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DIAGNOSIS PUMP PROBLEMS USING VIBRATION ANALYSIS

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ABSTRACT: *Pump stations are generally exposed to various mechanical and structural problems causing vibration affecting efficiency, performance, operating life, and maintenance cost. The motivation of this research is to identify the causes of the high vibration of El-Marashda (1) pumping station due to weakness of the foundation and support. Effect of adding steel supports to motor foundation is studied to overcome structural weakness of the pump support. Vibration level is measured and frequency analysis is done by adding steel supports gradually. From initial measurements, vibration levels measured are in the danger level. Adding steel supports to motor foundation in two steps at different locations solved the problem and reduced the high vibration level. Applying the first scenario reduced overall velocity vibration level 54%, overall acceleration level reduced 30%, and bearing defect factor reduced 20% but the problem is still there and the vibration level is high. Applying the second scenario by increasing steel support reduced the overall vibration level 91%, reduced overall acceleration level 43%, and reduced the bearing defect factor 40% than the initial state and solved the structure weakness problem and reduced the high vibration level to safe limit. Adding definitive supports to weak motor foundation of the pump enhanced the dynamic characteristics, overcame structural weakness, and reduced vibration level. Pump foundation should be carefully designed and strengthened to resist the dynamic loads. Inspection and regular maintenance is important to avoid any abnormal conditions, affecting both pump components and foundation.*

KEYWORDS: Pump Vibration, Support Weakness, Maintenance, Dynamic Performance.

INTRODUCTION

Pumping stations are subjected to many problems affecting performance, efficiency, and maintenance cost. High vibration level causes damage to the structure of the housing building and foundations of the pumping stations. Smalley [1] presented a method for assessing the severity of vibration in terms of the probability of damage by analysis of vibration and its related cost. Damage due to vibration cost millions of dollars for maintenance and replacement expenses. Vibration monitoring of pumps as a part of a good predictive maintenance program is becoming increasingly important as pressures increase to reduce damage [2]. Vibration condition monitoring as an aid to fault diagnosis of rotary machines has been used successfully since more than 30 years. However, vibration is used as an effective tool for fault detection and diagnosis. Many researches evaluate mechanical and hydraulic pump performance using vibration analysis [3, 4].

The pump baseplate is the interface between the casing feet and the foundation. A baseplate and the foundation have some degree of flexibility, and therefore are a contributing factor in the overall stiffness with which the mass of the pump is grounded mechanically to the earth. Therefore, the baseplate and foundation are often a key factor in establishing the so-called "reed" frequencies of a pump, the vibration motion that particularly vertical pumps often

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exhibit near running speed. This factor in the installation and qualification of new pumps is often overlooked by civil engineers and mechanical contractors when they design and construct a new or revised pump installation [5].

Machine foundations require a special consideration because they transmit dynamic loads to soil in addition to static loads due to weight of foundation, machine and accessories. The dynamic load due to operation of the machine is generally small compared to the static weight of machine and the supporting foundation. In a machine foundation the dynamic load is applied repetitively over a very long period of time but its magnitude is small and therefore the soil behavior is essentially elastic, or else deformation will increase with each cycle of loading and may become unacceptable. The amplitude of vibration of a machine at its operating frequency is the most important parameter to be determined in designing a machine foundation, in addition to the natural frequency of a machine foundation soil system [6]. Due to misalignment, improper installation and pipe loads imposed due to poor support of suction and discharge pipes. Low rigidity, other cause, of pump vibration is due to low strength of components including casing, and low foundation strength due to weak foundations or improper tightening of foundation bolts [7&8]. Resonance or self excited oscillation is mainly due to:

- Pressure pulsation in the pump coincides with the natural frequency of casing or piping,
- Vortex formed near the suction pipe, and
- Speed corresponding to natural frequency of the rotating component.

Pump vibration is evaluated on the basis of the value at the center of the bearing supporting the rotating portion. When pumps and drivers are firmly installed on a large foundation, nearly 100% of the vibration force generated by each machine is transmitted to the foundation. Foundation vibration is proportional to their weight, and when a sufficiently large foundation is used, both foundation vibration and pump vibration can be held to a low value. When the size of the foundation is not so large, and its vibration is great, noise may occur in the surroundings. Also, when the vibrating force transmitted to the foundation must be reduced because of low building strength, vibration damping measures are necessary [8].

The effect of imbalance on a single stage end pump with the impeller cantilevered relative to the bearings is studied. If the impeller mass is M, the mass of the shaft is M_s, the shaft length and moment of inertia are L and, respectively, and is Young's modulus of elasticity, then the lowest natural frequency (the "reed" mode) in cycles per minute is:

$$f_{nl} = \left(60 \Big/ 2\pi \left[(3EI) \Big/ \{ L^3 (M + 0.49 M_S) \} \right]^{1/2} \right)$$

f_{nl} = Lowest natural frequency

EI = Young's modulus of elasticity

L = Shaft length and moment of inertia

M = Impeller mass

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$M_S =$ Mass of the shaft

If the eccentricity of the impeller relative to the bearing rotational centerline is, and the rotational speed is rad/s, then the unbalance force is simply:

$$F_{ub} = M_e \omega^2 / g_c$$

$F_{ub} =$ Unbalance Force

$\omega =$ Rotational speed

$M_e =$ Impeller mass eccentricity

$g_c =$ Gravitational speed

and the amount of vibration displacement expected at the impeller wearing rings is:

$$\delta = \left(F_{ub} * L^3\right) / \left(3EI\right)$$

METHODOLOGY

Problem Statement

In this research, mechanical problems of Marashda (1) Pumping Station are assessed. Marashda (1) Pumping Station is used to serve irrigation of 500 feddans in Nagaa Hamadi Area in Upper Egypt. It consists of 5 pump units as shown in **Figure (1)**. Each pump unit is of discharge 2.2 m^3/sec, head 12 m, pump speed 598 rpm, motor power 456 kW, motor speed 1483 rpm, and gearbox ratio 62/25 (2.48), number of drive Gear teeth is 25, number of driven Gear teeth is 62, and rated output power is 430 KW.

Dynamic Analysis was done by measuring overall vibration velocity, gravity vibration acceleration, and bearing defect factor at 12 locations on five units in three directions axial, horizontal, and vertical perpendicular, as shown in **Figure(2)** and compared the results with standards of machines (ISO 10816-1) [9], as shown in **Figure (3)**. Frequency analysis was done at low and high frequency to define the exciting frequencies and determine the level of vibration at each specific frequency, to determine the sources of vibration, to control vibration levels, and to solve vibration problems. Then, measurements were repeated twice after maintenance and adding supports to motor foundation with load and no load conditions to fix the high vibration level.

