.235mx0.001m) in the frontal position with respect to the scanner heads was carried out. The purpose is to evaluate the functionality of the 3D SLDV through the comparison with an FE model of the plate. In the preparation of the test, 55 measurement points were initially scored uniformly distributed over the surface of the plate to represent the rectangular surface. After the marking of the measurement points, developer spray was applied as an alternative way to improve the signal-to-noise ratio. The second step comprehend the experimental modal analysis of the pump. For the visualization of the modes of the pump only 1/4 of its surface was used due to its axis symmetry and, therefore, retro-reflective tape was applied in that part of the surface. The use of retro-reflective tape is another alternative form that greatly improves the signal-to-noise ratio. The plate was suspended by a pair of elastics while the pump was suspended by steel wire ($3.175 x 10^{-3}$m, in diameter) both suspensions simulating the free-free condition. Figure 3 shows the support of the test structures together with the coupling of the excitation source, an electrodynamic shaker.

Figure 3 – Preparation of test structures for measurements.

Table 1 show the measurement signal acquisition informations for both plate and pump.

Table 1 – Signal acquisition information

Bandwidth	0 to 1000 Hz	Excitation signal	White noise
Low-pass filter cutoff frequency	850 Hz	Windows	Hanning
Sampling frequency	256 kHz	Averaging	50
Sampling time	32 s	Overlap	75%
Resolution	31.25 mHz	Reference and excitation	Free end

RESULTS AND DISCUSSION

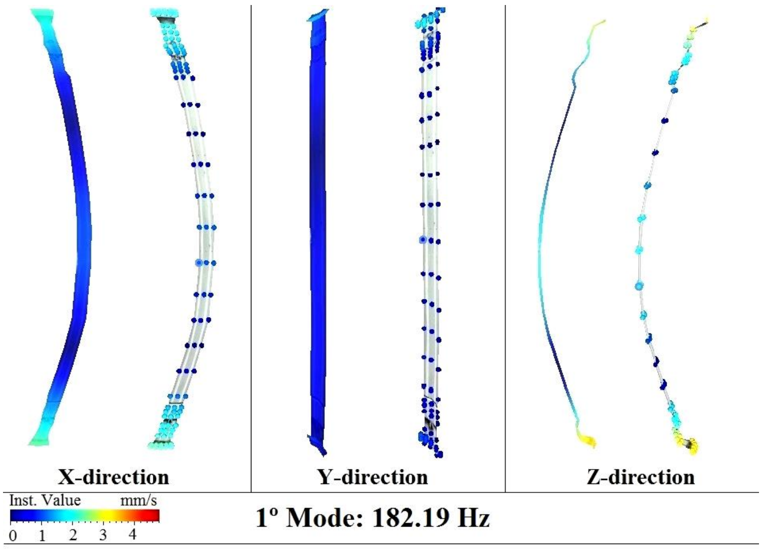
The numerical simulation of the plate was performed in the ANSYS using the following parameters: aluminum material, E = 71 GPa, ν = 0.33, ρ = 2770 kg/m^3, 180 square flat elements. To extract the dynamic or modal properties of the tested plate and pump, the corresponding FRFs were processed into the modal analysis directory of LMS Test.Lab software. In this directory, the modal parameters were estimated through the PolyMAX estimator that automatically selects the physical poles of the system. The numerical and experimental results for plate can be seen in Tab.2 being the percentage error calculated in relation to the numerical results.

Table 2 – Numerical and experimental results for the first five modes of the plate.

Modes	Numerical [Hz]	Experimental [Hz]	Error [%]
1º mode	26.94	26.76	0.67
2º mode	31.64	31.70	-0.19
3º mode	72.94	73.71	-1.06
4º mode	121.26	122.28	-0.84
5º mode	307.55	306.24	0.43

Based on the results obtained for the plate it is possible to attest good quality of the measurements made by the 3D SLDV. Regarding the type of preparation of the measuring surface, the use of reflective tape proves to be more effective in comparison with the use of developer spray for reduction of the signal-to-noise ratio. This can be verified by measuring the drive point because the FRFs of this point have particular characteristics.

Considering the pump were defined 111 scan points by means of the vibrometer software. The first three modes of flexion in the x, y (in-plane) and z (out-plane) directions are shown in Fig.4. In order to obtain some longitudinal mode, a further measuring cycle was conducted with excitation at 45 degrees respect at the surface of the pump, but the desired result could not be obtained.



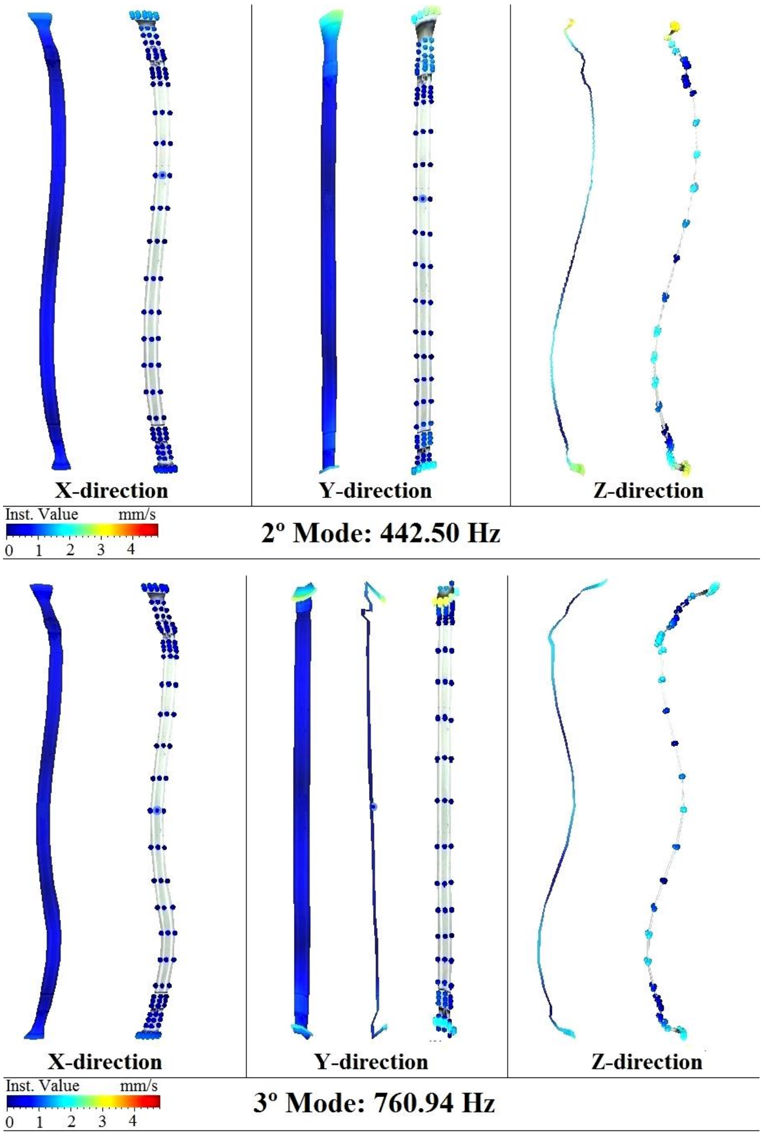


Figure 4 – Experimental results for the first three bending modes of the pump.

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