Sudan University of Science and Technology

College Of Post Graduate Studies

School Of Mechanical Engineering

M.sc Program in Power Engineering - (Batch 10)

Predictive Maintenance by Using Ultrasound Technique for Rotating Equipments in Thermal Power Plants

الصيانة التنبؤية باستخدام تقنية الموجات فوق الصوتية للمعدات الدوارة في محطات التوليد الحراري

Thesis submitted to Postgraduate College Sudan University of Science and Technology in Partial fulfillment of the Requirements for the Degree of M.Sc.

(Mechanical Engineering-Power Department)

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وَقُل رَّبِّ زِدْنِي عِلْمًا

صدق الله العظيم

DEDICATION

To

My Dearest Parents who are the part of my soul and whose love, affection and confidence enabled me to achieve this goal.

TO

My brothers and my sisters for their help and patience, despite the distance...

To

My Friends who have encouraged me to complete this work.

To anyone who have supported me with good ideas throughout the Project.

ACKNOWLEDGEMENT

To the Almighty GOD "ALLAH" Who have granted me all these graces to fulfill this work and who blessed and supported me by His power in all my life. Without this guidance I would have never reached this position where I am writing this page. To Him I extend my heartfelt thanks.

I would like to show my greatest appreciation to my honorable supervisor **Dr. Tawfeeg Ahmed Gmal Al deen** *, school of Mechanical Engineering, He is not only a great Professor with deep vision but also most importantly a kind person. I sincerely thank for him exemplary guidance and encouragement. Without his encouragement and guidance, this project would not have materialized.*

It is impossible to find the right words to thank my beloved parents, uncle, brothers and sisters for their love and encouragement. Without it, this thesis would not be completed.

Abstract

This thesis proposes an ultrasound condition monitoring technique to determine the condition of rotating equipments and deals with detection of fault conditions based on measurements of ultrasound made on rotating machines in Garri-4 power plant. Features data, from different case studies, were analyzed and used to give results to define the machine condition. The results indicated that the ultrasound technique is accurate method for the inspection of rotating machines in various mechanical systems. By using ultrasound technique, rotating equipments condition was identified accurately and its faults were detected during the operation before the failure occurred.

المستخلص

استعرضت هذه الاطروحة الصيانة التنبؤية بإستخدام تقنية الموجات فوق الصوتية للمعدات الدوارة في محطات التوليد الحراري وذلك لتوضيح حالة المعدات الدوارة وتحديد اعطالها والتي اعتمدت على قراءات الموجات فوق الصوتية للاجزاء الدوارة في محطة كهرباء قري4 . جمعت البيانات من الحالات موضوع الدراسة وتم تحليلها لاعطاء النتائج .اظهرت النتائج أن استخدام تقنية الموجات فوق الصوتية طريقة دقيقة لفحص المعدات الدوارة للانظمة الميكانيكية المختلفة .باستخدام تقنية الموجات فوق الصوتية تم التعرف على حالة المعدات الدوارة بدقة كما تم تحديد اعطالها اثناء التشغيل قبل تعرضها للضرر.

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NOMENCLATURE

CBM	Condition based maintenance
PdM	Predictive maintenance
DFR	Decreasing Failure Rate
IFR	Increasing Failure Rate
RUL	Remaining Useful Life
CM	Corrective Maintenance
PM	Preventive Maintenance
VSA	Vibration signature analysis
AET	Acoustic Emission Testing
IRT	Infrared thermography
LOA	Lubrication oil analysis
UCM	Ultrasonic condition monitoring
CFB	Circulating fluidized bed boiler
C.W.P	circulating water pump
C.E.P	Condensate extraction pump
H.P.S	High pressure seal blower
BRG	Bearing
UT	Ultrasound
DE	Drive End
NDE	Non Drive End
RMS	Root mean square

CHAPTER I

INTRODUCTION

1.1 Introduction

The condition based maintenance (CBM) process requires technologies, people skills, and communication to integrate all available equipment condition data, such as: diagnostic and performance data; maintenance histories; operator logs; and design data, to make timely decisions about the maintenance requirements of major/critical equipment. Condition based maintenance assumes that all equipment will deteriorate and that partial or complete loss of function will occur. CBM monitors the condition or performance of plant equipment through various technologies. The data is collected, analyzed, trended, and used to project equipment failures. Once the timing of equipment failure is known, action can be taken to prevent or delay failure. In this way, the reliability of the equipment can remain high. Condition based maintenance uses various process parameters (e.g. pressure, temperature, vibration, flow) and material samples (e.g. oil and air) to monitor conditions. With these parameters and samples, condition based maintenance obtains indications of system and equipment health, performance, integrity (strength) and provides information for scheduling timely correction action. The maintenance is initiated when indicators show the sign of faults in the incipient stages. In simple words, the main criterion is to maintain the right equipment at the right time. The practice of CBM is done by acquiring and analyzing the real time data, so that maintenance activities and resources can be prioritized/ optimized accordingly.

1.2 Problem Statement

The complicity of mechanical systems in thermal power plants makes monitoring process through preventive maintenance and online reading of bearings temperature and motor current a highly un efficient method ,since the prediction of failure time and causes cannot be determined. The implementation of ultrasound technique has been investigated in this research as a method of predicting and analyzing failure causes in rotating equipments for the case study of high pressure seal blowers, condensate extraction pumps and circulating water pumps in garri-4 power plant.

1.3 The Objective

This thesis aims to:

- To prevent rotating equipments from catastrophic failures;
- To recognize potential failures in their early stage;
- To detect the mechanical faults.

1.4 Methodology

By putting the rotating equipments in garri-4 power plant(high pressure seal blowers, condensate extraction pumps and circulating water pumps) under monitoring by using ultrasound condition monitoring technique (SDT 270 ultrasound device with two types of ultrasound sensors: RS1 Needle contact sensor and RS1 Threaded sensor) for diagnosing the mechanical faults to predict the need for maintenance before a deterioration or breakdown occurs. All data obtained may then be transferred to ultranaylsis suite software to make analysis.

CHAPTER II

LITERATURE REVIEW

2.1 Preface

In recent years, developed industrial systems have needed reliable machining systems. Today's industry uses many complex types of machines such as rotating machines. These machines should be well maintained in order to increase their availability and safety. Machine failure can have consequences such as production loss and safety problems because of unplanned production interruption (Yang et al., 2005). When a failure is noticed, the machine should be shut down immediately in order to prevent ruinous consequences. In this situation, time and money will be lost because the maintenance must be performed at inconvenient times (Li et al., 2000). an effective maintenance system is required to minimize the loss due to stoppage of production and machine breakdown cost, and to maximize the reliability, availability and safety of the machinery.

2.2 The Bathtub Curve

The change in the probability of the failure of a component over time is defined as the hazard rate, which is an important function in reliability engineering. The hazard rate is denoted by h (t), and it usually exhibits a bathtub shape for components. Therefore, it is referred to as a bathtub curve. This curve may be different for various types of components. A typical bathtub curve is shown in Figure (2.1).

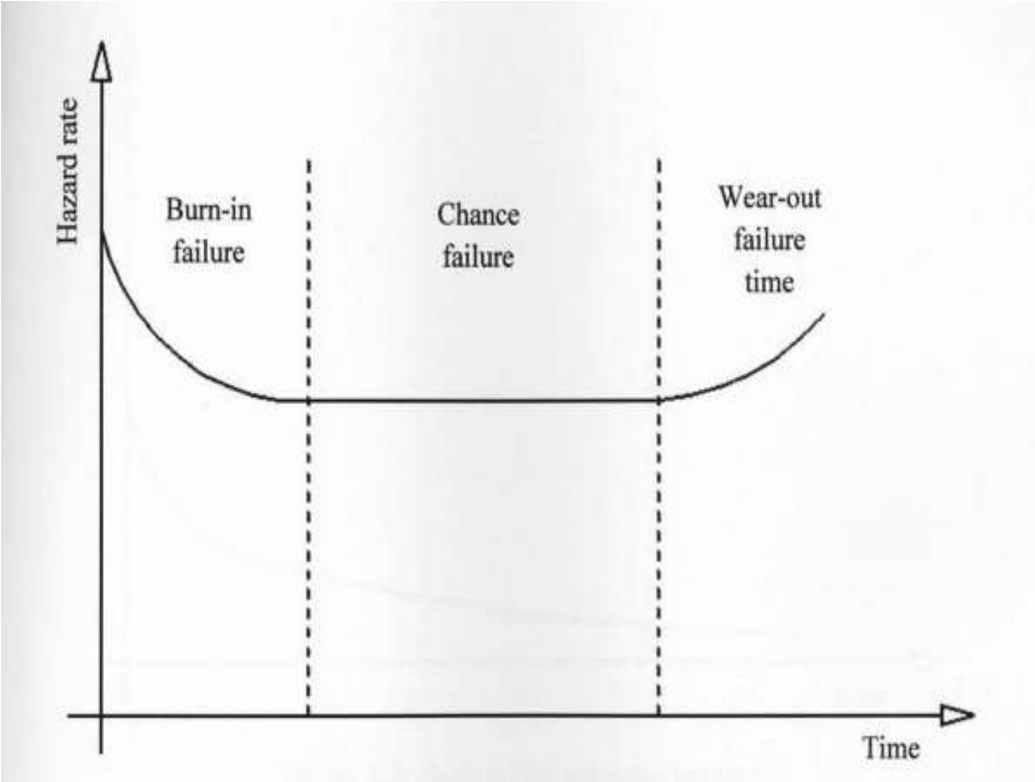


Figure (2.1) a typical bathtub curve

In general, this curve consists of three regions: burn-in failure, chance failure, and wear-out failure time.

2.2.1 Burn-in early failure

This region includes the potential failures that may take place due to the defects in design, manufacturing, construction, handling, or installation. This region exhibits a Decreasing Failure Rate (DFR). This period is unwanted because a great number of failures may happen. These failures are called "early infant mortality failures".

2.2.2 Chance failure

This region of a bathtub curve, which is also called the useful life region, includes the random failures that may occur during the useful life of a component. This region has a relatively constant failure rate. This does not mean that the failure rate is zero; it indicates that the failure rate is low, and it does not change significantly over time. It is wanted for the bottom of the bathtub curve in this region to be as low as possible.

2.2.3 Wear-out failure

This region includes the failures which may result from excessive wear in the component. In this region, the component weakens due to factors such as accumulated fatigue, and it is more vulnerable. Therefore, this region has an Increasing Failure Rate (IFR). The wear-out failures increase when the component becomes old.

2.3 Types of Maintenance

Maintenance is defined as a combination of all technical administrative and managerial actions during the life cycle of an item intended to retain in it, or restore it to a state in which it can perform the required function (EESTI STANDARD, 2010).The objectives of maintenance are to keep the machinery up and running, and to increase the Remaining Useful Life (RUL) of the machinery. These strategies can generally be classified to Corrective Maintenance (CM), Preventive Maintenance (PM), and Condition-Based Maintenance (CBM).

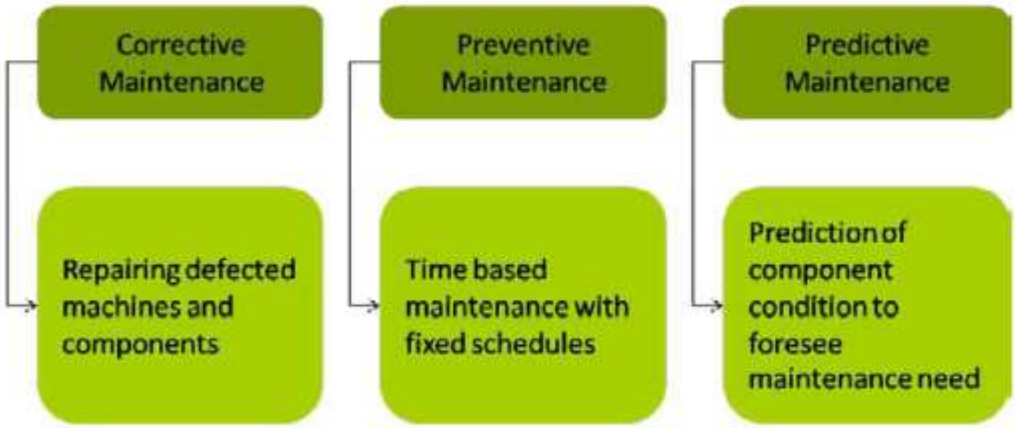


Figure (2.2) Maintenance Approaches (Söderbäack & Östman, 2010)

2.3.1 Corrective Maintenance (CM)

Corrective Maintenance (CM), also called breakdown maintenance (Mahalungkar and Ingram, 2004; Heng et al., 2009) is the first generation of maintenance strategy (Mourbay, 2000) which aims at rectifying the failure root causes resulting in the system breakdown. In other words, actions are taken to maintain the machinery only when it fails and requires repair or replacement. CM is used for simple machines that only need basic lubrication, cleanup, and servicing (Mahalungkar and Ingram, 2004).

2.3.2 Preventive Maintenance (PM)

Due to the complexity of the machinery and downtime cost, PM was introduced in the 1950s (Heng et al., 2009). It is also called time-based maintenance (Stephan and Laird, 2003) or scheduled maintenance (Mahalungkar and Ingram, 2004). PM is performed to keep machines working. Therefore, the equipment is routinely inspected and serviced in order to prevent potential breakdowns from occurring. In other words, the machine should be shutdown at scheduled intervals for maintenance/service regardless of the machine's health status. In order to have an effective PM, the maintenance interval should be determined optimally (Heng et al., 2009). In PM, most of the maintenance is unnecessary. Moreover, it is labor intensive, and there is no guarantee that the equipment will continue to work even if the maintenance actions are taken according to the routine schedule.

2.3.3 Condition-Based Maintenance (CBM)

Condition based maintenance (CBM) or Predictive maintenance (PdM) can be best described as maintenance practiced when need arises (Morales, 2002). This is done by monitoring the condition of the machine (or equipment) continuously or periodically depending upon the need for the availability of the machine. In this type of maintenance, the machinery health condition is monitored to detect any abnormality, and maintenance actions are only taken when required. Generally, mechanical components generate an abnormal transient signal in case of the occurrence of any fault condition (Wu and Hsu, 2009).