Equipment that used for test/measurement is one proD/ACOEM vibration analyzer and Data collector MVP200 serial 11141 with Machine Monitoring SW type XPR300 Premium, as shown in **Figure (4)**.

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Figure (1) Photograph for Marashda (1) P. S.

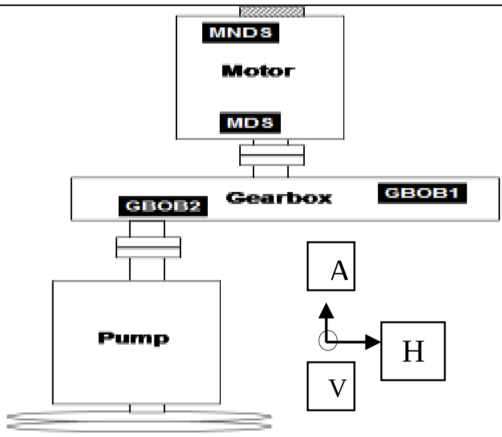

Figure (2) Measurement locations for Marashda (1) P s

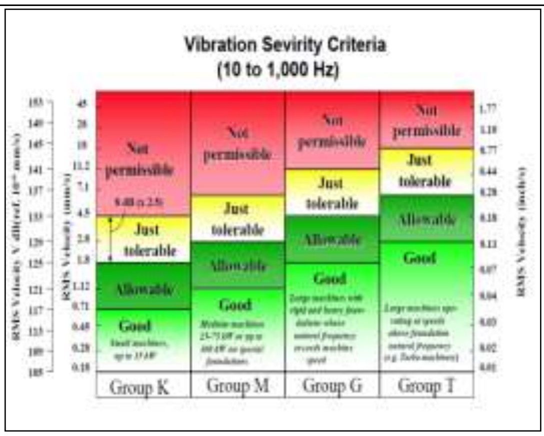

Figure (3) ISO standard for vibration

Figure (4) 01dB Movipack with machine monitoring SW type *XPR300 premium*

RESULTS AND ANALYSIS OF VIBRATION MEASUREMENTS

Firstly, overall vibration levels in terms of rms vibration velocity, gravity vibration acceleration, and bearing defect factor (BDF) were measured and analyzed at load and no load conditions. Maintenance and fixation of the problems were done and measurements were repeated. Dynamic analyses were done at all conditions to determine seriousness and causes of the problems. Lastly; dynamic analysis indicated disappearance of the problems.

Results of vibration measured at full load "Initial state"

Overall vibration levels that are measured with load for five units show that the level of vibration in terms of vibration velocity, gravity vibration acceleration, and bearing defect factor for all units are in the danger level. So, measurements were done for unit 1, with load and with no load to judge if the problem from motor or from pump and then measurements are repeated with load and with no load after doing maintenance, as shown in **Table [1].**

From measurements and analyses overall vibration velocity level for motor non drive side (MNDS) is in danger level where level is reached to **17.6 mm/sec** at (MNDSH), and the level is reached to **4.8 mm/sec** at (MNDSV), and vibration levels measured at motor drive side (MDS) is in the good margin. While the gearbox overall vibration levels next to motor side (GBMS) and next to pump side (GBPS) in the vertical direction are in alarm level where levels are reached to **6.21 mm/sec** and **6.01 mm/sec** receptively.

Also, from measurements and analyses, the overall vibration acceleration level for motor are within the acceptable range and in the alarm level for all measurements except at the MNDSV is in danger where level is reached to **1.59 g**. While, the gearbox overall vibration levels are in danger level at all measurements especially on the GBPSH where the level is reached to **15.5 g**.

From measurements and analyses, the levels of bearing defect factor BDF are within the acceptable range except at the gearbox is in the alarm level.

Table [1]: Overall Vibration Levels with full load and with No load

Measurement Locations	Overall Velocity (mm/s)		Overall Acceleration (g's)		Overall Bearing defect Factor (DEF)	
	Load	No Load	Load	No Load	Load	No Load
MNDSH	17.60	16.30	01.42	01.32	04.88	05.11
MNDSV	04.80	05.10	01.18	01.02	03.96	04.32
MNDSA	01.20	01.48	01.06	02.02	04.26	05.35
MDSH	01.50	01.12	01.23	01.31	05.12	06.34
MDSV	0.597	01.06	01.59	02.27	04.53	08.10
MDSA	01.40	02.87	0.703	01.95	05.94	08.04
GBMSH	03.12		02.72		05.52	
GBMSV	06.21		03.47		05.86	
GBMSA	02.32		08.10		07.72	
GBPSH	03.18		15.50		08.82	
GBPSV	06.01		05.79		07.43	
GBPSA	0.877		03.41		05.61	

Results of frequency analyses that was done show that the there is an unbalance problem caused by the electric motor is not perpendicular to the ground or from dust accumulation on the rotor, and there is an indication to cracked or broken rotor bars or defective or loose rotor bar joints see **Figures (5-a,** and **5-b**). Also, the gearbox vibration measurement at motor side analysis shows a problem in the gear teeth could be caused by misalignment or by using bad oil see **Figures (5-c** and **5-d)**. Also, the gearbox vibration measurement at pump side analysis shows a looseness problem in gear **Figures (5-e,** and **5-f)**.

