

DYNAMIC PERFORMANCE APPLICATION OF A VARIABLE SPEED CENTRIFUGAL PUMP

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ABSTRACT

The need to match fluctuations in the flow rate demand and control energy costs in pumping system arise the range of using Variable Speed Drives (VSDs). These drives improve performance of pumping system and allow them to operate efficiently and hence saving energy. Tests were done on a variable speed centrifugal pump unit at different operating speeds ranged from 25Hz to 50Hz. Forced vibration test was done to determine vibration levels and exciting frequencies at different operating speeds. Experimental modal testing and operational modal analysis were done at different condition to simulate the design, installation, and operation cases. Dangerous rotating speeds were determined to avoid operating at resonance conditions.

Keywords: variable speed pumps, dynamic performance, vibration, centrifugal

1. INTRODUCTION

In most of water pumping stations, the speed of the pumping system is approximately constant with controllable flow rate to match the load demand. This water load demand is fulfilled by the traditional control methods such as throttling valves or bypass techniques to change the operating condition in the pumping system by increasing the system's backpressure or resistance to flow. This increase in pressure or head requirements shifts the pump's operating point to the left along its performance curve, and, typically, away from its best efficiency point.. It is confirmed whoever, that these methods rise energy losses and hence bad efficiency performance over the range of operation, Stefan M. Abelin [1]. It should be admitted that a variety of approaches can be considered to eliminate the traditional control losses and reduce the electrical energy consumption of water pumps. It is believed now that the most appropriate and most economic way for improving water pump performance is the variable speed drive (VSDs), Howard, G., and Murphy, P.E [2]. Pumping units when driven by VSD, will have a flexible adjustment and monitoring for pressure and flow over a very wide range of operation. In addition the VSD will improve the performance of pumping unit and allow the pump to operate as near as possible to its maximum efficiency and hence saving energy over the required range of field operation. (VSDs) adjust motor speeds driving the pump to mach fluctuations in flow. In addition to energy savings, (VSDs) offer precise speed control and a soft-starting

capability, Abu-Zeid, M. A [3]. each control technique of course has its merits and demerits so; (VSDs) also have some potential drawbacks which can be avoided with appropriate design and application. Resonance problem is the most seriously drawback of the (VSDs). It can cause excessive vibration levels, which in turn are potentially harmful to equipment and environment. For (VSDs) applications, the excitation frequencies become variable and the likelihood of encountering a resonance condition within the continuous operating speed range is greatly increased from a variety of sources they may not have been excited by a constant speed drive, Sanders, D [4]. The risk of the rotating element encountering a lateral critical speed increases when using (VSDs), [www. Bpma.org.uk](http://www.Bpma.org.uk) [5]. However, vibration level increases with increasing speed of (VSDs) and amplitude of vibration increases greatly with increasing excitation forces. At normal operating condition, vibration level increased 3.8% by increasing running speed 66%, Abdel-Rahman, S. M., and El-Shaikh, S. A [6]. It is known that varying speed of the pump affects head, discharge and power according to the affinity law relationships:

- Flow \propto speed : $Q \propto N$
- Head \propto (speed)² : $H \propto N^2$
- Power \propto (speed)³ : $P \propto N^3$

In centrifugal applications with no static lift, system power requirements vary with the cube of the pump speed. Small decreases in speed or flow can significantly reduce energy use. For example, reducing the speed (flow) by 20% can reduce input power requirements by approximately 50%, Boyadjis, P [7]. The objective of this research is to obtain the optimum dynamic behavior and its sensitivity due to speed variation of the variable speed pumping unit. The objective of this research is to obtain the optimum dynamic behavior and its sensitivity due to speed variation of the variable speed pumping unit. The present work was done on a test rig of a centrifugal pump unit with variable speed drive in the hydraulic lab of Mechanical & Electrical Research Institute (MERI).

2. RESEARCH METHODOLOGY & FACILITIES

The test rig consists of a centrifugal pump used for irrigation purposes in the hydraulic lab of Mechanical & Electrical Research Institute (MERI). The pump is of type Epara with power of 7.5 Hp, 9 A, 3000 rpm, flow rate of 36 m³/hr, and head of 7.5 m with variable speed motor. The pumping system consists of motor, pump, suction, and delivery pipelines.