2.3.3.1 Condition-Based Maintenance Objectives

The CBM objectives can be summarized as follows: (Ciarapica and Giacchetta, 2006)

- To prevent harmful failures;
- To increase the safety of the machinery;
- To maximize the availability of the components;
- To decrease the maintenance cost of the equipment;
- To recognize potential failures in their early stage;
- To have an efficient inventory system, ordering only what is required, and only when needed;
- To detect damages in advance in order to prevent severe breakdown of the machines; and
- To document the health of the equipment.

2.3.3.2 Requirements of CBM

As mentioned before, CBM has many advantages over the other maintenance strategies; however, it requires that: (Wetzer et al., 2000)

1. The mechanisms of component failure and their criticality are known;

2. Appropriate indicators should be defined for the status of breakdown and degradation;

3. Suitable diagnostic tools are needed to compute these indicators; and

4. Some assessment tools are required to analyze the computations and evaluate the condition of the components in order to make maintenance decisions.

2.3.3.3 Key Elements of CBM

In a typical CBM model, useful data and information regarding the current condition and state of a machine are obtained. Then, the data should be processed by a model for the purpose of making decisions for maintenance actions. Three essential components of a successful CBM are:

1. Data Acquisition: The main objective of CBM is to minimize maintenance costs by performing timely maintenance and replacement actions. Therefore, the condition of the components should be assessed accurately, and the health information of the machine should be collected and stored for further analysis. This can be done by employing advance monitoring technology based on sensing devices mounted on the machine to collect the useful information. The information includes vibration, acceleration, temperature, pressure, and oil debris that can be measured and transmitted by sensors.

2. Data Processing: In this step, useful information for condition monitoring, which is called "features", should be extracted from the collected data. This is one of the most important steps of the CBM that is critical for the success of the diagnostic process (Yang et al., 2005). The selected feature(s) should provide precise information about the machine status. In addition, the features(s) should be able to reflect whether the component is working properly or not.

3. Decision Making: In this step, maintenance actions are recommended through diagnosis and/or prognosis:

a) Diagnosis: This contains the detection and classification of failures. Using sophisticated data acquisition and sensing technology, it aims at identifying the actual failures of a system. There exist three diagnostic techniques which can be used for CBM: (Wetzer et al., 2000)

1. Online monitoring: This is used to monitor appropriate features constantly to provide a timely warning.

2. Online diagnosis: This technique offers in service diagnosis, which can be at regular intervals (maintenance) or when potential failure is expected (intensive care).

3. Off-line diagnosis: This method is mostly used for costly components in order to find out the reason, location, and required maintenance/service action in case of observing a fault or degradation in the system.

b) Prognosis: This determines how likely it is for a failure to take place, and also how soon it will happen. In other words, prognosis means to apply predictive maintenance methods in order to evaluate the trends of machine condition against recognized engineering limits .The objective of prognostics is to identify, analyze, and correct problems before the failure actually occurs. Also, more advanced prognostic methods exist, which examine performance degradation of the machinery for the purpose of predicting and preventing the faults, and failures. There are three essential steps required for prognostics as follows: (Qiu et al., 2003)

1. The capability to detect the failure at its early stage;

2. To measure the performance of the equipment constantly; and

3.To assess the RUL with a confidence interval, and to estimate the possible failure modes of the equipment. Prognostics have many advantages including minimizing such problems as machine downtime, excessive spares inventory, maintenance costs, and unsafe circumstances (Heng et al., 2009). In general, prognostic methods can be categorized into model based and data driven approaches. The model based approaches need prior knowledge such as physical model or domain expert experiences about the system failure condition. In contrast, the data driven approaches do not require previous data about the system to be monitored. As a result, they are more effective and practical. Also, the data driven approaches are based on statistical techniques and the machine learning concepts from the theory of pattern recognition (Lei et al., 2007).

2.4 Condition Monitoring

Condition monitoring is a process of continuously monitoring operational characteristics of a machine to predict the need for maintenance before a deterioration or breakdown occurs.

2.4.1 Periodic Monitoring

Periodic monitoring involves intermittent data gathering and analysis with portable, removable monitoring equipment. On occasion, permanent monitoring hardware may be used for this type of monitoring strategy, but data is only collected at specific times. This type of monitoring is usually applied to noncritical equipment where failure modes are well known (historically dependable equipment).Trending of condition and severity level checks are the main focus, with problems triggering more rigorous investigations.

2.4.2 Continuous Monitoring

Constant or very frequent data collection and analysis is referred to as continuous monitoring. Permanently installed monitoring systems are typically used, with samples and analysis of data done automatically. This type of monitoring is carried out on critical equipment (expensive to replace, with downtime and lost production also being expensive).

2.5 Condition Monitoring Techniques

For mechanical systems condition monitoring technique include:

1. Vibration signature analysis (VSA)

2. Acoustic Emission Testing (AET)

3. Infrared thermography (IRT)

4. Lubrication oil analysis (LOA)

5. Ultrasonic condition monitoring (UCM)

2.5.1 Vibration signature analysis (VSA)

Vibrations in the context of condition monitoring is defined as “a periodic motion or one that repeats itself after a certain interval of time” by Mobley R Kieth in his book ‘Vibration Fundamentals’ (Mobley, Vibration Fundamentals, 1999).Vibration signature analysis (VSA) is a widely used condition monitoring technique to determine the overall condition of a machine, which is based on measurement of vibration severity of the machine under test. Vibration analysis, detects repetitive motion of a surface on rotating or oscillating machines. The repetitive motion may be caused by unbalance, misalignment, resonance, electrical effects, rolling element bearing faults, or many other problems.

2.5.2 Acoustic Emission Testing (AET)

Acoustic Emission Testing (AET) is a condition monitoring technique that is used to analyze emitted sound waves caused by defects or discontinuities. These acoustic emissions (AE) are transient elastic waves induced from a rapid release of strain energy caused by small deformations, corrosion or cracking, which occur prior to structure failure. In machines sources of AE include impacting, cyclic fatigue, friction, turbulence, material loss, cavitations, leakage, etc.(Alfayez and D. MBA,2004; Mba and Rao, 2006).

2.5.3 Infrared Thermography (IRT)

Temperature is one of the most common indicators of the structural and functional health of equipment and components. Faulty machineries, corroded electrical connections, damaged material components, etc., can cause abnormal temperature distribution .Infrared thermography (IRT) is the process of using thermal imagers to capture infrared radiations emitted by an object to locate any abnormal heat pattern or thermal anomaly which indicate possible fault, defects or inefficiencies within a system or machine asset(Chou and Yao, 2009).

2.5.4 Lubrication oil analysis (LOA)

Lubrication oil is used in electrical and mechanical machines to reduce friction between moving surfaces. The lubrication oil is important source of information for early machine failure detection. In comparison with vibration based machine health monitoring techniques, lubrication oil condition monitoring can provide approximately 10 times earlier warnings for machine malfunction and failure(Zhu,Yoon, He, Qu, and Bechhoefer, 2013). Lubrication oil analysis (LOA) includes fluid property analysis (fluid viscosity, additive level, oxidation properties and specific gravity), fluid contamination analysis (moisture, metallic particles, coolant and air) and wear debris analysis.

2.5.5 Ultrasound condition monitoring (UCM)

Ultrasound is defined as "sound waves having a frequency above the limits of human hearing, or in excess of 20,000 cycles per second"(A. Rienstra and J. Hall, 2002). Many physical events cause sound at audible and/or ultrasonic frequencies, analysis of these frequencies can frequently indicate correct or incorrect operation(Buckley, 2007). Ultrasonic condition monitoring (UCM) is a technique that uses airborne(non-contact) and structure borne(contact) ultrasound instruments to receive high frequency ultrasonic emissions produced by operating equipment, electrical emissions and leaks etc. to monitor the condition of equipment under test(A.Bandes, 2012). Ultrasound transducers electronically translate ultrasound frequencies through a process called heterodyning, down to the audible range while maintaining the sound quality during the transition. These signals are observed at intensity and/or dB levels for analysis.

In passive techniques ultrasound detected by airborne or structure borne instruments is produced by a physical process i.e. by the component being analyzed. Passive ultrasound is used mainly for contact methods of monitoring such as bearing faults, lubrication issues, gear damage and pump cavitations"(A. Rienstra and J. Hall, 2002) and non-contact methods of monitoring like leaks in boilers, condensers, and heat exchangers(A. Rienstra and S. D. T. N. America,2005), electrical discharge and corona in high voltage equipment(Buckley, 2007) etc. Airborne ultrasound detects high frequency sound produced by mechanical equipment, electrical discharges and most leakages which is extremely short wave in nature. These short wave signal tends to be fairly directional and localized which make them very easy to separate from background plant noises and to detect their exact location(A.Bandes, 2012). On the other hand active ultrasound is an approach where a precisely guided beam of ultrasound is transmitted to a physical structure to analyze both surface and subsurface discontinuities like delaminations, disbonds, cracks and porosity at early stages. The guided wave interacts with the structural discontinuity which causes reflection from a particular depth in material or scattering of guided waves in all directions, both results in transmission loss. These transmission losses can be detected by mapping the transmitted signal over the whole structure, known as a Through-transmission C-scan (R. A. Smith). From various characteristics of the received ultrasonic signal, such as the time of flight, amplitude, frequency content, etc., the information about the depth of the damage is assessed (Raišutis, Jasiūnienė, Šliteris, and Vladišauskas, 2008; Raišutis, Jasi, and Žukauskas, 2008).Ultrasound inspection offers a unique position for condition monitoring as both a "stand-alone" inspection technology and as an effective screening tool that can speed up the inspection process and help inspectors determine effective follow-up actions for mechanical, electrical and leak applications. The basic advantages of ultrasound are:

1. Ultrasound emissions are directional.
2. Ultrasound tends to be highly localized.
3. Ultrasound provides early warning of impending mechanical failure
4. The instruments can be used in loud, noisy environments
5. They support and enhance other PDM technologies or can stand on their own in a maintenance program.

2.6 Literature Review

Rotating machinery can be seen in many mechanical systems. In order to increase availability, reliability, and safety of the machinery systems, and to reduce maintenance cost, an effective maintenance system should be employed. Considering all components of rotating machinery, rolling element bearings play a vital role in the proper operation of the machinery (Qiu et al., 2003). Bearings failure is one of the foremost causes of failure in rotating machinery (Al-Raheem et al., 2009; Qiu et al., 2003; Li et al., 2000; Qiu et al., 2002; Yang et al., 2005). Although bearings are cheap components, they are critical to most machinery because bearing failure results in the failure of the whole machine. Feature extraction is an essential step for a successful diagnosis and prognosis procedure.

As Desforges et al. stated in 2000, measured parameters such as temperature, pressure, flow rate, or vibration patterns can generally be used for diagnostic purposes. According to Li et al., 2000, features such as temperature, wear debris, oil content, vibration, and acoustic emission can be measured to monitor the condition of rotating machines. Mba and Rao, 2006 and Menon et al., 2000 used acoustic emissions (AE) as a feature for monitoring the condition of rotating equipment .Generally, structural alternation in/on a solid material under thermal or mechanical stress will release strain energy. This can generate some transient elastic waves, which are called acoustic emissions AE (Tan et al., 2007). In rotating machinery, AE are described as elastic waves produced by the interaction of two media in relative motion. There are some sources of AE in rotary machinery such as impacting, cyclic fatigue, friction, turbulence, material loss, cavitation, and leakage (Tan et al., 2007).As discussed in (Anderson et al., 1999), spectrometric oil analysis (SOA) has been used for wear analysis of machinery. It is also an established tool for diagnosing the failures in mechanical components (Pusey, 2007).

In general, oil-wetted components impart tiny solid particles of metal on the lubricating oil. Therefore, a specific amount of metal particles in the oil is normal. However, any increase in this value is considered abnormal and should be detected in order to prevent failures and significant life reduction of the components. The idea behind the SOA is that the wear particles in the oil can provide some information about the source of the wear and machine condition. In other words, wear particles in an oil sample can be identified and quantified for the purpose of condition assessment of the machinery. Spectrometers can normally detect the wear particles between 5µm to l0µm in an oil sample (Tan et al., 2007).

Vibration monitoring has also been probed comprehensively in many engineering maintenance papers (Koo and Kim, 2000; McFadden and Toozhy, 2000; Jardine et al., 1999). A wide range of problems in rotating machinery such as imbalance, mechanical looseness, misalignment, gear defects, and motor problems can be identified using vibration analysis (Mahalungkar and Ingram, 2004). Moreover, it has been widely used for many bearing condition monitoring techniques to avoid sudden bearing breakdown (McFadden and Smith, 1984). As a result, vibration measurement can be used in order to predict the failure lifetime of a bearing (Qiu et al., 2003). Also, the application of vibration analysis for gear fault diagnosis is well recognized in industry (Gadd and Mitchell, 1984; Cameron and Stuckey, 1994). In addition, the vibration signal is more effective than the current signals for condition monitoring and fault diagnosis for induction motors (Han et al., 2007). As mentioned above, in a lot of cases, vibration is an outstanding tool for machinery health diagnosis (Suyi and Shuqing, 2006). The use of vibration signals is considered effective because the signals carry dynamic information on the health state of the machine (Lin and Qu 2000). As a result, vibration is considered a unique and applicable feature for condition monitoring of rotating machinery, and has received considerable attention because of economic benefits we get from its effectiveness (Zhan et al., 2003).