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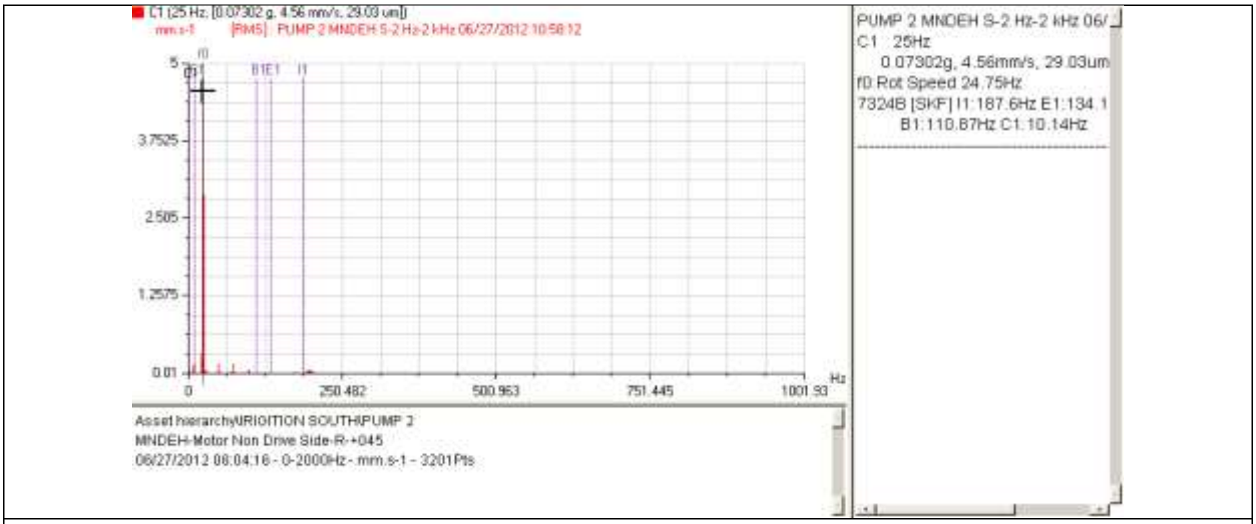
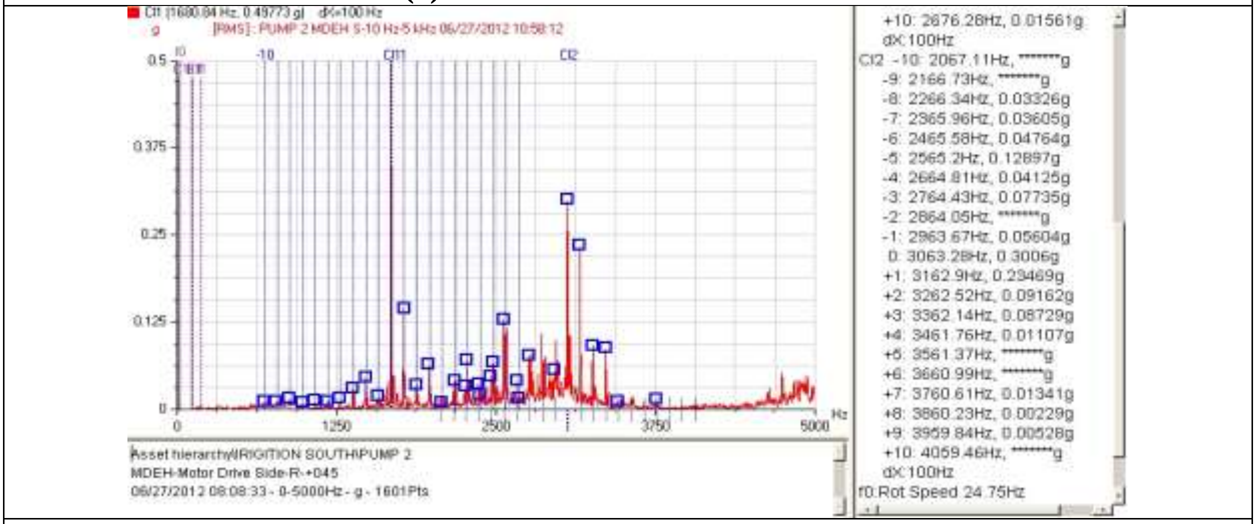
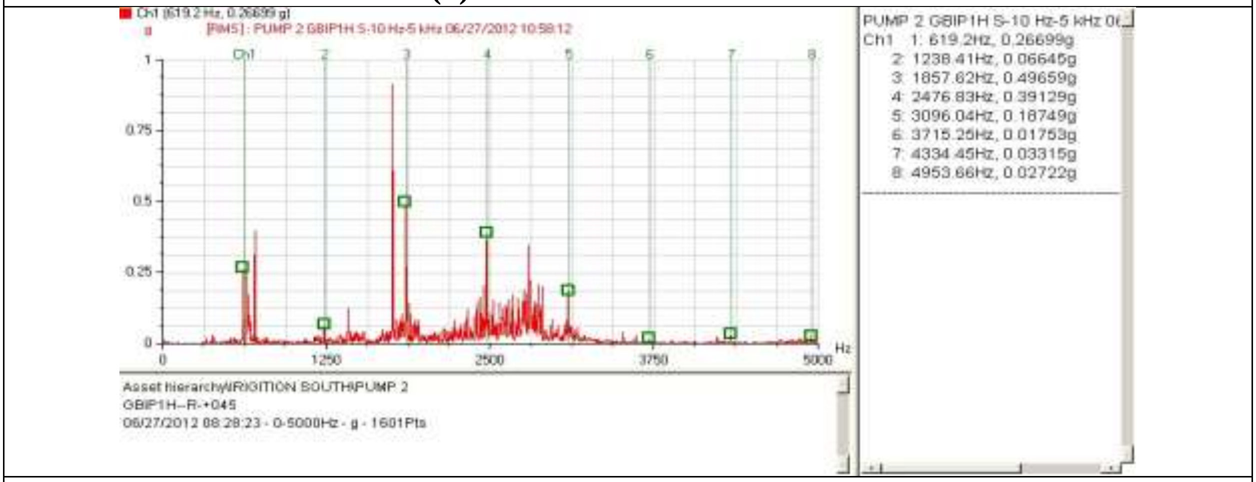