Tests were done to evaluate dynamic performance of the pump unit. Forced vibration test is done to determine vibration levels and exciting frequencies using a dual channel (01dB Movipack analyzer) and a machine monitoring software package (eDiag) for evaluating dynamic running condition of the pump unit.

Experimental modal testing is conducted using a spectrum analyzer (B&K pulse 3560 hardware module 5 channels), Impact hammer to excite the pump unit with an impulse, accelerometer, and modal analysis software package (Modal Test Consultant — Type 7753). The modal testing facility is capable of determining the inherent dynamic characteristics of the pump unit including natural frequencies, damping

factors, and mode shapes. Experimental modal analyses were done on the pump unit in two boundary and supporting conditions to simulate the design and installation conditions.

Operational modal analysis was conducted using LMS Test. Lab. Software with the (B&K pulse 3560 hardware module 5 channels) analyzer. The system is capable of determining natural frequencies, damping factors, and mode shapes which are important in evaluating the dynamic behavior of the system. Configuration patterns of the system at the resonant frequencies and the operating conditions were defined. The natural frequencies of the pumping system were defined and when the exciting frequency approaches the natural frequency of the test object, the vibration level at the resonance are rapidly approaches a sharp maximum value. The pumping system and all facilities are shown in Figure 1.

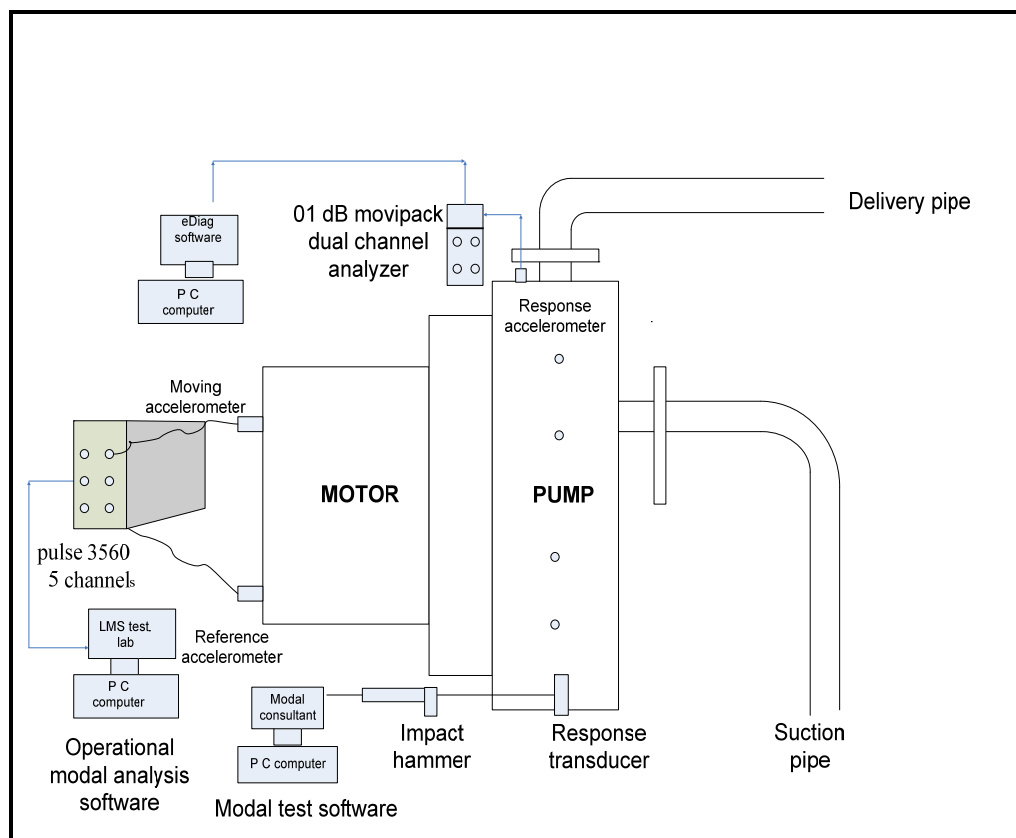


Fig. 1 Test facilities

3. FORCED VIBRATION ANALYSIS

Forced vibration analysis was done on the variable speed centrifugal pump unit at different speeds in the range (25, 30, 35, 40, 45, and 50 Hz) to specify the sources of vibration and define the exciting operational frequencies at different locations and different boundary conditions. The measurement location were done on the parts of the