CHAPTER III

FIELD DESCRIPTION

3.1 Preface

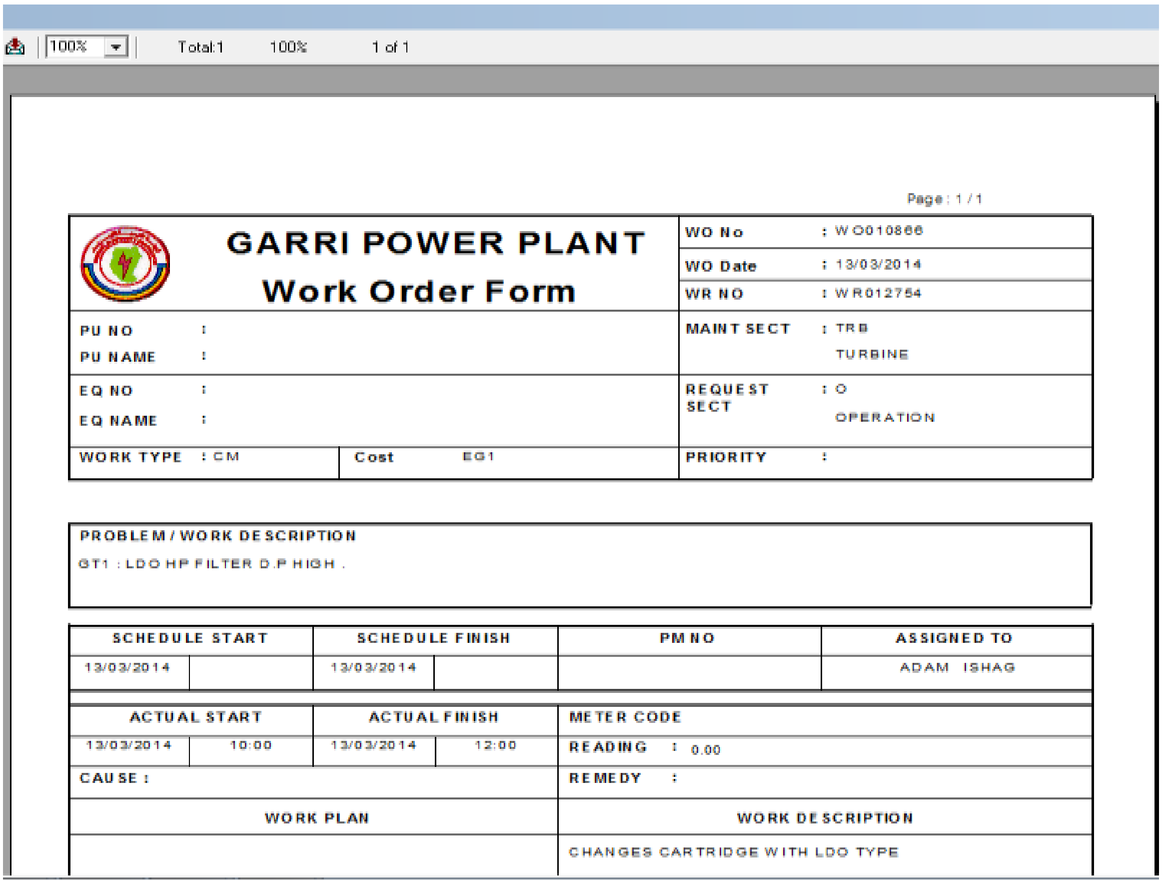
Garri-4 2×55MW Sponge Coke Fired power plant is located 70km north of Khartoum (capital of Sudan),13km east of the river Nile, and is nearby the Khartoum Refinery Cooperation . The power plant covers an area of about 16ha. It has an oblong structure, with a length of: 510.00m from south to north and width of 325.00 m. It consists of main power building: including two complete sponge coke fired CFB boiler units of 240 t/h, two units of 55 MW condensing turbo-generator and the relevant auxiliaries, Chemical demin station, Cooling tower and circulating water pumps, Clean water basin and industrial water pump room, Industrial wastewater treatment station, Domestic wastewater treatment station, Building of fuel conveying system such as coke conveying trestle and conveying transfer station, Building of limestone conveying system (reserved), Building of sand (bed material) injecting system, Building of fly ash and bottom ash conveying system, Substation , Air compressing station , Oil storehouse , Auxiliary boiler room , Emergency diesel generator room , Administration building, Garage , Firefighting station , Equipment maintenance workshop , Load meter room ,Bounding wall, watchtower and guards room.

3.2 Types of Maintenance in Garri-4 Power Plant

All maintenance operations in Garri-4 power plant are managed by cedar software. Garri-4 has two types of maintenance: Corrective Maintenance (CM) and Preventive Maintenance (PM).

3.2.1. Corrective Maintenance (CM)

Corrective maintenance can be divided into those items that require prompt attention and those that have been determined to be non-critical and can be repaired as needed. The operators monitor all the mechanical and electrical systems to detect faults (failure, leakage, up normal noise ….. etc), then transfer it to maintenance section to solve it.



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GARRI POWER PLANT

Work Order Form

	WO No : WO010866
	WO Date : 13/03/2014
	WR NO : WR012754
PU NO : PU NAME :	MAINT SECT : TRB TURBINE
EQ NO : EQ NAME :	REQUEST SECT : O OPERATION
WORK TYPE : CM Cost EG1	PRIORITY :

PROBLEM / WORK DESCRIPTION

GT1 : LDO HP FILTER D.P HIGH .

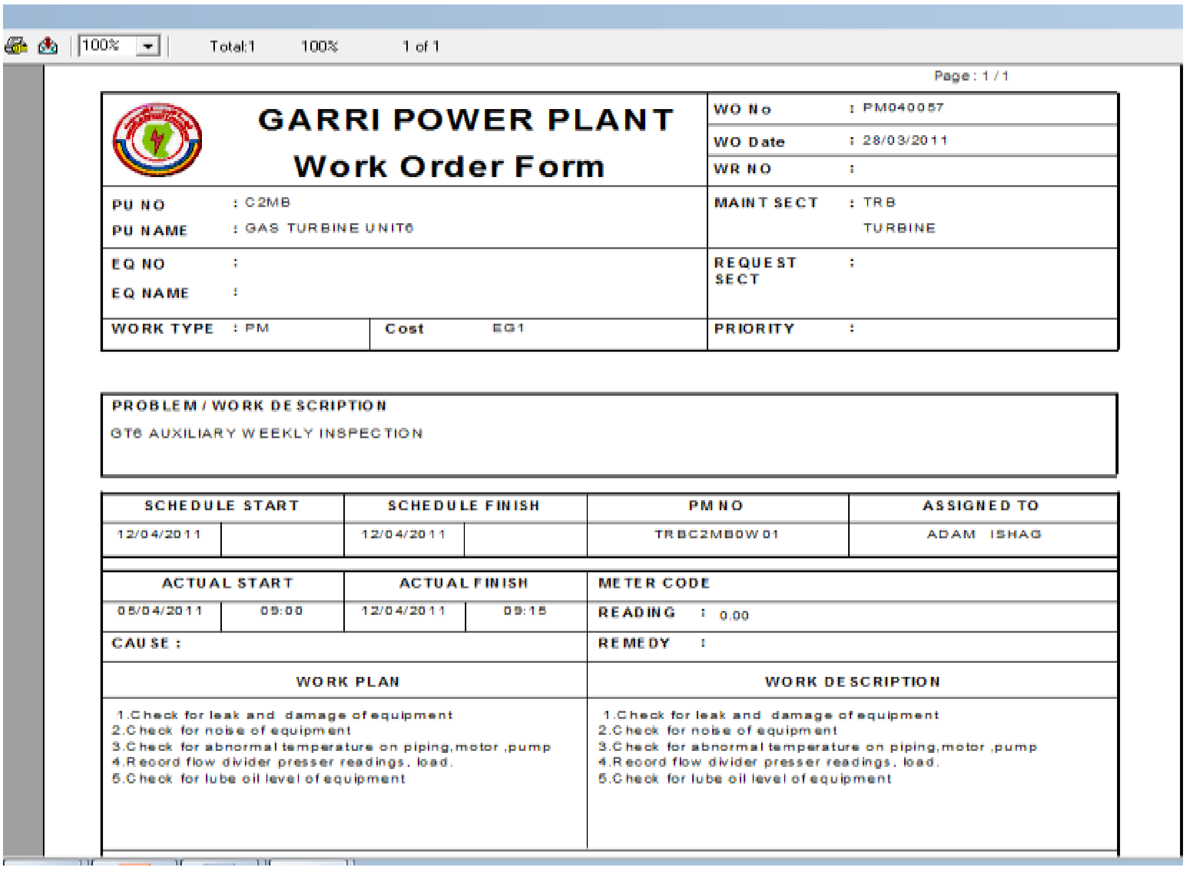
SCHEDULE START		SCHEDULE FINISH		PM NO	ASSIGNED TO
13/03/2014		13/03/2014			ADAM ISHAG

ACTUAL START		ACTUAL FINISH		METER CODE
13/03/2014	10:00	13/03/2014	12:00	READING : 0.00
CAUSE :				REMEDY :
WORK PLAN				WORK DESCRIPTION
				CHANGES CARTRIDGE WITH LDO TYPE

Figure (3.1) cedar corrective maintenance form

3.2.2. Preventive Maintenance (PM)

Preventive or periodic maintenance may be done at calendar intervals, after a specified number of operating cycles, or a certain number of operating hours. These intervals are established based on manufacturers recommendations, and utility and industry operating experience.PM can be daily, weekly or monthly and it work by maintenance team .


Total:1 100% 1 of 1

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GARRI POWER PLANT

Work Order Form

WO No	: PM040057
WO Date	: 28/03/2011
WR NO	:
PU NO	: C2MB
PU NAME	: GAS TURBINE UNIT6
MAINT SECT	: TRB TURBINE
EQ NO	:
EQ NAME	:
REQUEST SECT	:
WORK TYPE	: PM
Cost	EG1
PRIORITY	:

PROBLEM / WORK DESCRIPTION

GT6 AUXILIARY WEEKLY INSPECTION

SCHEDULE START		SCHEDULE FINISH		PM NO	ASSIGNED TO
12/04/2011		12/04/2011		TRBC2MB0W01	ADAM ISHAG

ACTUAL START		ACTUAL FINISH		METER CODE
05/04/2011	09:00	12/04/2011	09:15	READING : 0.00
CAUSE :				REMEDY :

WORK PLAN	WORK DESCRIPTION
1.Check for leak and damage of equipment 2.Check for noise of equipment 3.Check for abnormal temperature on piping,motor ,pump 4.Record flow divider presser readings, load. 5.Check for lube oil level of equipment	1.Check for leak and damage of equipment 2.Check for noise of equipment 3.Check for abnormal temperature on piping,motor ,pump 4.Record flow divider presser readings, load. 5.Check for lube oil level of equipment

Figure (3.2) cedar preventive maintenance form

3.3 Circulating water pumps (C.W.Ps)

Sudan Garri-4 power plant's circulating water system has six circulating water pumps (four in operation, two are standby)which have the same model, same specifications and same performance. Three of them are rotating clockwise (viewing from driven end to pump), the other three are turning anticlockwise. The circulating water pump is single stage, horizontal type, intermediate opening type, double-suction centrifugal pump. Each unit has three circulating water pumps (two operating and one standby). Circulating water is pumped into open cooling water header by circulating water pumps. Each set of circulating water pump system consist s of inlet motor-operated butterfly valve, circulating water pump and outlet hydraulic-operated butterfly valve. The outlet hydraulic-operated butterfly valve will cooperate circulating water pump to start.

3.4 Condensate extraction pumps (C.E.Ps)

The function of condensate pump is to extract the condensate in hot well of condenser uninterruptedly, making sure the necessary vacuum of condenser. Each set of CEP system consists of manual inlet valve, filter, CEP, manual no-return valve and outlet motor-operated valve. The outlet valves shall be close in the course of CEP start-up. The pump consists of pump body, pump cover, which bear all working pressure and thermal load caused by media. The bearing adopts the rolling bearing which is lubricated by dilute oil. Gland seal adopts mechanical seal.

3.5 High Pressure Seal Blowers (H.P.Ss)

JTS series group type blower, Roots blower is a kind of capacity type power machinery; the two impellers rotate in reverse directions through the driving of a pair of synchronous gear. The air inlet and the exhaust outlet are separated by a meshing of the impeller (a certain clearance exists between the impellers so they don’t contact each other) to push the sucked air from the suction inlet to exhaust without internal compression; at the instant of reaching the exhaust outlet, the conveyed air does work as being conveyed to the system by pressure because of discharging the reflux of the side high pressure air.

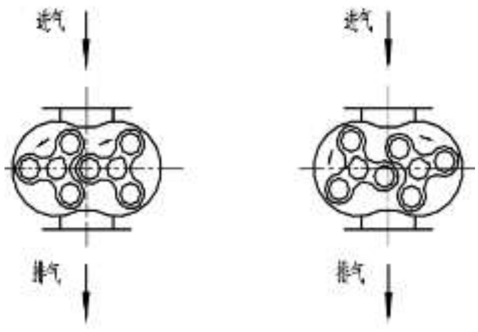


Figure (3.3) Brief diagram of working principle of H.P.S

3.5.1. Performance parameters of material return Roots fan

Table (3. 1) Performance parameters of material return Roots fan

Air intake temperature	20℃
Air intake pressure	101.325kPa
Relative humidity	50%
Conveying medium	clean air
Pressure rise	0~58.8kPa
Inlet flow	0.54~64.7m 3 /min

3.5.2. Installation of JTS type Roots fan

Table (3.2) components of JTS root fan

1. Roots blower	6. Sound shield
2. Inlet silencer LKM type	7. Safety valve
3. Motor	8. Pressure meter
4. Outlet silencer	9. T type joint
5. Elastic joint	10. Non-return valves

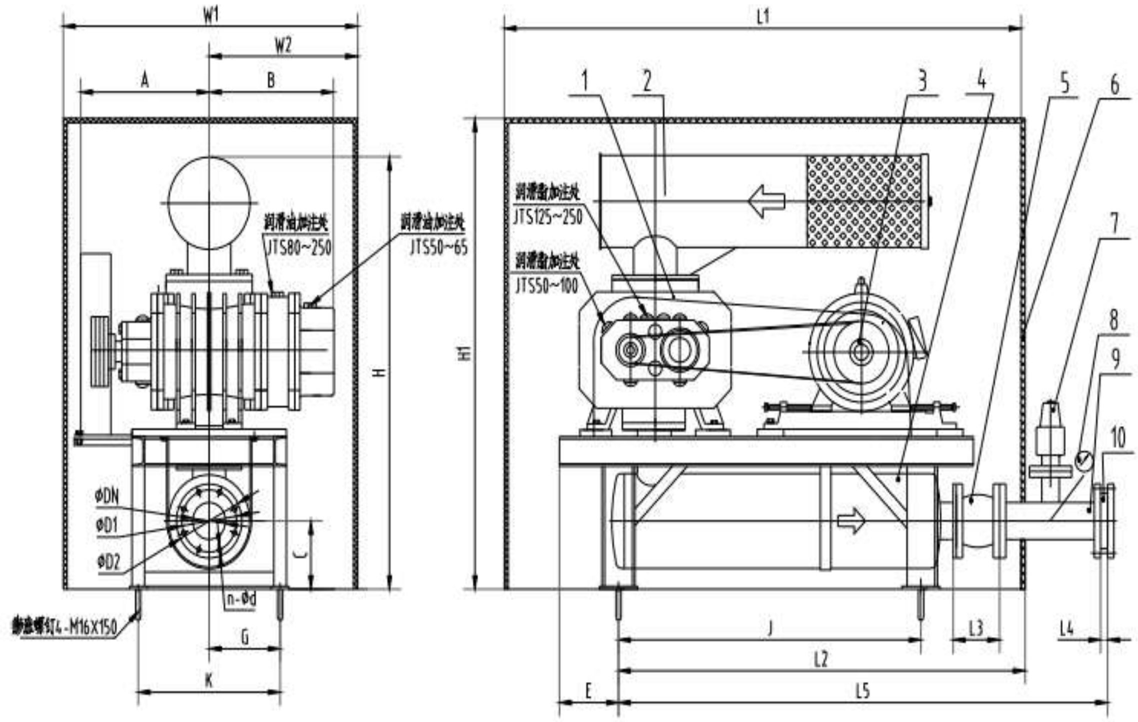


Figure (3.4) Installation diagram of JTS type Root fan

3.6 Ultrasound Technique

Condition monitoring is about using measurements and observations to identify the presence of a defect or problem in such a way that maintenance can be scheduled to repair or alleviate that problem. Condition monitoring is a wide-ranging discipline which requires the training of many different craft groups within a business – mechanical, electrical, steam, process, instrument and of course operators. Whenever there is a failure mode which generates friction, turbulence or impacting. Ultrasound offers a potentially higher return on investment than any other tool simply in terms of the wide range of applications of ultrasound. Ultrasound has another specific application area which provides unique help namely when trying to perform condition assessment on rotating machines which are themselves in areas of high vibration: screens, mobile applications and marine applications are typical examples.