(a) motor non drive side horizontal



(b) motor drive side horizontal



(c) Gear Box motor side horizontal

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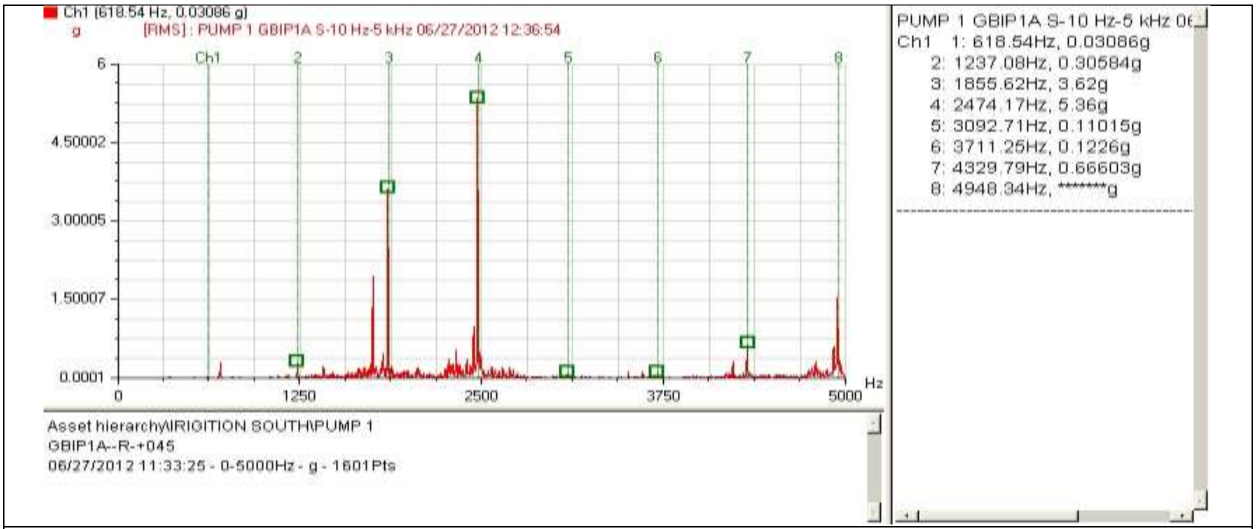
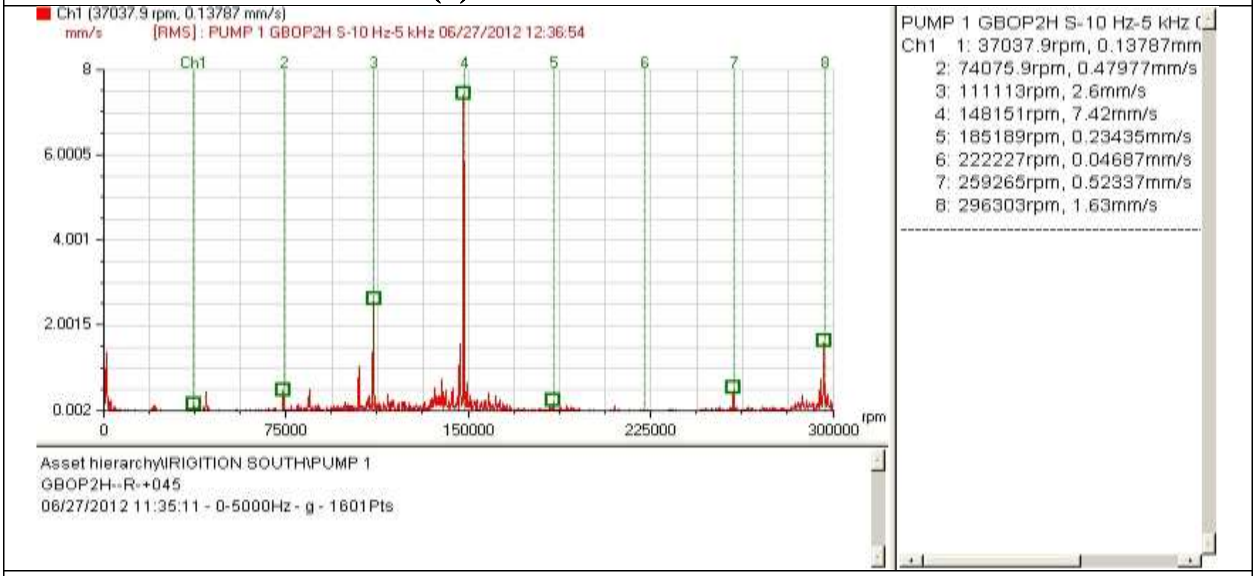
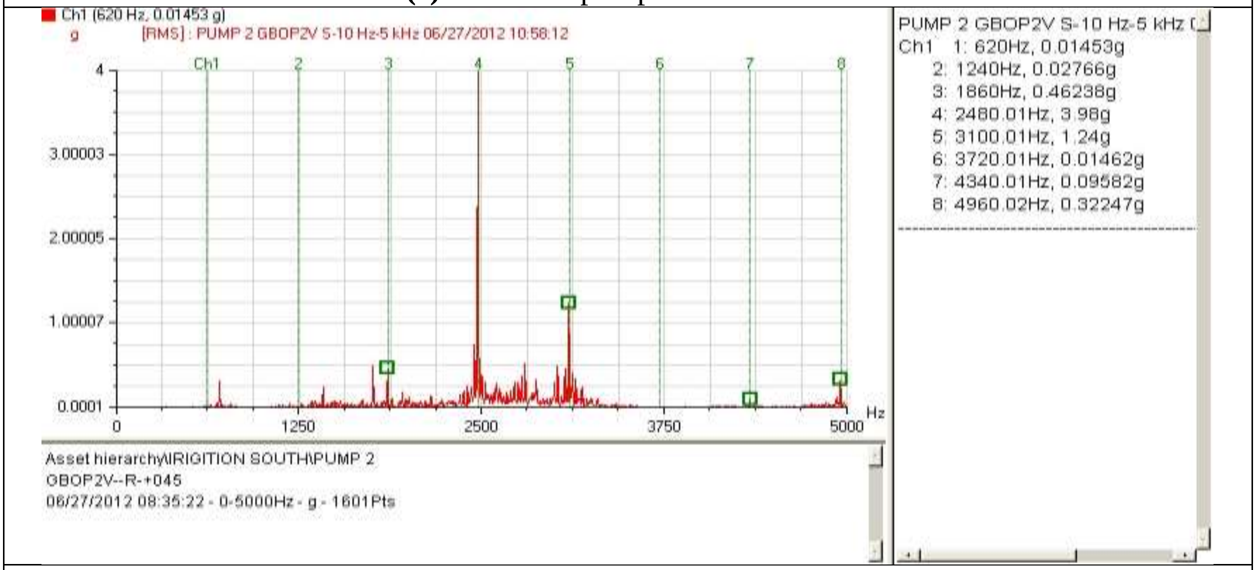


(d) Gear Box motor side Axial



(e) Gear Box pump side horizontal



(f) Gear Box pump side vertical

Fig. (5) Frequency analyses at full load on the motor and gearbox

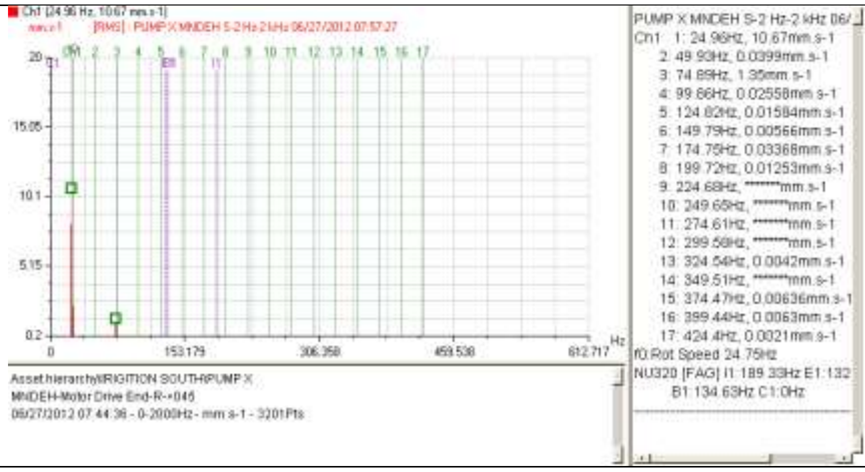
Results of vibration measured at no load "Initial state"

Results and analyses for overall vibration and frequency analyses with full load show that high level of vibration reached to danger level. So, measurements were done for one unit with no load, as shown in **Table [1]** and then frequency analysis is done.