pumping unit include the motor and the pump at 8 locations in the axial, vertical, and radial directions as shown in Figure 2. The measured parameters at every location are simple spectrum vibration velocity (FFT) in a frequency range from 2 Hz to 1 kHz and overall vibration velocity 10 Hz 2 kHz. The signals from the accelerometers are directly fed into the 01dB movipack analyzer which possesses an internal signal conditioning system comprising filters, integrators, amplifiers, etc. The signals are then transferred to the PC via USB connection to the eDiag software for signal analysis for and further analysis.

All these measurements taken according to the ISO 1-10861 where the root mean square (RMS) were measured for all parameters because it is the most accommodate one for machine diagnosing where it is express for the energy consumption due to vibration also it takes the time history of vibrations [8]. The measurement locations are as follows:

- Point (1) motor non drive end in the radial direction.
- Point (2) motor non drive end in the vertical direction.
- Point (3) motor drive end in the radial direction.
- Point (4) motor drive end in the vertical direction.
- Point (5) pump drive end in the radial direction.
- Point (6) pump drive end in the axial direction.
- Point (7) pump drive end in the vertical direction.
- Point (8) pump non drive end in the horizontal direction.

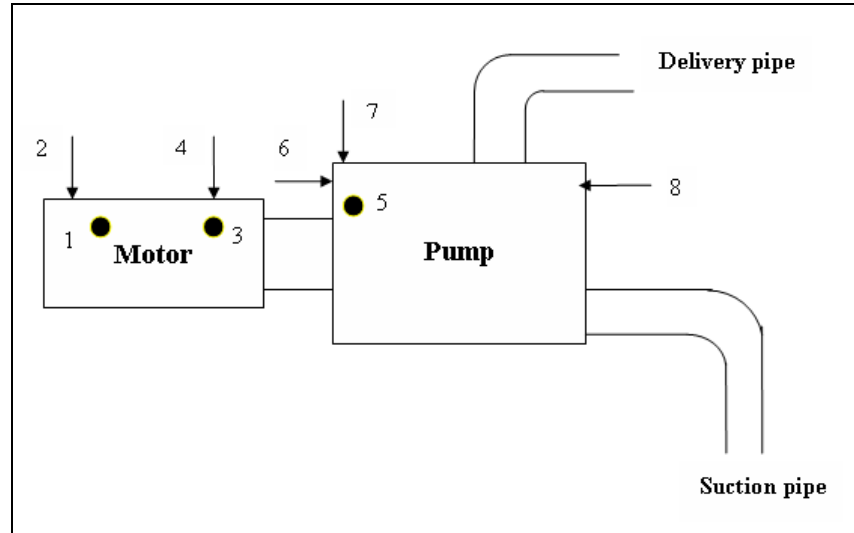


Fig. 2 Locations of vibration measurements

The measurements show that the maximum overall vibration level measured was reached 1.58 mm/s on the motor and 1.28 mm/s on the pump at running speed 50 Hz, 1.1 mm/s on the motor and 1.06 mm/s on the pump at running speed 45 Hz, 0.815 mm/s on the motor and 0.646 mm/s on the pump at running 40 Hz, 0.646 mm/s on the

motor and 0.594 mm/s on the pump at running speed 35 Hz, and 0.393 mm/s on the motor and 0.50 mm/s on the pump at running speed 25 Hz .

Vibration levels measured are good and safe according to ISO 1-10861 at all tests speeds except at resonant speed frequency (30 Hz), the overall vibration level reached value 2.91 mm/s while the spectra shows that the vibration amplitude reached a value of 3.07 mm/s at 30 Hz as shown in Figure 3 and this value are dangerous and not permissible. The results prove that operation at resonant frequency generates dangerous vibration level. The results show that vibration level increases slightly and smoothly with increasing running speed as excitation frequencies may be excited at higher speeds as shown in Figure 4. The results indicate the importance of defining resonant frequencies firstly to avoid operation at these speeds or modifying structural properties to change resonant frequency through modal analysis.