3.6.1 Airborne Sensors

There are two key types of sensor used for ultrasound – airborne and structure-borne. Airborne sensors detect ultrasound in the air. It is useful to be able to select a sensor which is most suited for the task in hand. If the inspection requires distance work, consider using an acoustic horn (Extended Distance Sensor) or a parabolic dish to increase the sensitivity of your ultrasound device. For general purpose applications, or for working in cramped conditions, a flexible sensor may be the ideal accessory. Airborne sensors have different types of response behavior. The parabolic dish works in a different way by focusing the ultrasound signal to a focal point on the dish. This makes this type of detector suitable for pin-point location from a distance.



flexible sensor	Paradish2 sensor	Extended distance sensor

Figure (3.5) airborne sensors

3.6.2 Structure-Borne Sensors

For detecting ultrasound inside a bearing housing or a valve or a steam trap, a structure-borne sensor is used. There are three basic arrangements: hand-held, magnet mount and permanent installation. A structure-borne sensor is a resonant sensor designed to produce as high a signal as possible from the very small level of ultrasound actually produced.

	
RS1 Needle contact sensor	RS1 Threaded sensor

Figure (3.6) structure-borne sensor

3.6.3 Heterodyne Principle

All quality ultrasound measurement instruments have a heterodyne circuit. The purpose of the heterodyne circuit is to make the inaudible ultrasound signal audible. The basis of the operation is a specific piece of trigonometry:

$$\sin\theta\sin\varphi = \frac{\cos(\theta-\varphi)-\cos(\theta+\varphi)}{2} \qquad (3.1)$$

This equation predicts that when multiplying two different frequencies together, two new frequencies are created – one at the sum frequency and one at the difference.Multiplying (or mixing) two sinusoidal signals together creates two cosine signals whose frequencies are the sum and the difference of the two original signals.

3.6.4 Measurement of Ultrasound

It is important to remember that an ultrasound signal is a dynamic signal. The nature or characteristic properties of that signal is something that you can listen to live and which you can characterize in a number of different ways. One way in which the measured ultrasound signal can be characterized presents the data as:

1. The peak value,
2. The RMS value,
3. The crest factor.

These Condition Indicators as they are sometimes called are used to provide a numeric classification of bearing condition which can be trended and have alarms applied. There is a very common misconception, in the vibration world particularly, that the peak value of a signal is 1.414x (√2x) the RMS value. In fact, this is only true for a single frequency sinusoidal signal.

The true Peak value will be the highest value measured in a signal and this needs to be measured very quickly in order to capture any fast transients in the signal. The higher the frequency used for the sampling of the signal, the better the detection of the peaks. The RMS (root mean square) value is calculated over the whole sample of the recorded signal and essentially represents how much total signal strength there is. The ratio of the peak value to the RMS value is called the Crest Factor and this parameter is an extremely useful means of quantifying how “peaky” a signal is. The Crest Factor for a single sine wave is therefore this value of 1.414. For random noise the Crest Factor would typically be about 3. If the signal were to include any sharp spikes or clicks or pops, the Crest Factor could easily increase to 6, 10, 20 or even higher.

3.6.5 Capturing time domain and spectrum signals for analysis

Recording the signal that is actually heard in the field can be of enormous benefit. Firstly it can be used for analysis and diagnosis but secondly it can be used for communication. The recorded signal can be either sent on its own as an email attachment or embedded in document.

There are two ways to collect dynamic data – in the Time Domain and in the Frequency Domain. It is important to remember that non-repeating, intermittent signals, break the laws of Fourier's mathematics and so this type of signal should be captured in the Time Domain rather than the Frequency Domain (also commonly known as the spectrum and the FFT). In fact, it is always going to be the case that capturing the time signal first is the correct way to collect data in ultrasound.

3.6.6 Trending Values

A major element in operating a successful on-condition lubrication program using ultrasound is replacing work orders that say "grease…." with work orders that say "measure and grease as indicated". Taking routine ultrasound readings allows the inspector to build up trends for the ultrasonic condition of each and every bearing. The trigger for assessment is a rule which was first proposed by NASA:

If the new value is more than 8dBµV above the last value, grease the bearing

If the new value is more than 16dBµV above the last value, there is possible damage.

If the new value is more than 24dBµV above the last value, there is probable damage.

This basic guideline does assume that the bearing is operating under conditions of constant speed and load and so may need to be refined in more complicated circumstances.

3.6.7 Spectrum Analysis

The spectrum is a way of analyzing and plotting a dynamic signal which shows the amount of signal present in each of a specific range of frequencies. The spectrum is an extremely important way to examine events which are continuous signals. Defect frequencies are calculated for this application in units of Hertz (Hz) or cycles per minute (CPM). The relationship between Hz and CPM is the same as the relationship between seconds and minutes, namely a factor of 60: CPM=60xHz making Hz = CPM/60.

To use these defect frequencies in the time signal, you need to convert the frequencies into period T which will be in units of seconds.

$$T = \frac{1}{Hz} \tag{3.2}$$

$$T = \frac{1}{\left(\frac{CPM}{60}\right)} = \frac{60}{CPM} \tag{3.3}$$

3.7 Bearings Defect Detection

Vibration analysis refers to 4 stages of bearing failure, the first of which is characterized by friction and then intermittent clicks and pops. These first stage events are evident in the ultrasonic frequency range. Contact ultrasound has a role to play in bearing condition assessment. There are various types of contact sensor. If multiple people will be taking readings, consider setting up magnetic targets (keeping in mind the Specific Acoustic Impedance discussions) and using a magnet sensor instead of a hand-held sensor. This will eliminate the variations in sensor positioning and applied pressure which can cause variations in the measured signals. Airborne ultrasound also has a role to play in bearing condition assessment. If the bearing is an open bearing on a shaft - for example a pillow block or Plummer block bearing this type of bearing will produce ultrasound which can be detected using either an airborne sensor or contact sensor. As an aside, another problem which can be detected in airborne mode is a loose mounting bolt. As a bearing defect deteriorates, discrete bearing defect frequencies may develop. These defect frequencies are dependent upon the geometry of the bearing and its rotational speed.

Ratio = d/D cos ∅ (3.4)

BPFO =n/2*(rpm/60)*(1-ratio) (3.5)

BPFI =n/2*(rpm/60)*(1+ratio) (3.6)

BSF =1/2*(rpm/60)*(1-ratio2) (3.7)

FTF =1/2*(rpm/60)*(1-ratio2) (3.8)

$\emptyset = contact\ angle$

n=number of rolling elements

3.8 Pumps Inspection

Pumps can have issues with bearings, coupling alignment, seals, cavitation and mechanical looseness. It is extremely important to remember that it is not sensible to look at the pump in isolation – the condition and operating conditions of the suction and discharge valves can have a significant impact on the operating condition of the pump. It is therefore good practice to include an inspection of these valves along with any non-return valves if there is more than one pump on the same skid or pipe work as part of the inspection of the pump.

Cavitation can be a big killer of pump impellors. These two impellors are prime examples:

Figure (3.7) pumps cavitation

Cavitation is caused by the implosion of vapor bubbles. This implosion sucks material off the surface of the impellor resulting in the damage seen here. The random popping of the bubbles is clearly audible even at relatively low levels of cavitation with ultrasound. Coupling issues like misalignment, looseness and wear can also be detected quite easily and quickly using airborne ultrasound. Misalignment produces a once-per-rev increase in friction which is detectable audibly at slow speed and visible in the time signal at any speed. Looseness, wear and poor friction produces the same continuous harsh noise associated with friction for example like a poorly lubricated bearing. It is possible that the poor lubrication condition of the coupling might mask a more sinister defect such as tooth wear in a gear coupling.

3.9 SDT 270 Ultrasound Device

The SDT 270 is a portable ultrasound device dedicated to Predictive Maintenance and Energy saving, covering a wide range of applications, meeting the needs of the Maintenance Departments. The device is upgradeable which means that you can add functionalities, sensors, software and accessories as and when you need it. So your investment in your SDT270 will be paying you back for years to come.

Figure (3.8) SDT270 Ultrasound Device

3.9.1. Main features of SDT 270

- Measures broadband ultrasound signals with a 100 kHz bandwidth.
- Realizes data acquisition with a 250 kHz sampling frequency.
- Uses long-duration time sampling and data streaming.
- Integrates built-in thermometer and tachometer with a laser.
- Includes a SQL database.
- Includes an Operator logging in.
- Insures full measurement traceability from Operator to sensor.
- Warns the Operator when an alarm is triggered.
- IP (Internet) addressable.
- Remotely controlled and operated.
- Incorporate 2 measurement channels.

SDT270 has two measurements channels for external sensors:

- The first one is equipped with a black collar. It corresponds to the B choice on the display. The black collar LEMO is reserved for ultrasonic and Mass Flow sensors.
- The second one with a red collar. It corresponds to the R choice on the display. The Red collar LEMO connector is reserved for accelerometers.

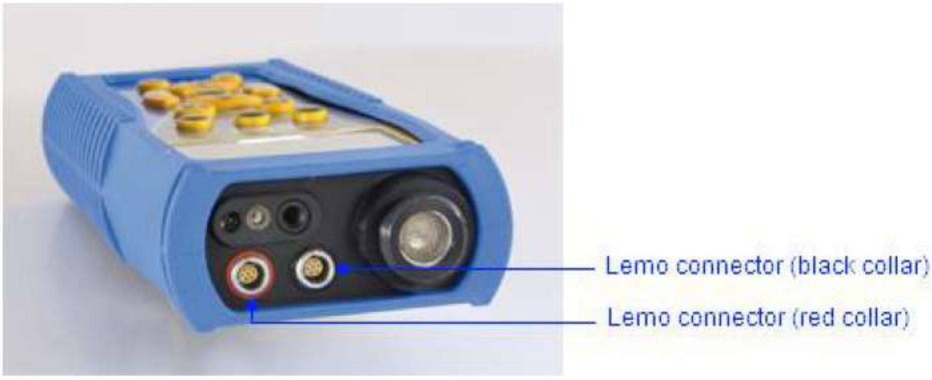


Figure (3.9) SDT connectors

3.9.2. Keyboard functions

- F1 to select a sensor.
- F2 to select a measurement type
- F3 to adjust the settings for the sensor in use.
- Disc button to save measurements.
- M button to start the measurement acquisition.
- Up and down arrows to increase and decrease amplification (used for US sensors).
- Left and right arrows to decrease and increase the audio volume of the headphones.
- Enter to access to the menus.