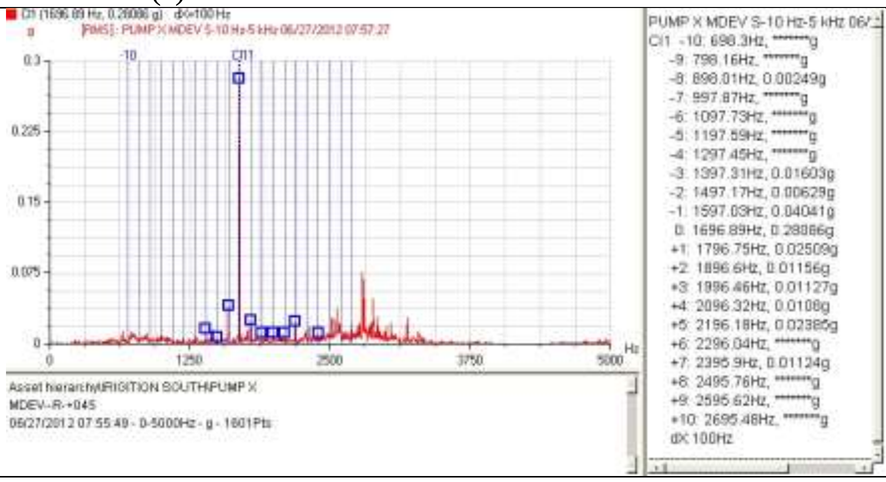
From measurements and analyses, the velocity overall vibration level for motor non drive side at no load are within the acceptable range except the motor non drive side horizontal (MNDSH) and at the motor non drive side vertical (MNDSV) is in danger and alarm level where it reached to **16.3 mm/sec**, **5.1 mm/sec** respectively as shown in **Table [1]**.

Also from measurements and analyses, overall vibration acceleration level for all measurements for the motor are in the alarm and danger levels where the smallest level is 1.02 g's and highest level is **2.27 g's**, as shown in **Table [1]**. From measurements and analyses, the levels of BDF are within the alarm levels range, where, the level is reached to **8.1** as shown in **Table [1]**.

Results of frequency analyses that were done at the motor show that the motor misalignment problem and resonance problems could be caused by weight of the electric motor, as shown in **Figures (6-a,** and **6-b)**.



(a) : motor non drive side horizontal **MNDSH**



(b) : motor drive side vertical **MNDSV**

Fig. (6) Frequency analyses at no load on the motor

Results of vibration measured after adding steel supports "First Scenario"

Adding steel supports to motor foundation in the four perpendicular sides and doing maintenance was done then, overall vibration velocity, gravity acceleration, and bearing defect factor were done, as shown in **Table (2)**.

From velocity measurements and analyses it's found that improvement for all overall vibration levels where level is reached to **8.13 mm/sec** at MNDSH with reduction ratio about **50%** where it was 17.6 mm/sec at the initial state, as shown in **Table [2]**, but it's **still danger** according to ISO standard [9] where, the gearbox overall vibration levels are within the acceptable range.

While, From gravity acceleration measurements and analyses, and adding steel supports to motor foundation it's found that improvement for all overall vibration levels, but it's still in the **alarm and danger level** where most measurements are higher than 1 g's where, overall vibration acceleration is reached to **11.66 g** at the GBPSH with reduction ratio **24.77%,** but it's still **danger**, as shown in **Table [2]**.

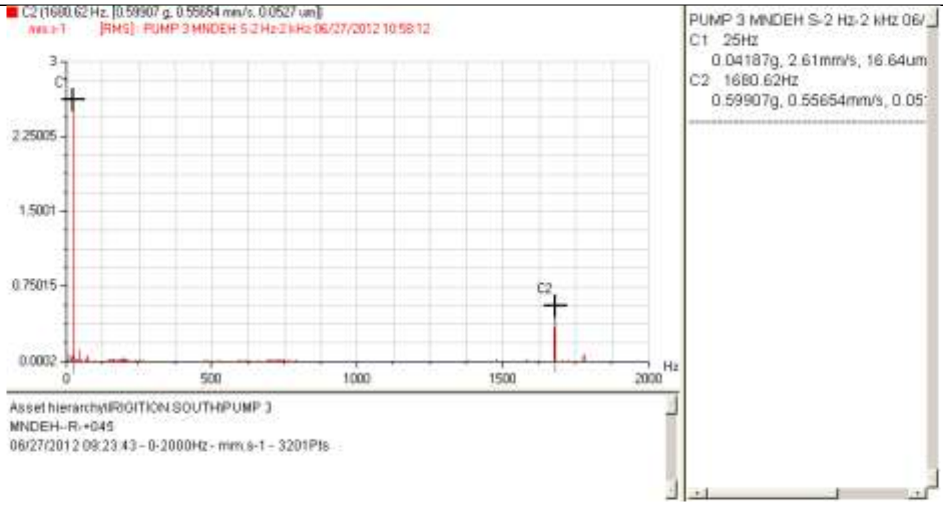
Also, it's found that improvement for all levels of BDF at the gearbox, where it reached to 6.66, 6.88, and 6.11 at GBMSA, GBPSH, and GBPSV receptively with reduction ratio 22%, 17.77%, and 22.82% receptively but it's still high and in the **alarm level**.

Table [2]: Results of vibration measured after adding steel supports **"First Scenario"**