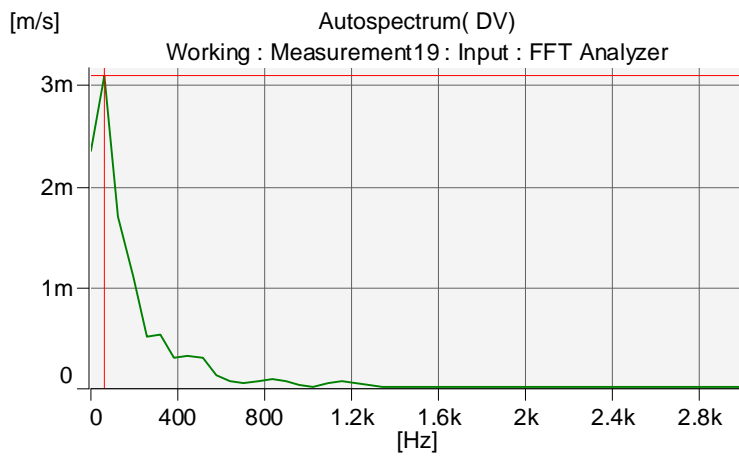


Fig. 3 Vibration spectrum measured at speed 30 Hz

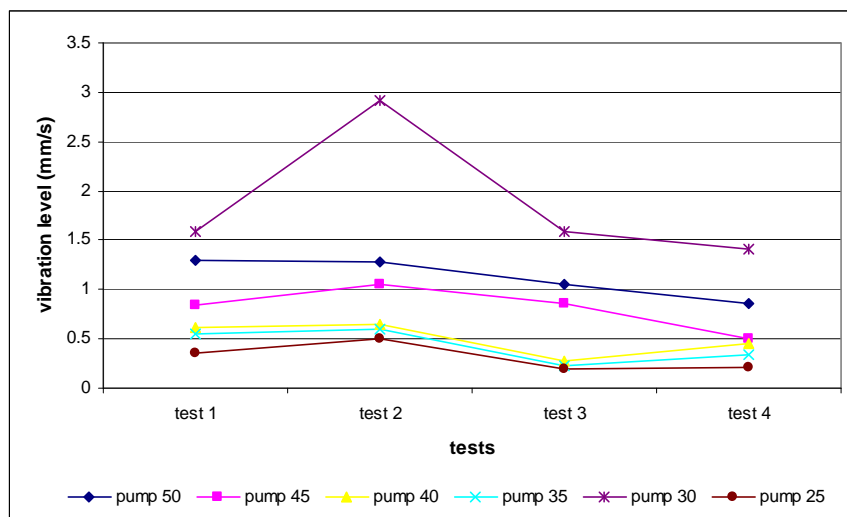


Fig. 4 Vibration level measured at different speeds on pump

4. EXPERIMENTAL MODAL ANALYSIS

Modal testing measurements are done on the whole pumping system at different boundary conditions at the laboratory. Different tests were done using different excitation and response locations to get reliable and applicable data. Experimental modal analysis was done at different phases of the pumping system representing design and installation stages. Modal testing was done by impacting the structure with the hammer to excite the system at fixed location and moving the response accelerometer around the whole structure at 47 locations as shown in Figure 5.