3.10 Case studies

3.10.1. Ultrasound measurements for H.P.S blower (1)

Table (3.3) Ultrasound measurements for BRG 1 of H.P.S (1)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #1/MOTOR/BRG 1/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	8.1	8.3	24.1	6.31	13/03/2018	09:59	default
	10.5	12.9	40.1	30.2	12/03/2018	10:08	default
	10.3	10.7	27.8	7.51	07/03/2018	09:36	default
	11.1	16.8	42.2	35.88	06/03/2018	09:26	default
	11.2	12.8	32.9	12.17	05/03/2018	09:58	default
	9.6	12.4	28.1	8.41	04/03/2018	08:37	default
	9.5	13.2	40.9	37.1	01/03/2018	08:38	default
	10.6	13.4	37.2	21.37	28/02/2018	09:00	default
	11.2	12.2	31.2	10	27/02/2018	08:06	default
	10.8	12.7	35.8	17.77	21/02/2018	07:45	default
	10.2	13.1	37.4	22.88	18/02/2018	13:50	default

Table (3.4) Ultrasound measurements for BRG 2 of H.P.S (1)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #1/MOTOR/BRG 2/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	98.9	99.8	118.2	9.23	14/03/2018	10:40	default
	94.8	95.4	113.5	8.61	13/03/2018	10:01	default
	97.9	98.6	119.5	12.02	08/03/2018	11:03	default
	88.6	90.6	116.2	23.99	07/03/2018	09:38	default
	84.4	89.5	108.3	15.67	06/03/2018	09:28	default
	87.2	87.8	111	15.49	05/03/2018	10:00	default
	84.1	86.1	109.5	18.62	04/03/2018	08:39	default
	80	80.6	98.8	8.71	27/02/2018	08:08	default
	86.7	88.5	112.2	18.84	26/02/2018	08:24	default
	81.5	82.9	108.9	23.44	21/02/2018	07:47	default

Table (3.5) Ultrasound measurements for BRG 3 of H.P.S (1)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #1/FAN/BRG 3/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	98.8	100.5	118.2	9.33	14/03/20...	10:42	default
	93.6	95.2	113.7	10.12	13/03/20...	10:03	default
	100	100.9	119.4	9.33	08/03/20...	11:05	default
	90.5	91.8	114	14.96	07/03/20...	09:39	default
	93.9	94.5	115.1	11.48	06/03/20...	09:30	default
	93.9	96	111.8	7.85	05/03/20...	10:02	default
	97.2	98.2	114.6	7.41	04/03/20...	08:41	default
	94.4	95.1	114.5	10.12	01/03/20...	08:42	default
	102.4	102.9	118.1	6.1	28/02/20...	09:05	default
	96.1	96.7	116.5	10.47	27/02/20...	08:10	default
	89.8	90.8	114.7	17.58	26/02/20...	08:27	default
	100.5	101.7	119.6	9.02	25/02/20...	11:00	default
	93.8	94.7	114.1	10.35	21/02/20...	07:50	default

Table (3.6) Ultrasound measurements for BRG 4 of H.P.S (1)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #1/FAN/BRG 4/UT/RS1T(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		88.2	89	109.8	12.02	14/03/2018	10:43	default
		91.2	93	113.8	13.49	13/03/2018	10:05	default
		91.6	93.2	113.6	12.59	08/03/2018	11:07	default
		91	91.9	114.7	15.31	07/03/2018	09:41	default
		93.1	96.1	116	13.96	06/03/2018	09:32	default
		87.7	88.9	109.7	12.59	05/03/2018	10:04	default
		89.9	91.8	113.4	14.96	04/03/2018	08:43	default
		90.8	93.2	113.9	14.29	27/02/2018	08:13	default
		91.1	92.8	117.5	20.89	26/02/2018	08:30	default
		90.6	91.8	113.6	14.13	25/02/2018	11:03	default
		90.4	91.8	114	15.14	21/02/2018	07:53	default

Table (3.7) Ultrasound measurements for BRG 5 of H.P.S (1)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #1/FAN/BRG 5/UT/RS1T(ST-Ht)

	Level Nam	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		83	86.5	110.7	24.27	14/03/2018	10:45	default
		84.5	85.7	102.2	7.67	13/03/2018	10:08	default
		82.2	83.7	103.4	11.48	12/03/2018	10:17	default
		89.3	91.6	115.4	20.18	08/03/2018	11:09	default
		83.7	84.4	104.1	10.47	07/03/2018	09:43	default
		81.1	84.1	107.6	21.13	06/03/2018	09:35	default
		84.7	85.4	103.4	8.61	05/03/2018	10:07	default
		86.5	88.9	116.9	33.11	04/03/2018	08:46	default
		79.5	80.2	98.1	8.51	01/03/2018	08:47	default
		97.5	98.8	116.8	9.23	28/02/2018	09:10	default
		82.5	87.9	115.9	46.77	27/02/2018	08:16	default
		80.1	80.9	104.3	16.22	26/02/2018	08:32	default
		85.3	86	111.7	20.89	25/02/2018	11:05	default
		84.1	92.1	117.6	47.32	21/02/2018	07:55	default

Table (3.8) Ultrasound measurements for BRG 6 of H.P.S (1)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #1/FAN/BRG 6/UT/RS1T(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		84	85.3	107.6	15.14	14/03/2018	10:47	default
		97.5	99.2	119.2	12.16	13/03/2018	10:10	default
		78.1	79.5	97.3	9.12	12/03/2018	10:19	default
		77.6	79.2	101.7	16.03	08/03/2018	11:10	default
		77.4	78.3	98.3	11.09	07/03/2018	09:45	default
		77.6	78.8	102.4	17.38	06/03/2018	09:37	default
		79.1	80.2	103.7	16.98	01/03/2018	08:50	default
		102.6	103.6	120.2	7.59	28/02/2018	09:12	default
		85.9	87.3	106.3	10.47	27/02/2018	08:18	default
		84	86.2	113.9	31.26	26/02/2018	08:34	default
		83.2	87.7	113	30.9	25/02/2018	11:07	default
		72.5	73.5	92.1	9.55	21/02/2018	07:58	default

3.10.2. Ultrasound measurements for H.P.S blower (2)

Table (3.9) Ultrasound measurements for BRG 1 of H.P.S (2)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #2/MOTOR/BRG 1/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Fact	Date	Time	Operator
	9.6	12.6	35.8	20.42	13/03/2018	10:13	default
	6	6.9	20.1	5.06	12/03/2018	10:22	default
	3.1	4.9	23.4	10.34	08/03/2018	11:13	default
	11.3	14.2	40.6	29.2	07/03/2018	09:48	default
	11.9	13.3	32.3	10.46	06/03/2018	10:48	default
	5	6.5	25.2	10.22	05/03/2018	10:13	default
	6.9	9.2	29.6	13.67	01/03/2018	08:53	default
	2.6	4.3	24.8	12.87	27/02/2018	08:20	default
	2.5	4.2	23.5	11.25	26/02/2018	08:37	default
	6.4	7.9	34.5	25.4	21/02/2018	08:02	default
	8.5	9.6	30.3	12.3	18/02/2018	14:11	default

Table (3.10) Ultrasound measurements for BRG 2 of H.P.S (2)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #2/MOTOR/BRG 2/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Fact	Date	Time	Operator
	91.3	93.7	114.4	14.29	14/03/2018	10:51	default
	85.7	85.9	97.9	4.07	13/03/2018	10:15	default
	97.1	97.4	108.6	3.76	12/03/2018	10:24	default
	94.1	94.7	107.4	4.62	08/03/2018	11:14	default
	87.5	87.7	103.8	6.53	07/03/2018	09:50	default
	84.6	89.2	114	29.51	06/03/2018	10:49	default
	96.1	96.3	108.9	4.37	05/03/2018	10:15	default
	86.9	87.5	100.7	4.9	28/02/2018	09:17	default
	83	84.3	102.7	9.66	27/02/2018	08:22	default
	82.3	83.1	97.4	5.69	26/02/2018	08:39	default

Table (3.11) Ultrasound measurements for BRG 3 of H.P.S (2)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #2/FAN/BRG 3/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	93.7	95	115.4	12.16	14/03/20...	10:53	default
	91.6	93.4	113	11.75	13/03/20...	10:17	default
	93.8	95.8	115.4	12.02	07/03/20...	09:52	default
	97.9	99	120.4	13.34	06/03/20...	10:51	default
	84.8	87.5	111.6	21.88	04/03/20...	08:56	default
	102.1	103.2	118.4	6.53	01/03/20...	08:58	default
	98.3	99.3	115.6	7.33	28/02/20...	09:18	default
	99.4	100.8	119	9.55	27/02/20...	08:24	default
	96.5	98.3	118.8	13.03	25/02/20...	11:14	default
	92.9	95.2	118.8	19.72	22/02/20...	08:49	default
	100.3	101.6	119	8.61	21/02/20...	08:07	default

Table (3.12) Ultrasound measurements for BRG 4 of H.P.S (2)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #2/FAN/BRG 4/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Fact	Date	Time	Operator
	91	93.8	113.9	13.96	14/03/2018	10:55	default
	91.5	94.7	114.5	14.13	13/03/2018	10:20	default
	95.3	96.7	115.8	10.59	07/03/2018	09:54	default
	99.9	100.7	119.4	9.44	06/03/2018	10:53	default
	83.4	85.8	108.9	18.84	04/03/2018	08:59	default
	101.5	103	119.4	7.85	01/03/2018	09:00	default
	101.3	103.7	119.2	7.85	28/02/2018	09:21	default
	96	98	119.1	14.29	25/02/2018	11:16	default
	91.7	93.4	116.4	17.18	22/02/2018	08:52	default
	102.7	103.9	119.4	6.84	21/02/2018	08:10	default

Table (3.13) Ultrasound measurements for BRG 5 of H.P.S (2)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #2/FAN/BRG 5/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Fact	Date	Time	Operator
	10.9	12.1	29.6	8.6	13/03/2018	10:24	default
	10.7	11.3	27.7	7.08	12/03/2018	10:32	default
	18	20.4	42.9	17.59	08/03/2018	11:20	default
	10.7	11.7	30.7	9.99	05/03/2018	10:21	default
	14.9	15.6	37.5	13.49	04/03/2018	09:01	default
	8.6	9.1	24.4	6.17	27/02/2018	08:30	default
	12.2	13	30	7.77	26/02/2018	08:47	default
	6.2	10.8	35.6	29.54	18/02/2018	14:20	default

Table (3.14) Ultrasound measurements for BRG 6 of H.P.S (2)

M.HUSSAIN/H.P SEAL FAN/SEAL FAN #2/FAN/BRG 6/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	80.2	83.2	105.2	17.78	14/03/20...	10:59	default
	97.6	98.7	117.1	9.44	13/03/20...	10:26	default
	83.1	85.3	111.1	25.12	08/03/20...	11:22	default
	86	86.7	107	11.22	07/03/20...	09:59	default
	81.6	82.8	107.2	19.05	06/03/20...	10:57	default
	78	79.9	96.4	8.32	05/03/20...	10:23	default
	77.6	78.3	98.4	10.96	04/03/20...	09:04	default
	86.7	88	110.2	14.96	01/03/20...	09:04	default
	84.3	85	105.9	12.02	28/02/20...	09:27	default
	78.6	79.3	98.1	9.44	27/02/20...	08:32	default
	78.2	80.6	103.4	18.2	26/02/20...	08:49	default
	86.6	87.1	101.8	5.75	25/02/20...	11:22	default
	85.3	86.4	107.4	12.74	22/02/20...	08:57	default
	87.3	88.3	104.3	7.08	21/02/20...	08:16	default

3.10.3. Ultrasound measurements for C.E.P (1)

Table (3.15) Ultrasound measurements for BRG 1 of C.E.P (1)

M.HUSSAIN/C.E.P/C.E.P PUMP #1/MOTOR/BRG 1/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	22.9	27.7	45.1	12.89	13/03/2018	10:44	default
	21.2	24.4	44.9	15.31	12/03/2018	10:51	default
	24.1	27.3	48.4	16.41	07/03/2018	11:26	default
	23.1	25.1	46.8	15.31	01/03/2018	10:29	default
	15.2	17.9	39.9	17.19	28/02/2018	10:40	default
	17	19.7	44.3	23.17	26/02/2018	10:23	default
	19.1	23.5	45.9	21.87	22/02/2018	10:31	default
	17.6	22.6	46.6	28.17	21/02/2018	10:11	default
	23.1	23.4	38.9	6.17	19/02/2018	10:21	default

Table (3.16) Ultrasound measurements for BRG 2 of C.E.P (1)

M.HUSSAIN/C.E.P/C.E.P PUMP #1/MOTOR/BRG 2/UT/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	99.1	100.3	115.4	6.53	12/03/2018	10:53	default
	101.4	102	116.5	5.69	08/03/2018	11:44	default
	99.2	100.4	116.2	7.08	07/03/2018	11:28	default
	99.5	100.8	115.7	6.46	06/03/2018	09:57	default
	100.3	101.1	115.1	5.5	05/03/2018	10:43	default
	97.9	98.6	113.4	5.96	04/03/2018	11:09	default
	98.1	98.8	116.8	8.61	01/03/2018	10:32	default
	98.4	99	112.3	4.95	26/02/2018	10:27	default
	98.3	99.2	113.4	5.69	22/02/2018	10:35	default
	99.3	100.3	112.9	4.79	21/02/2018	10:16	default
	93.8	94.7	113.8	10	19/02/2018	10:31	default

Table (3.17) Ultrasound measurements for BRG 3 of C.E.P (1)

M.HUSSAIN/C.E.P/C.E.P PUMP #1/PUMP/BRG 3/UT/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	44.4	45.8	66.1	12.16	14/03/2018	11:18	default
	45.8	47	61	5.75	12/03/2018	10:56	default
	42.6	43.3	58.3	6.1	08/03/2018	11:47	default
	43.8	45.1	60.2	6.61	07/03/2018	11:31	default
	44.5	45.9	58.8	5.19	06/03/2018	10:00	default
	44.4	45.4	61.7	7.33	05/03/2018	10:46	default
	44.2	45.4	61.8	7.59	04/03/2018	11:12	default
	42.8	43.4	59.5	6.84	01/03/2018	10:34	default
	43	44.7	57.5	5.31	26/02/2018	10:29	default
	41.7	42.7	58.6	7	22/02/2018	10:39	default

Table (3.18) Ultrasound measurements for BRG 4 of C.E.P (1)

M.HUSSAIN/C.E.P/C.E.P PUMP #1/PUMP/BRG 4/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	89.7	90.8	104.8	5.69	12/03/20...	10:58	default
	88.1	89.1	104.9	6.92	08/03/20...	11:49	default
	87.8	89	104.8	7.08	07/03/20...	11:33	default
	86.9	87.8	102.6	6.1	06/03/20...	10:03	default
	86.9	87.4	102.7	6.17	05/03/20...	10:48	default
	88.5	89.1	105.5	7.08	04/03/20...	11:14	default
	86.4	87.4	102.5	6.38	01/03/20...	10:37	default
	91.7	93	112.1	10.47	28/02/20...	10:45	default
	92.8	93.8	110.1	7.33	27/02/20...	11:17	default
	87.6	88.3	102.6	5.62	26/02/20...	10:31	default
	97.3	98.4	112.5	5.75	25/02/20...	13:39	default
	88.3	89	105.4	7.16	22/02/20...	10:41	default

3.10.4. Ultrasound measurements for C.E.P (2)

Table (3.19) Ultrasound measurements for BRG 1 of C.E.P (2)

M.HUSSAIN/C.E.P/C.E.P PUMP #2/MOTOR/BRG 1/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	25.2	25.6	38.9	4.84	14/03/2018	11:23	default
	25.2	26.8	47.6	13.18	13/03/2018	10:56	default
	23.2	23.5	37.2	5.01	12/03/2018	11:01	default
	20.2	20.7	32.1	3.94	08/03/2018	11:50	default
	18.4	19.2	35.5	7.16	07/03/2018	11:35	default
	19.3	19.5	32.7	4.67	06/03/2018	10:06	default
	18	18.9	37.7	9.66	05/03/2018	10:51	default
	15.1	15.7	27.9	4.36	04/03/2018	11:17	default
	21.4	22	42.1	10.84	01/03/2018	10:40	default
	23.6	23.9	36.8	4.57	28/02/2018	10:50	default
	26.5	27.4	42.9	6.61	26/02/2018	10:35	default
	21.9	22.4	37.2	5.82	25/02/2018	13:43	default
	19.4	19.8	32.4	4.47	22/02/2018	10:44	default
	16.2	16.6	29.7	4.73	21/02/2018	10:27	default
	24.8	25.2	42.4	7.59	19/02/2018	13:27	default