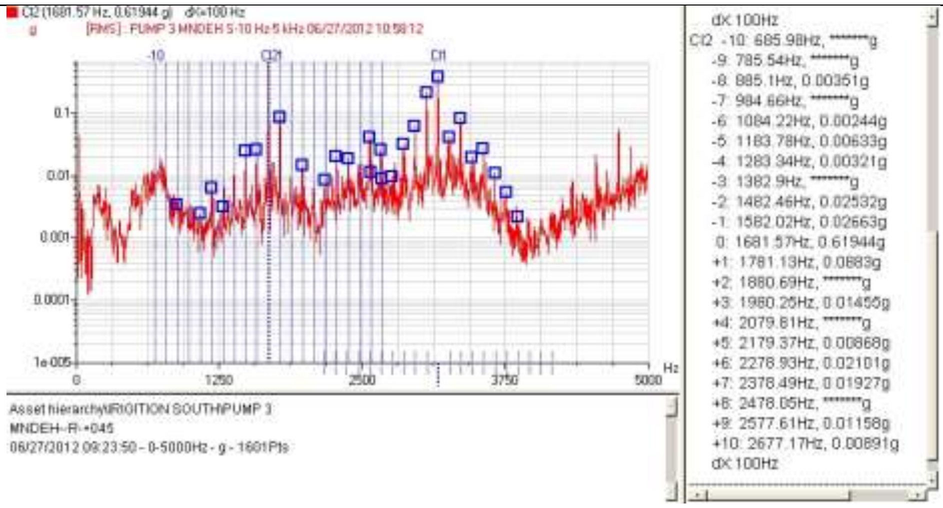
Measurement Locations	**Overall Velocity (mm/s)**			**Overall Acceleration (g's)**			**Overall Bearing defect Factor**		
	Initial state	First Scenario	Reduction Ratio (%)	Initial state	First Scenario	Reduction Ratio (%)	Initial state	First Scenario	Reduction Ratio (%)
MNDSH	**17.6**	**8.13**	53.81%	**1.42**	**0.88**	38.03%	**4.88**	**3.19**	34.63%
MNDSV	**4.8**	**3.06**	36.25%	**1.18**	**0.95**	19.49%	**3.96**	**3.71**	6.31%
MNDSA	**1.2**	**1.41**	-17.50%	**1.06**	**0.99**	6.60%	**4.26**	**3.91**	8.22%
MDSH	**1.5**	**1.09**	27.33%	**1.23**	**1.19**	3.25%	**5.12**	**4.58**	10.55%
MDSV	**0.597**	**0.043**	92.80%	**1.59**	**1.44**	9.43%	**4.53**	**4.95**	-9.27%
MDSA	**1.4**	**0.097**	93.07%	**0.703**	**0.88**	-25.18%	**5.94**	**5.11**	13.97%
GBMSH	**3.12**	**3.09**	0.96%	**2.72**	**2.22**	18.38%	**5.52**	**5.81**	-5.25%
GBMSV	**6.21**	**6.35**	-2.25%	**3.47**	**3.03**	12.68%	**5.86**	**5.24**	10.58%
GBMSA	**2.32**	**2.19**	5.60%	**8.1**	**5.77**	28.77%	**7.72**	**6.66**	13.73%
GBPSH	**3.18**	**3.42**	-7.55%	**15.5**	**11.66**	24.77%	**8.82**	**6.88**	22.00%
GBPSV	**6.01**	**5.71**	4.99%	**5.79**	**3.57**	38.34%	**7.43**	**6.11**	17.77%
GBPSA	**0.877**	**1.11**	-26.57%	**3.41**	**2.18**	36.07%	**5.61**	**4.33**	22.82%

From frequency analyses, there is frequency equal frequency clutch (GUF) at rotating speed and its harmonics reached to 6.66 mm /sec as shown in **Figures (7-a, 7-b, 7-c, and 7-d).** Also, resonance problem was still found, but less than the previous, as shown in **Figure (6-a)**.

Clutch frequency values appear in the gearbox pump side in the case of full load, which indicates unbalance problem in the axial direction according to incorrect putting steel foundation under the motor over the base of concrete, as shown in **Figures (7-e and 7-f).**



(a) motor non drive side horizontal



(b) motor drive side horizontal

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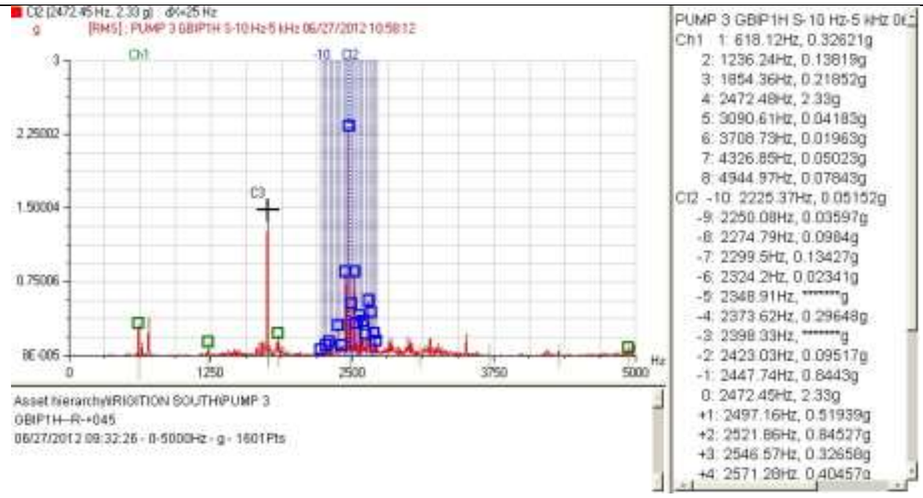
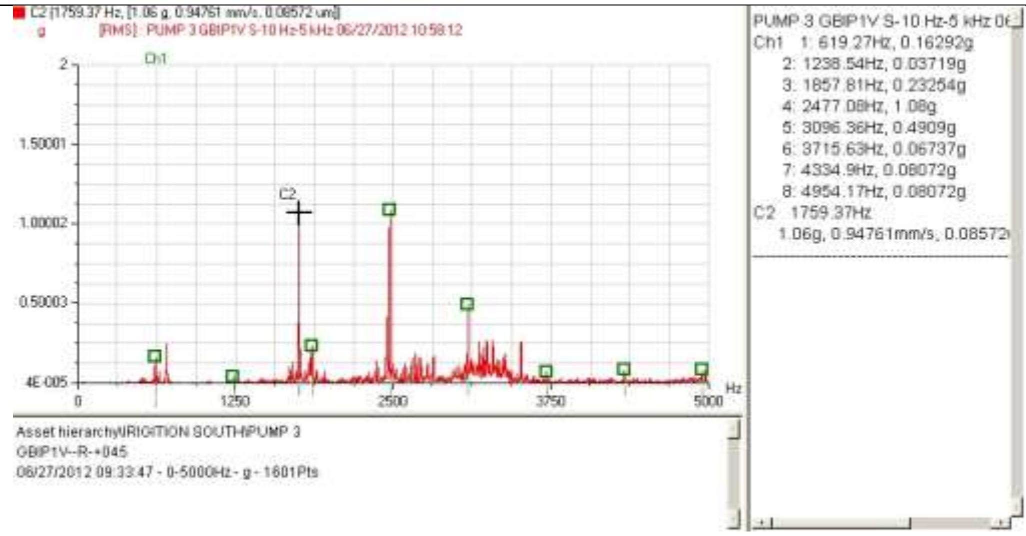
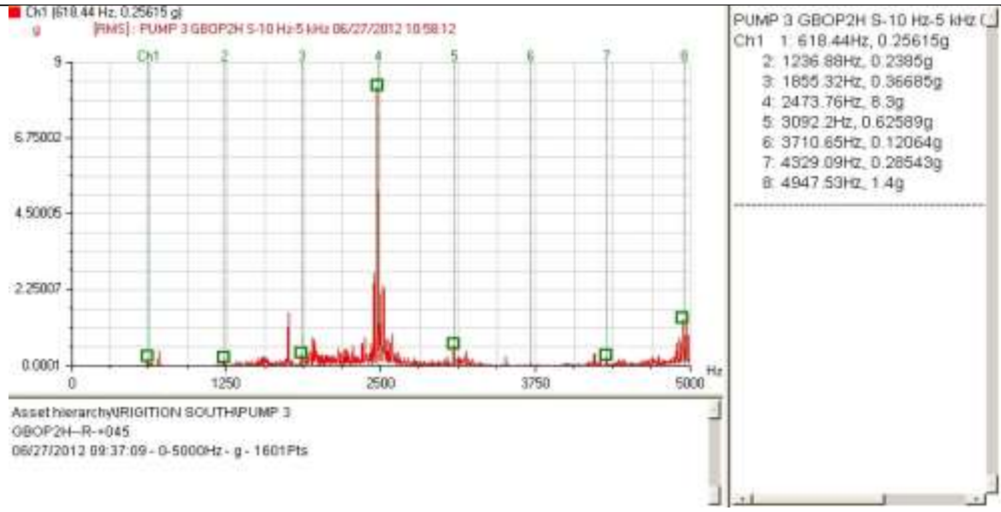