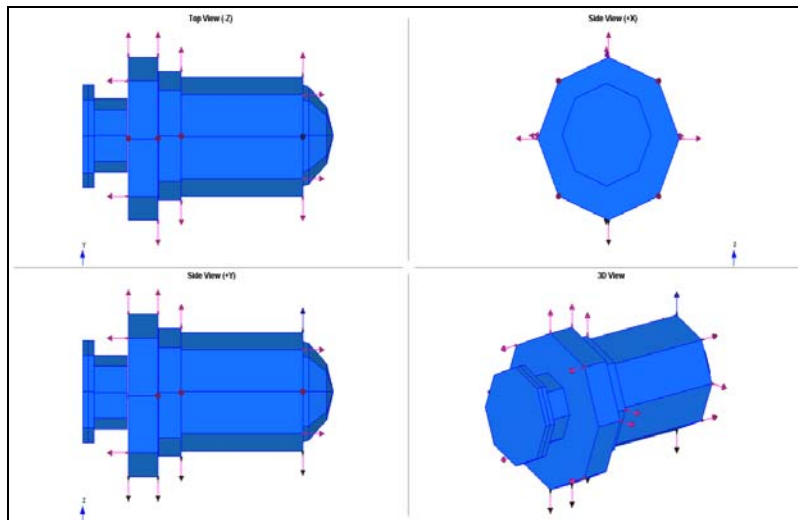


Fig. 5 Top and side views of the pumping system showing measurement locations

Modal parameters extracted from FRFs measurements are located in Table 1 that shows the first 10 modes obtained from 8 Hz to 1000 Hz. The results indicated that the most seriously mode of the system is at 30 Hz as it coincides with the operational frequencies of the system and cause resonance. Also it is indicated that the natural frequencies in the case of the pump grounded supported in water are completely different from the natural frequencies in the case of pump freely supported in air except in the first three modes. Also the number of natural modes that produced from the pump grounded in water (installation case) that about 11 modes (between 81Hz to 265 Hz) is more than the natural modes produced from the pump freely supported in air (design case)

Table 1 Natural frequencies of the pump at different cases

Mode No.	Natural frequency (Hz) of the pump unit freely support in air	Natural frequency (Hz) of the pump unit ground supported in water
1	15.75	15.24
2	31.25	30.0
3	60	68.40
4	300	81.20
5	600	86.0
6	700	122.60
7		130
8		200.0
9		248.5
10		265.36

5. OPERATIONAL MODAL ANALYSIS

Operational Modal Analysis has a significant advantage over Classical Modal Analysis. Higher estimation accuracy can be obtained by letting the better, spatially distributed, natural loading excite the structure. Classical Modal Analysis using hammer, shaker or multiple shaker excitation, and Operational Modal Analysis based on output-only measurements, DeMatteo, T [9]. For a good simulation, the pumping system is represented by 36 node, 56 line, and 34 surfaces as shown in Figure 6. The measurements were done at speed of 30 Hz (60% of rating speed) because it is the most serious speed of the system that can cause resonance problem.

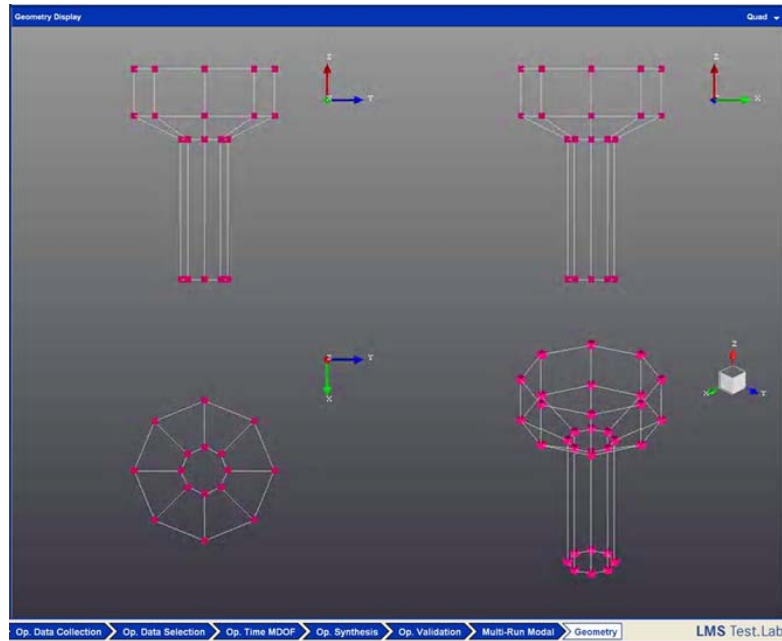


Fig. 6 Pump unit represented as nodes, lines, and surfaces

Table 2 shows the first 7 modes obtained from 8 to 1000 Hz. According to these results it is indicated that the most serious mode shape is at 33.62 Hz (66 %) so, it is very important to modify this mode to avoid the problem of resonance. The measured frequency response function FRF is shown in Figure. 8 indicated that the natural modes are extremely different from the natural modes obtained from case of the pump free supported in air and the case of pump grounded in water because of changing of the boundary condition (the pump is operating at speed 30 Hz) except at the resonance frequency.