Table (3.20) Ultrasound measurements for BRG 2 of C.E.P (2)

M.HUSSAIN/C.E.P/C.E.P PUMP #2/MOTOR/BRG 2/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	97.5	98	116.6	9.02	14/03/2018	11:25	default
	95.9	96.6	111.3	5.89	13/03/2018	10:59	default
	98.5	98.9	114.6	6.38	12/03/2018	11:04	default
	95.4	96.1	109.6	5.13	08/03/2018	11:53	default
	96.4	97	112.8	6.61	06/03/2018	10:09	default
	93.8	95.2	112.7	8.81	05/03/2018	10:54	default
	97.7	98.3	111.3	4.79	01/03/2018	10:43	default
	87.6	87.9	102.3	5.43	28/02/2018	10:52	default
	96.8	97.4	111.3	5.31	26/02/2018	10:38	default
	92.6	93.1	107.6	5.62	25/02/2018	13:45	default
	95.6	96.6	112.5	7	22/02/2018	10:48	default
	95.7	96.1	114.1	8.32	21/02/2018	10:30	default
	93.8	94.1	106	4.07	19/02/2018	13:34	default

Table (3.21) Ultrasound measurements for BRG 3 of C.E.P (2)

M.HUSSAIN/C.E.P/C.E.P PUMP #2/PUMP/BRG 3/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	48.9	49.9	64.4	5.96	14/03/20...	11:27	default
	51.2	52.2	69.1	7.85	13/03/20...	11:00	default
	48.9	50.1	65.1	6.46	12/03/20...	11:05	default
	49.6	50.9	65.6	6.31	08/03/20...	11:55	default
	47.3	48.3	66.3	8.91	06/03/20...	10:11	default
	44.3	45.5	59.7	5.89	01/03/20...	10:45	default
	53.7	54.9	69.9	6.46	28/02/20...	10:54	default
	45.9	46.5	58.7	4.37	26/02/20...	10:40	default
	44.5	46.2	61.7	7.24	25/02/20...	13:48	default
	45.2	46.7	64	8.71	22/02/20...	10:51	default
	48.6	49.5	65.1	6.68	21/02/20...	10:34	default
	36	37.2	55.6	9.55	19/02/20...	13:41	default

Table (3.22) Ultrasound measurements for BRG 4 of C.E.P (2)

M.HUSSAIN/C.E.P/C.E.P PUMP #2/PUMP/BRG 4/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	82	83.3	101.3	9.23	14/03/20...	11:29	default
	86.3	86.9	100.7	5.25	13/03/20...	11:03	default
	86.9	87.8	103.1	6.46	12/03/20...	11:08	default
	87	88.5	101.6	5.37	08/03/20...	11:58	default
	84.7	85.8	98.7	5.01	07/03/20...	11:42	default
	87.9	88.6	103.1	5.75	06/03/20...	10:13	default
	87.7	88.2	102.8	5.69	04/03/20...	11:26	default
	82.5	84.1	97.6	5.69	01/03/20...	10:49	default
	76.8	78.3	92.9	6.38	28/02/20...	10:56	default
	94.9	95.3	112.4	7.5	27/02/20...	11:28	default
	79.7	81.2	92.6	4.42	25/02/20...	13:50	default
	88.4	89.6	103	5.37	22/02/20...	10:54	default
	77.3	78.8	98.5	11.48	19/02/20...	13:47	default

3.10.5. Ultrasound measurements for C.W.P (1)

Table (3.23) Ultrasound measurements for BRG 1 of C.W.P (1)

M.HUSSAIN/CW. PUMPS/CW PUMP #1/MOTOR/BRG 1/UT/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	28.7	29.2	42.6	4.95	14/03/2018	11:34	default
	28.5	28.8	41.9	4.68	13/03/2018	11:07	default
	25.8	26.2	38.5	4.31	12/03/2018	11:13	default
	28	28.4	40.2	4.07	08/03/2018	12:54	default
	23.2	23.6	36.7	4.73	07/03/2018	11:46	default
	28.5	29	40.2	3.85	06/03/2018	10:31	default
	24	24.5	38	5.01	05/03/2018	11:04	default
	30.1	30.6	44.4	5.19	01/03/2018	10:53	default
	21.6	22	35.5	4.96	27/02/2018	11:33	default
	26.4	26.6	39.5	4.52	26/02/2018	10:50	default
	22.8	23.1	36.6	4.9	25/02/2018	13:56	default
	31.4	31.6	45.8	5.25	22/02/2018	11:01	default
	28.6	29.1	41.6	4.47	21/02/2018	10:44	default
	22.2	27.5	47.7	18.84	19/02/2018	13:56	default

Table (3.24) Ultrasound measurements for BRG-2 of C.W.P (1)

M.HUSSAIN/CW. PUMPS/CW PUMP #1/MOTOR/BRG 2/UT/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	91.6	92.1	112.6	11.22	14/03/2018	11:36	default
	86.6	87.4	109.3	13.65	13/03/2018	11:09	default
	90.1	90.5	108.1	7.94	12/03/2018	11:16	default
	93.1	98.8	118.9	19.5	08/03/2018	12:57	default
	93.5	94.8	118.4	17.58	07/03/2018	11:49	default
	99.8	100.2	115.8	6.31	05/03/2018	11:07	default
	87.3	87.7	98.3	3.55	04/03/2018	11:34	default
	96.1	96.5	110.3	5.13	01/03/2018	10:56	default
	86.9	87.4	104.8	7.85	27/02/2018	11:37	default
	77.9	78.3	97.5	9.55	26/02/2018	10:54	default
	86	86.7	105.6	9.55	25/02/2018	13:59	default
	79.7	80.4	100.5	10.96	22/02/2018	11:06	default
	93.9	94.4	116	12.74	21/02/2018	10:49	default
	98.2	99.3	112.4	5.13	19/02/2018	14:04	default

Table (3.25) Ultrasound measurements for BRG-3 of C.W.P (1)

M.HUSSAIN/CW. PUMPS/CW PUMP #1/PUMP/BRG 3/UT/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Fact	Date	Time	Operator
	57.3	58.5	78.7	11.75	13/03/2018	11:13	default
	56.3	58.3	75	8.61	12/03/2018	11:19	default
	56.2	57.3	75.3	9.02	08/03/2018	12:59	default
	57.9	59.7	81.1	14.45	07/03/2018	11:52	default
	56.4	58.1	75.9	9.44	06/03/2018	10:38	default
	54	56.3	76.6	13.49	05/03/2018	11:10	default
	56.6	58.3	78.2	12.02	27/02/2018	11:39	default
	57.5	59.7	80.8	14.62	26/02/2018	10:57	default
	57.4	59.9	79.4	12.59	22/02/2018	11:09	default
	58.3	60	79.2	11.09	21/02/2018	10:53	default
	51.2	52.5	69.3	8.04	19/02/2018	14:11	default

Table (3.26) Ultrasound measurements for BRG 4 of C.W.P (1)

M.HUSSAIN/CW. PUMPS/CW PUMP #1/PUMP/BRG 4/UT/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		51.5	53.2	72.2	10.84	08/03/20...	13:03	default
		51.3	52.4	71.3	10	07/03/20...	11:54	default
		34.1	35.5	52.1	7.94	05/03/20...	11:13	default
		35.2	36.5	56	10.97	01/03/20...	11:03	default
		50.5	52.2	69.8	9.23	27/02/20...	11:42	default
		53.1	55.8	72.3	9.12	26/02/20...	11:00	default
		53.6	55	73.3	9.66	25/02/20...	14:06	default
		52.8	54	73.7	11.09	22/02/20...	11:13	default
		50.9	52.4	72	11.35	21/02/20...	10:58	default

3.10.6. Ultrasound measurements for C.W.P (2)

Table (3.27) Ultrasound measurements for BRG 1 of C.W.P (2)

M.HUSSAIN/CW. PUMPS/CW PUMP #2/MOTOR/BRG 1/UT/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		28.2	29	41.4	4.57	14/03/20...	11:45	default
		26.8	27.2	40.3	4.73	13/03/20...	11:18	default
		27.5	28.4	41.9	5.25	12/03/20...	11:26	default
		23.5	24	36	4.22	08/03/20...	13:06	default
		24.2	24.8	38	4.9	07/03/20...	11:58	default
		24.4	24.9	34.9	3.35	06/03/20...	10:19	default
		25	25.9	39.5	5.31	05/03/20...	11:17	default
		27.6	28.3	41.5	4.95	04/03/20...	11:43	default
		30.8	31.5	43.8	4.47	01/03/20...	11:07	default
		31.6	32.3	46.6	5.62	27/02/20...	11:46	default
		28.8	29.9	42.8	5.01	25/02/20...	14:09	default
		30.3	30.8	44.8	5.31	22/02/20...	11:17	default
		20.7	21.6	32.9	4.07	19/02/20...	14:20	default

Table (3.28) Ultrasound measurements for BRG 2 of C.W.P (2)

M.HUSSAIN/CW. PUMPS/CW PUMP #2/MOTOR/BRG 2/UT/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		85.3	85.8	98.6	4.62	14/03/20...	11:47	default
		82	82.5	94.3	4.12	13/03/20...	11:20	default
		86.9	87.6	99.7	4.37	12/03/20...	11:29	default
		93.1	93.4	106	4.42	07/03/20...	12:00	default
		91.4	92.3	104.2	4.37	06/03/20...	10:22	default
		95.4	95.8	106.7	3.67	05/03/20...	11:19	default
		90.6	92.1	102.4	3.89	04/03/20...	11:45	default
		84.3	84.8	97.6	4.62	01/03/20...	11:09	default
		83.6	84.1	96.4	4.37	27/02/20...	11:49	default
		82.5	83.2	95.3	4.37	26/02/20...	11:07	default
		80.5	81.4	94.8	5.19	25/02/20...	14:12	default
		85.5	85.9	96.2	3.43	21/02/20...	11:05	default
		90.5	91.6	110	9.44	19/02/20...	14:25	default

Table (3.29) Ultrasound measurements for BRG 3 of C.W.P (2)

M.HUSSAIN/CW. PUMPS/CW PUMP #2/PUMP/BRG 3/UT/RS1T(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		85.5	86.2	103.5	7.94	14/03/2018	11:49	default
		84.1	85.7	101.1	7.08	13/03/2018	11:22	default
		88.2	89.2	106.2	7.94	12/03/2018	11:31	default
		88.3	89.6	106.8	8.41	08/03/2018	13:12	default
		94.3	95.6	114	9.66	07/03/2018	12:02	default
		76.4	77.8	100.4	15.85	06/03/2018	10:24	default
		87.4	88	105	7.59	01/03/2018	11:12	default
		85.9	86.5	105.4	9.44	28/02/2018	11:17	default
		83.6	85.2	107	14.79	27/02/2018	11:51	default
		83.1	84.2	103.1	10	26/02/2018	11:09	default
		86.2	87.4	105.2	8.91	25/02/2018	14:15	default
		79.2	80.1	100.1	11.09	22/02/2018	11:23	default
		82.3	83	100.6	8.22	21/02/2018	11:07	default

Table (3.30) Ultrasound measurements for BRG 4 of C.W.P (2)

M.HUSSAIN/CW. PUMPS/CW PUMP #2/PUMP/BRG 4/UT/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		84.2	85.8	103.2	8.91	14/03/2018	11:52	default
		90.1	92.6	107.6	7.5	13/03/2018	11:25	default
		90.8	92.8	109.7	8.81	08/03/2018	13:15	default
		87.6	89	104.7	7.16	05/03/2018	11:25	default
		92.1	93.2	109.5	7.41	04/03/2018	11:52	default
		92.4	93.6	115.1	13.65	01/03/2018	11:15	default
		97.7	99.2	118.9	11.48	27/02/2018	11:55	default
		98.6	100.3	116.8	8.13	26/02/2018	11:13	default
		101.8	103.3	118.6	6.92	25/02/2018	14:19	default
		101.3	102.3	119.6	8.22	22/02/2018	11:28	default
		101	101.7	116.5	5.96	21/02/2018	11:13	default
		92.4	94	108.7	6.53	19/02/2018	14:33	default

3.10.7. Ultrasound measurements for cavitation in C.E.P (1)

Table (3.31) Ultrasound measurements for suction pipe of C.E.P (1)

cavitation M. hessain/C.E.P #1/Suction pipe/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		61.6	63.2	83.4	12.3	26/03/2018	12:26	default
		55.7	56.8	75.8	10.12	25/03/2018	11:10	default
		59.6	60.5	78.1	8.41	22/03/2018	11:15	default
		55	55.9	73.4	8.32	21/03/2018	13:24	default
		66	66.4	83.9	7.85	18/03/2018	13:13	default

Table (3.32) Ultrasound measurements for volute of C.E.P (1)

cavitation M. hessain/C.E.P #1/Volute/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	55.8	56.8	71.9	6.38	26/03/2018	12:26	default
	54.5	55.1	69	5.31	25/03/2018	11:09	default
	54.4	55.2	72.9	8.41	22/03/2018	11:14	default
	55.9	56.8	72.8	7	21/03/2018	13:24	default
	54.9	55.4	70.2	5.82	18/03/2018	13:13	default

Table (3.33) Ultrasound measurements for discharge pipe of C.E.P (1)

cavitation M. hessain/C.E.P #1/Discharge pipe/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	54.7	55.6	68.7	5.01	26/03/2018	12:27	default
	54	54.7	69.9	6.24	25/03/2018	11:10	default
	47.6	48.1	62.6	5.62	22/03/2018	11:15	default
	51.9	52.7	68.5	6.76	21/03/2018	13:25	default
	54.4	55.3	68	4.79	18/03/2018	13:13	default