(c) Gear Box motor side horizontal



(d) Gear Box motor side Axial



(e) Gear Box pump side horizontal

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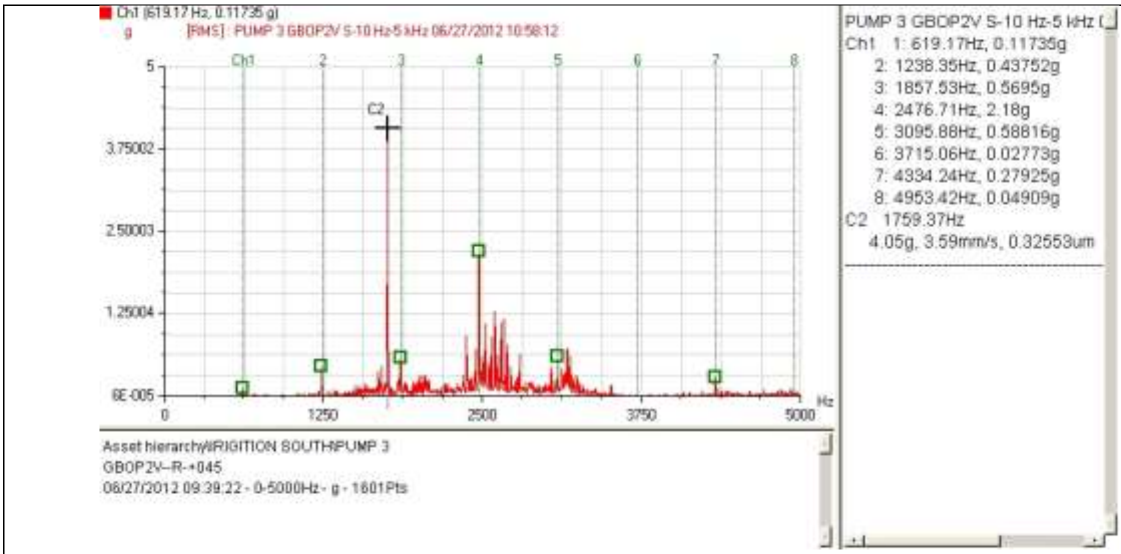

(f) Gear Box pump side vertical

Fig. (7) Frequency analyses at full load on the motor and gearbox

Results and discussions after increasing steel supports "Second Scenario"

Measurements were repeated after increasing steel supports to motor foundation in the four perpendicular sides, are shown in **Figure (9)**. Photo for indicate increasing steel supports to motor foundation in the four perpendicular sides shown in **Figure (9-c).** Overall vibration velocity, gravity acceleration, and bearing defect factor were done. Also, frequency analysis is done.

(a) Before adding steel supports

(b) After adding steel supports

(c) After increasing steel supports

Fig. (9) Photograph for Marashda (1) Pumping Station showing steel supports

Overall Vibration Velocity, acceleration, and BDF were done after increasing steel supports to motor foundation.

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From velocity measurements and analyses it's found that improvement for all overall vibration levels and become within the acceptable range where overall vibration level is reached to 1.59 mm/sec at MNDSH with reduction ratio about 90.97 % where it was 17.6 mm/sec at the initial state and become 8.13 mm/sec with reduction ratio about 53.8% after applying the first scenario, as shown in **Table [2]**. Also, the overall vibration levels at gearbox become in the safe limit where the levels of vibration were reduced with reduction ratio about 40%, as shown in **Table [3]**. While it's found that improvement for all gravity acceleration levels where it became within the acceptable range, as shown in **Table [3]**. The highest gravity acceleration level is reached to 1.47 g's with reduction ratio reached to 90.52% where it was 15.5 g's at the initial state and become 11.66 g's with reduction ratio about 24.77% after applying the first scenario, as shown in **Table [3]**.

Also, from measurements, analyses, and after applying the second scenario it's found that improvement for all levels of BDF, where the highest level is reached to 4 with reduction ratio reached to 48.19% where it was 7.72 at the initial state and become 6.66 mm/sec with reduction ratio about 13.73% after applying the first scenario, as shown in **Table [4]**.

After increasing steel supports to motor foundation stronger than the previous and adding iron base under the motor foundation so, it become hardness then vibrations decreased on the motor where it reached to 1.29 mm/sec and 1.1 mm/sec respectively, as shown in **Figures (10-a and 10-b)**. Also resonance problems disappeared and also frequency clutch and its harmonics were disappeared, as shown in **Figures (10-c and 10-d)**.