Table 2 Modal parameters measured from operational modal analysis

Mode No	Frequency [Hz]	Damping Ratio (%)
1	3362.	0.405
2	86.47	0.7202
3	89.32	0.3155
4	547.1	0.5435
5	562.8	0.1471
6	879.8	0.4224
7	1070	0.08212

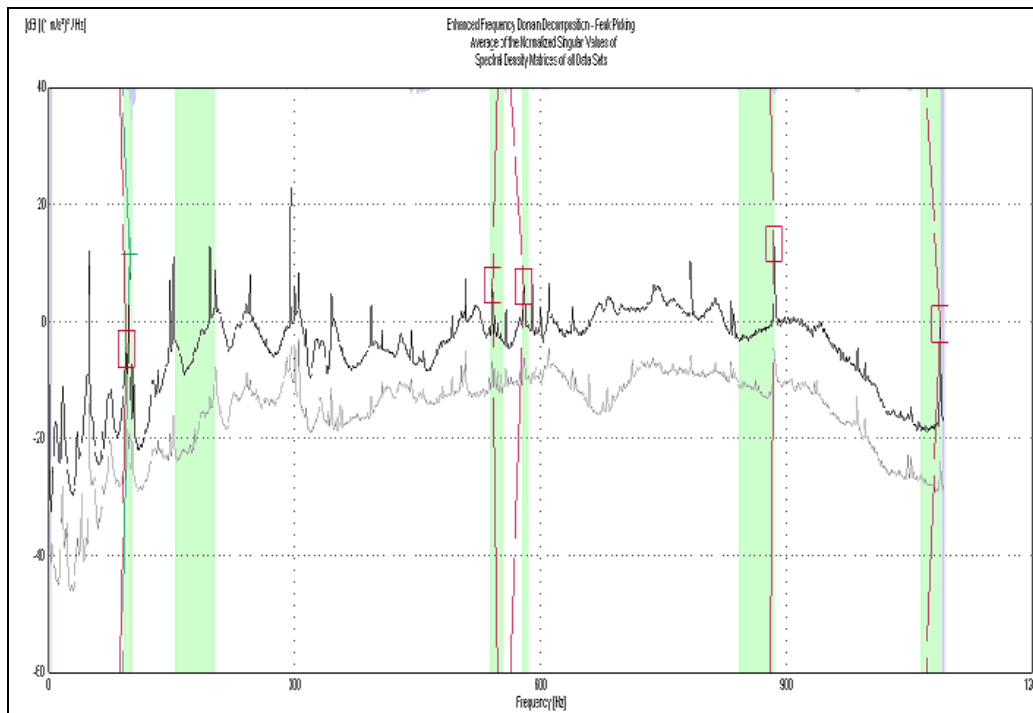


Fig. 8 Frequency response function of the pumping system at 60% of rating speed

6. CONCLUSION

- Vibration level increases slightly with increasing the running speed as long as the running speeds are not a resonant frequency.
- It is necessary to do modal analysis at different conditions to predict the dynamic behavior.
- Operating at resonance frequency affects performance and increase vibration level in obviously way.
- The results indicate that resonance is a major problem that can be encountered in variable speed pumps.
- Natural frequencies obtained from experimental modal testing are extremely different from that obtained from operational modal analysis.
- It is important to evaluate the dynamic behavior of variable speed pumps and determine the dangerous operating frequencies to avoid occurring of mechanical problems such as resonance.
- Yet, while variable speed drives clearly offer versatility to the pumping industry and cost savings to the consumer, they also present some difficult engineering challenges for both suppliers and users particularly in the area of vibration.

7. REFERENCES

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