3.10.8. Ultrasound measurements for cavitation in C.E.P (2)

Table (3.34) Ultrasound measurements for suction pipe of C.E.P (2)

cavitation M. hessain/C.E.P #2/Suction pipe/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	51.7	52.8	66.7	5.62	01/04/2018	12:53	default
	52.3	53.8	73.4	11.35	29/03/2018	13:56	default
	51.9	52.5	70	8.04	28/03/2018	11:52	default
	51	52.1	67.3	6.53	27/03/2018	10:13	default
	55	56.2	77.9	13.96	26/03/2018	12:27	default
	55.6	57.3	74.6	8.91	25/03/2018	11:11	default
	58.2	60.2	78.8	10.72	22/03/2018	11:16	default
	63.5	64.6	85.2	12.16	21/03/2018	13:26	default
	58.7	60.1	78.9	10.23	18/03/2018	13:14	default

Table (3.35) Ultrasound measurements for volute of C.E.P (2)

cavitation M. hessain/C.E.P #2/Volute/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		56.4	57.1	73	6.76	01/04/2018	12:53	default
		47.8	48.5	62.7	5.56	29/03/2018	13:56	default
		46.3	46.9	61	5.43	28/03/2018	11:52	default
		49.2	49.8	62.9	4.84	27/03/2018	10:12	default
		50.6	51.3	67.2	6.76	26/03/2018	12:27	default
		49.8	51	65.4	6.03	25/03/2018	11:11	default
		46.5	47.2	64.1	7.59	22/03/2018	11:16	default
		49.6	51.8	70.3	10.84	21/03/2018	13:25	default
		51.5	52.6	68.4	7	18/03/2018	13:14	default

Table (3.36) Ultrasound measurements for discharge pipe of C.E.P (2)

cavitation M. hessain/C.E.P #2/Discharge pipe/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		52	53.2	66.1	5.07	01/04/2018	12:53	default
		40.9	41.6	56.3	5.89	29/03/2018	13:56	default
		41.7	46.3	58	6.53	28/03/2018	11:52	default
		41.9	42.5	55.1	4.57	27/03/2018	10:13	default
		44.8	45.9	60.3	5.96	26/03/2018	12:28	default
		42.6	44.4	63	10.47	25/03/2018	11:11	default
		42.7	43.6	58.3	6.03	22/03/2018	11:16	default
		44.3	45.4	60.2	6.24	21/03/2018	13:26	default
		44.4	46.2	59.4	5.62	18/03/2018	13:14	default

3.10.9. Ultrasound measurements for cavitation in C.W.P(1)

Table (3.37) Ultrasound measurements for suction pipe of C.W.P (1)

cavitation M. hessain/CW. PUMP #1/Suction pipe/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		45.3	46.9	67.7	13.18	01/04/2018	12:56	default
		41.4	42.9	60.5	9.02	29/03/2018	13:59	default
		42	42.7	59.4	7.41	28/03/2018	11:55	default
		43.2	44.4	60.9	7.67	27/03/2018	10:16	default
		43.4	44.8	60	6.76	26/03/2018	12:31	default
		40.4	41.4	62.5	12.74	25/03/2018	11:15	default
		39.5	40.2	59.5	10	22/03/2018	11:20	default
		37.8	39	59.6	12.3	21/03/2018	13:29	default
		44.1	44.6	61.8	7.67	18/03/2018	13:18	default

Table (3.38) Ultrasound measurements for volute of C.W.P (2)

cavitation M. hessain/CW. PUMP #1/Volute/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	38	39.2	58.4	10.47	01/04/2018	12:55	default
	37	40.1	62.5	18.84	29/03/2018	13:59	default
	36.2	37.1	55.7	9.44	28/03/2018	11:55	default
	38.1	39.1	55.6	7.5	27/03/2018	10:15	default
	38.8	40.4	57.3	8.41	26/03/2018	12:30	default
	37.6	39.3	54.2	6.76	25/03/2018	11:15	default
	41.2	42.8	60.9	9.66	22/03/2018	11:20	default
	37.6	39.3	56.7	9.02	21/03/2018	13:29	default
	37.8	38.8	59	11.48	18/03/2018	13:19	default

Table (3.39) Ultrasound measurements for discharge pipe of C.W.P (1)

cavitation M. hessain/CW. PUMP #1/Discharge pipe/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	33.7	35.2	51.7	7.94	01/04/2018	12:56	default
	34	34.7	55.5	11.88	29/03/2018	13:59	default
	35.1	36.5	57.1	12.59	28/03/2018	11:55	default
	34.7	35.5	48.9	5.13	27/03/2018	10:16	default
	35.5	36.3	51.9	6.61	26/03/2018	12:31	default
	31.2	31.8	48	6.92	25/03/2018	11:15	default
	36.8	37.5	52.7	6.24	22/03/2018	11:21	default
	32.5	33.7	47.9	5.89	21/03/2018	13:30	default
	34.4	35.4	50.1	6.1	18/03/2018	13:19	default

3.10.10. Ultrasound measurements for cavitation in C.W.P (2)

Table (3.40) Ultrasound measurements for suction pipe of C.W.P (2)

cavitation M. hessain/CW. PUMP #2/Suction pipe/RS1NL100(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
	44.3	45.8	62.6	8.22	01/04/2018	12:57	default
	43.8	44.7	60.1	6.53	29/03/2018	14:00	default
	46.5	47.9	66.7	10.23	28/03/2018	11:56	default
	45.2	46.4	61.7	6.68	27/03/2018	10:17	default
	44.4	45.1	60.8	6.61	26/03/2018	12:32	default
	41.7	42.5	63.1	11.75	25/03/2018	11:17	default
	42.2	42.6	59.3	7.16	22/03/2018	11:21	default
	43.3	44.6	60.4	7.16	21/03/2018	13:30	default
	44.1	45.5	65.5	11.75	18/03/2018	13:20	default

Table (3.41) Ultrasound measurements for volute of C.W.P (2)

cavitation M. hessain/CW. PUMP #2/Volute/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		35.9	36.4	53.4	7.5	01/04/2018	12:56	default
		34.7	36.4	53.5	8.71	29/03/2018	14:00	default
		36.6	38	58.2	12.02	28/03/2018	11:56	default
		38.6	39.8	59	10.47	27/03/2018	10:16	default
		40	40.7	57.2	7.24	26/03/2018	12:31	default
		35.2	35.7	51.7	6.68	25/03/2018	11:17	default
		38.9	39.8	54.8	6.24	22/03/2018	11:21	default
		38.6	40.2	61.3	13.65	21/03/2018	13:30	default
		39.8	41	61	11.48	18/03/2018	13:20	default

Table (3.42) Ultrasound measurements for discharge pipe of C.W.P (2)

cavitation M. hessain/CW. PUMP #2/Discharge pipe/RS1NL100(ST-Ht)

	Level Name	RMS	Max RMS	Peak	Crest Factor	Date	Time	Operator
		32.9	33.8	49.6	6.84	01/04/2018	12:57	default
		32.7	34	49.7	7.08	29/03/2018	14:00	default
		33.5	35.3	52	8.41	28/03/2018	11:56	default
		36.1	37.7	51.2	5.69	27/03/2018	10:17	default
		36.8	37.3	51.1	5.19	26/03/2018	12:32	default
		32.6	33.1	53.3	10.84	25/03/2018	11:18	default
		38.3	39	53.1	5.5	22/03/2018	11:22	default
		37.2	38.2	54.9	7.67	21/03/2018	13:31	default
		36.9	37.7	54.2	7.33	18/03/2018	13:21	default

CHAPTER IV

ANALYSIS AND DISCUSSION

4.1 Ultrasound Trend for Healthy and Defective Bearings:

Table (4.1) Ultrasound measurements for healthly bearing

DEMO_DATA/Trending/Healthy bearing/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Facto	Date	Time	Operator
	29.8	34.7	43.1	4.62	03/08/2012	13:11	default
	32.5	33.6	41.2	2.72	02/07/2012	13:10	default
	30.7	31.2	38.9	2.57	01/06/2012	13:05	default
	28.1	32.3	38.6	3.35	03/05/2012	13:04	default
	27.9	31.2	38.5	3.39	02/04/2012	13:03	default
	28.6	31.4	41.8	4.57	02/03/2012	13:02	default
	33.6	36.5	43	2.95	01/02/2012	13:01	default
	31.2	35.6	40.2	2.82	03/01/2012	13:01	default
	30.7	33.6	39.4	2.72	02/12/2011	13:00	default
	29.1	33.2	40.3	3.63	02/11/2011	12:59	default
	30.3	30.6	37.8	2.37	03/10/2011	12:58	default
	33.4	37.2	39.6	2.04	02/09/2011	12:56	default
	28.5	31.5	42.5	5.01	02/08/2011	12:55	default
	30.3	31.3	38.8	2.66	04/07/2011	12:54	default
	32.1	33.5	41.7	3.02	03/06/2011	12:52	default
	28.9	32.1	41.8	4.42	04/05/2011	12:51	default
	31.6	35.8	43.1	3.76	04/04/2011	12:49	default

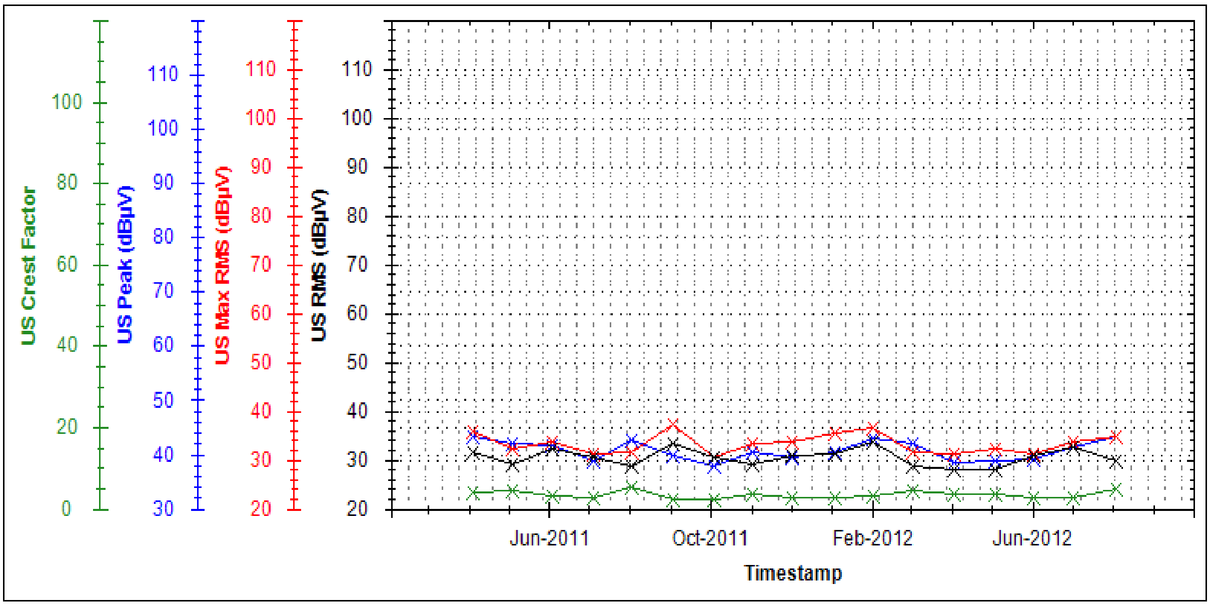


Figure (4.1) Ultrasound Trend for healtly bearing

According to table (4.1) and figure (4.1) the RMS readings within accepted limits , in addition to the non - appearance of upnormal sounds which indicates this bearing is healthy.

Table (4.2) Ultrasound measurements for defective bearing

DEMO_DATA/Trending/Defective breaing/RS1T(ST-Ht)

Level Name	RMS	Max RMS	Peak	Crest Facto	Date	Time	Operator
	50.7	54.6	70.2	9.44	03/08/2012	09:37	default
	49.8	56.8	73.7	15.67	04/07/2012	09:40	default
	43.9	49.5	72.1	25.7	05/06/2012	09:41	default
	41.7	46.1	74.5	43.65	10/05/2012	09:42	default
	36.1	40.2	69.5	46.77	04/04/2012	09:43	default
	35.1	36.9	71.4	65.31	05/03/2012	09:44	default
	33.6	36.5	53.8	10.23	07/02/2012	09:45	default
	31.5	34.3	47.1	6.03	04/01/2012	09:46	default
	31.2	31.4	43.9	4.32	01/12/2011	09:47	default
	30	32.4	34.8	1.74	03/11/2011	09:48	default
	31.1	31.3	39.1	2.51	03/10/2011	09:48	default
	30.4	30.6	35.6	1.82	02/09/2011	09:50	default
	31.3	32.4	41.7	3.31	02/08/2011	10:06	default
	31.7	33.2	39.8	2.54	06/07/2011	10:12	default
	32.4	34.2	43.8	3.72	03/06/2011	10:12	default
	29.8	34.2	43.9	5.07	04/05/2011	12:44	default
	28.9	35.6	44.2	5.82	04/04/2011	12:45	default

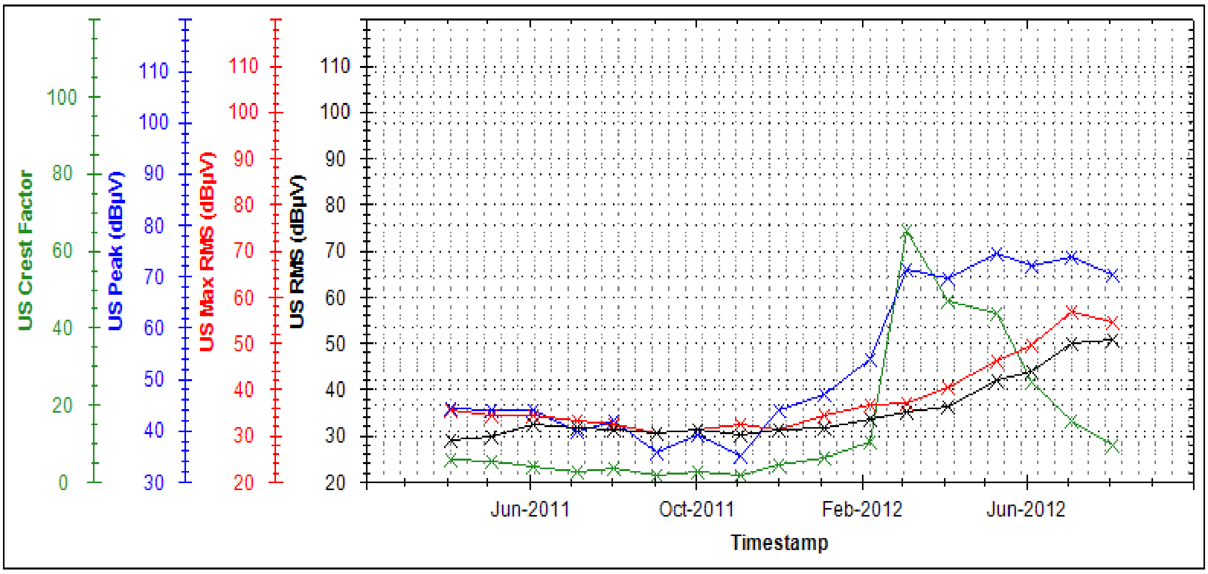


Figure (4.2) Ultrasound Trend for defective bearing

According to table (4.2) and figure (4.2) the RMS readings have increased from acceptable to unacceptable values in addition to appearance of upnormal sounds which indicates the bearing beaing defective.