Table [3]: Overall Vibration Levels Measured after increasing supports **"Second Scenario"**

Measurement Locations	Overall Velocity (mm/s)					Overall Acceleration (g's)				
	Initial state	First Scenario	Reduction Ratio (%)	Second Scenario	Reduction Ratio (%)	Initial state	First Scenario	Reduction Ratio (%)	Second Scenario	Reduction Ratio (%)
MNDSH	**17.6**	**8.13**	**53.81%**	**1.59**	**90.97%**	**1.42**	**0.88**	**38.03%**	**0.8**	**43.66%**
MNDSV	**4.8**	**3.06**	**36.25%**	**1.13**	**76.46%**	**1.18**	**0.95**	**19.49%**	**0.45**	**61.86%**
MNDSA	**1.2**	**1.41**	**-17.50%**	**1.34**	**-11.67%**	**1.06**	**0.99**	**6.60%**	**0.79**	**25.47%**
MDSH	**1.5**	**1.09**	**27.33%**	**0.75**	**50.00%**	**1.23**	**1.19**	**3.25%**	**0.92**	**25.20%**
MDSV	**0.597**	**0.043**	**92.80%**	**0.29**	**51.42%**	**1.59**	**1.44**	**9.43%**	**0.94**	**40.88%**
MDSA	**1.4**	**0.097**	**93.07%**	**0.36**	**74.29%**	**0.703**	**0.88**	**-25.18%**	**0.48**	**31.72%**
GBMSH	**3.12**	**3.09**	**0.96%**	**3.27**	**-4.81%**	**2.72**	**2.22**	**18.38%**	**0.98**	**63.97%**
GBMSV	**6.21**	**6.35**	**-2.25%**	**3.7**	**40.42%**	**3.47**	**3.03**	**12.68%**	**1.03**	**70.32%**
GBMSA	**2.32**	**2.19**	**5.60%**	**1.63**	**29.74%**	**8.1**	**5.77**	**28.77%**	**0.77**	**90.49%**
GBPSH	**3.18**	**3.42**	**-7.55%**	**3.07**	**3.46%**	**15.5**	**11.66**	**24.77%**	**1.47**	**90.52%**
GBPSV	**6.01**	**5.71**	**4.99%**	**3.26**	**45.76%**	**5.79**	**3.57**	**38.34%**	**0.5**	**91.36%**
GBPSA	**0.877**	**1.11**	**-26.57%**	**0.781**	**10.95%**	**3.41**	**2.18**	**36.07%**	**1.03**	**69.79%**

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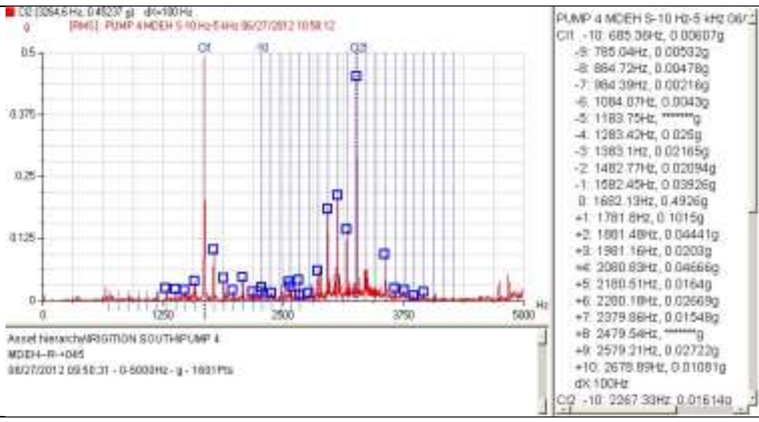
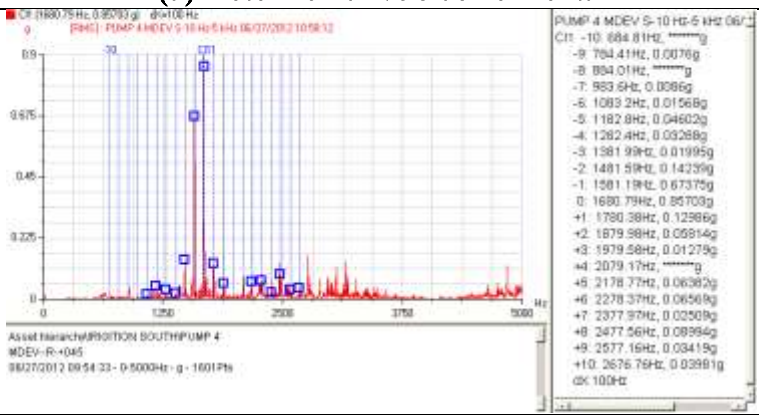
Table [4]: Overall Vibration Levels Measured after increasing supports **"Second Scenario"**

Measurement Locations	Overall Bearing defect Factor (BDF)				
	Initial state	First Scenario	Reduction Ratio (%)	Second Scenario	Reduction Ratio (%)
MNDSH	**4.88**	**3.19**	**34.63%**	**2.79**	**42.83%**
MNDSV	**3.96**	**3.71**	**6.31%**	**3.12**	**21.21%**
MNDSA	**4.26**	**3.91**	**8.22%**	**2.93**	**31.22%**
MDSH	**5.12**	**4.58**	**10.55%**	**4.23**	**17.38%**
MDSV	**4.53**	**4.95**	**-9.27%**	**3.29**	**27.37%**
MDSA	**5.94**	**5.11**	**13.97%**	**3.32**	**44.11%**
GBMSH	**5.52**	**5.81**	**-5.25%**	**3.16**	**42.75%**
GBMSV	**5.86**	**5.24**	**10.58%**	**3.28**	**44.03%**
GBMSA	**7.72**	**6.66**	**13.73%**	**4**	**48.19%**
GBPSH	**8.82**	**6.88**	**22.00%**	**3.85**	**56.35%**
GBPSV	**7.43**	**6.11**	**17.77%**	**2.23**	**69.99%**
GBPSA	**5.61**	**4.33**	**22.82%**	**1.15**	**79.50%**



(a) motor non drive side horizontal



(b) motor drive side horizontal

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(c) Gear Box pump side horizontal

(d) Gear Box pump side vertical

Fig. (10) Frequency analyses at full load on the motor and gearbox after increasing supports

CONCLUSIONS & RECOMMENDATIONS

- From initial measurements, vibration levels measured on the pumps are in the danger level due to weakness of the foundation structure.
- Frequency analysis defined the sources of vibration, which easily helped to monitor the running conditions and solve the problems.
- Adding steel supports to motor foundation at two scenarios solved the structure weakness problem and reduced the high vibration level.
- Applying the first scenario by adding steel supports to motor foundation reduced the overall vibration level 54%, reduced the overall acceleration level 30%, and reduced the bearing defect factor 20% than the initial state but the problem is still there, and the vibration level is high.
- Applying the second scenario by increasing steel support reduced the overall vibration level 91%, reduced the overall acceleration level 43%, and reduced the bearing defect factor 40% than the initial state and solved the structure weakness problem and reduced the high vibration level to safe limit.
- Vertical pump foundation should be carefully designed and strengthened to resist the dynamic loads.

- Inspection and regular maintenance is important to avoid any abnormal conditions leading to dynamic loads affecting both pump components and foundation.

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