4.2 Ultrasound Analysis for High pressure seal blowers

4.2.1 Ultrasound Analysis for High pressure seal blower (1)

4.2.1.1 Ultrasound analysis for BRG-1 NDE Motor

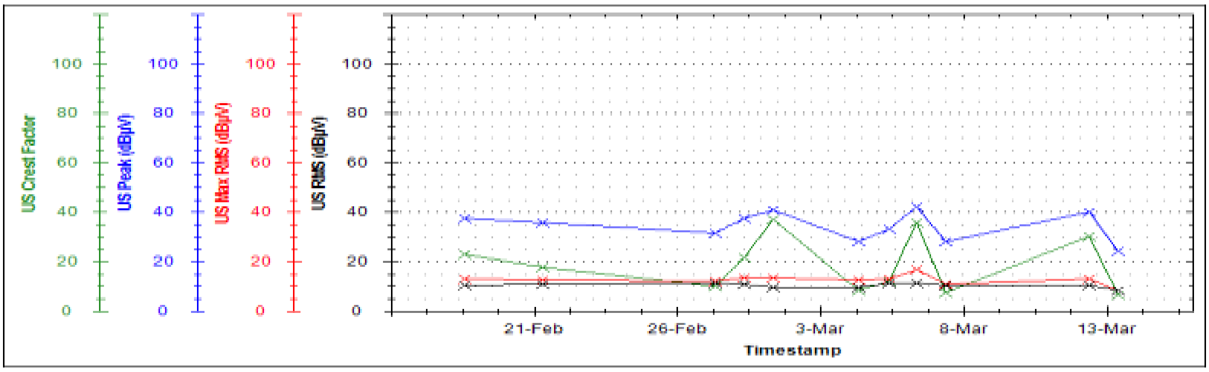


Figure (4.3) Ultrasound Trend for BRG-1 of H.P.S (1)

According to table (3.3) and figure (4.3) the RMS readings for BRG-1 NDE motor within accepted limits, in addition to non-appearance of up normal sounds which indicates BRG-1 NDE motor of H.P.S (1) is healthy bearing without defects.

4.2.1.2 Ultrasound analysis for BRG -2 DE Motor

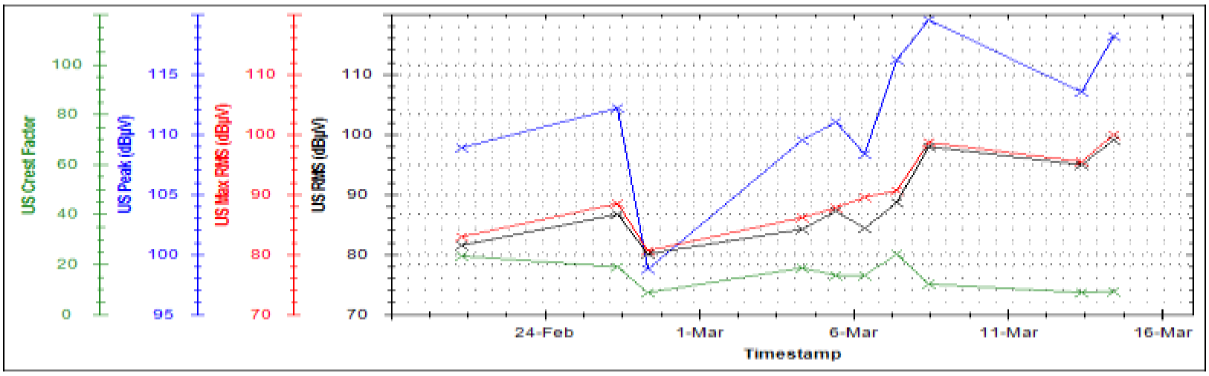


Figure (4.4) Ultrasound trend for BRG-2 of H.P.S (1)

According to table (3.4) and figure (4.4) the RMS readings for BRG-2 DE motor are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-2 of H.P.S (1) DE motor is defective.

4.2.1.3 Ultrasound analysis for BRG-3 (fan)

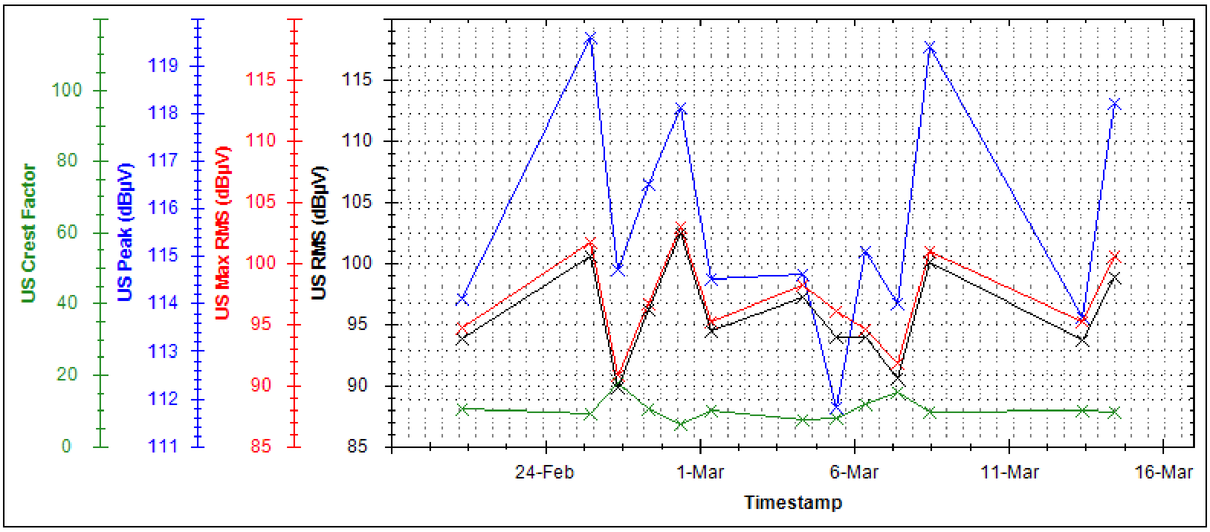
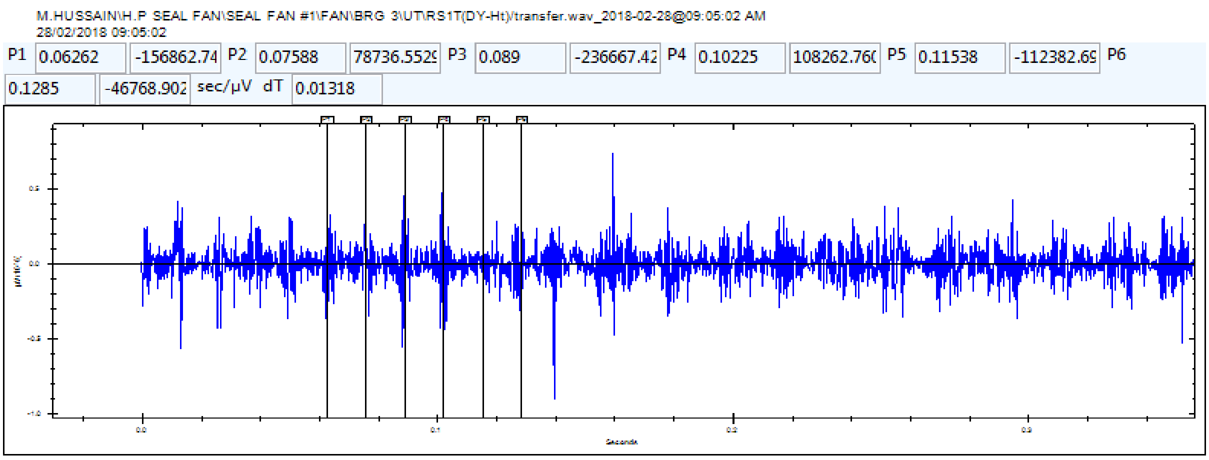


Figure (4.5) Ultrasound trend for BRG-3 of H.P.S (1)

According to table (3.5) and figure (4.5) The RMS readings for BRG-3 of H.P.S (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-3 of H.P.S (1) beaing defective. To identify the location of fault exactly in BRG 3 :



Figure(4.6) Time domin for BRG-3 of H.P.S (1)

According to figure (4.6) dt= 0.01318 s , the frequeency =1/dt = 1/0.01318= 75.87 Hz . Accorging to appendix 1 the frequency 75.87 Hz detect the defect in outer ring exactly.

4.2.1.4 Ultrasound analysis for BRG-4 (fan)

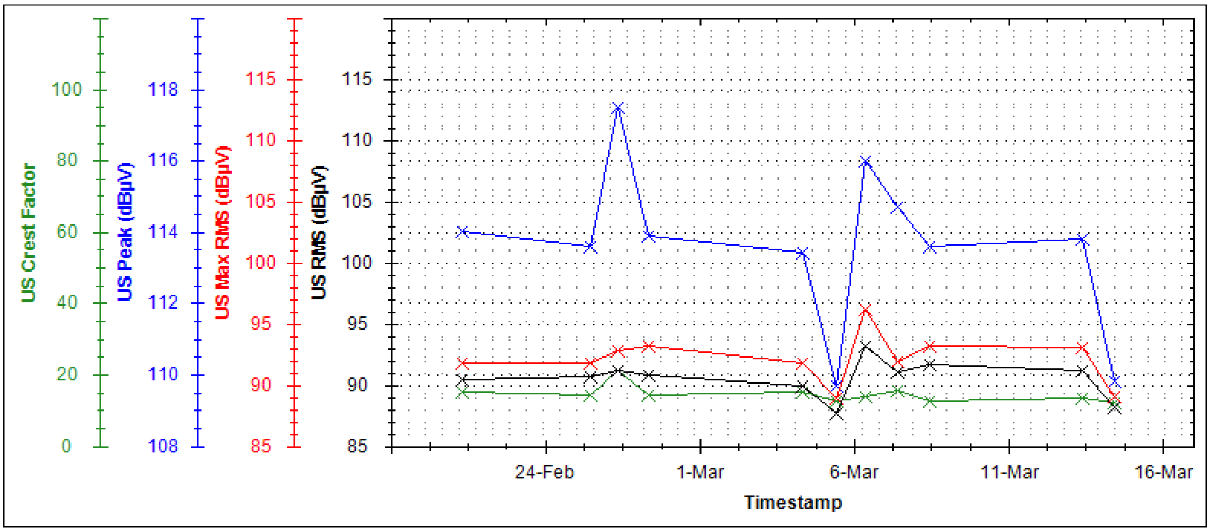
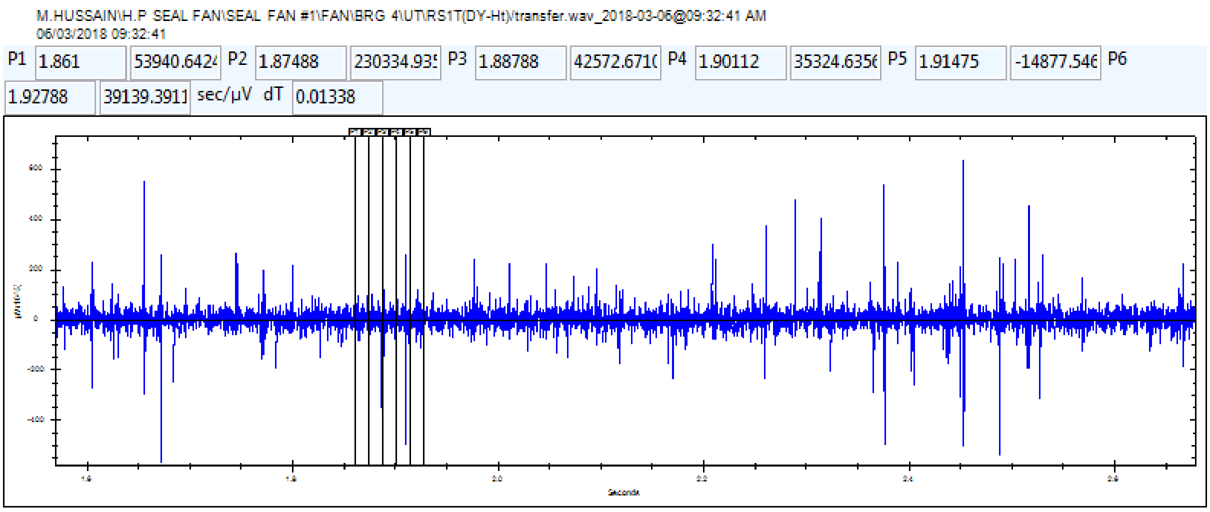


Figure (4.7) Ultrasound trend for BRG-4 of H.P.S (1)

According to table (3.6) and figure (4.7) The RMS readings for BRG-4 of H.P.S (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-4 of H.P.S(1) beaing defective.



Figure(4.8) Time domin for BRG-4 of H.P.S (1)

According to figure (4.8) dt= 0.01338 s, the freqeuency =1/dt = 1/0.01338= 74.74 Hz . Accorging to appendix 1 the frequency 74.74 Hz detect the defect in outer ring .

4.2.1.5 Ultrasound analysis for BRG-5 (fan)

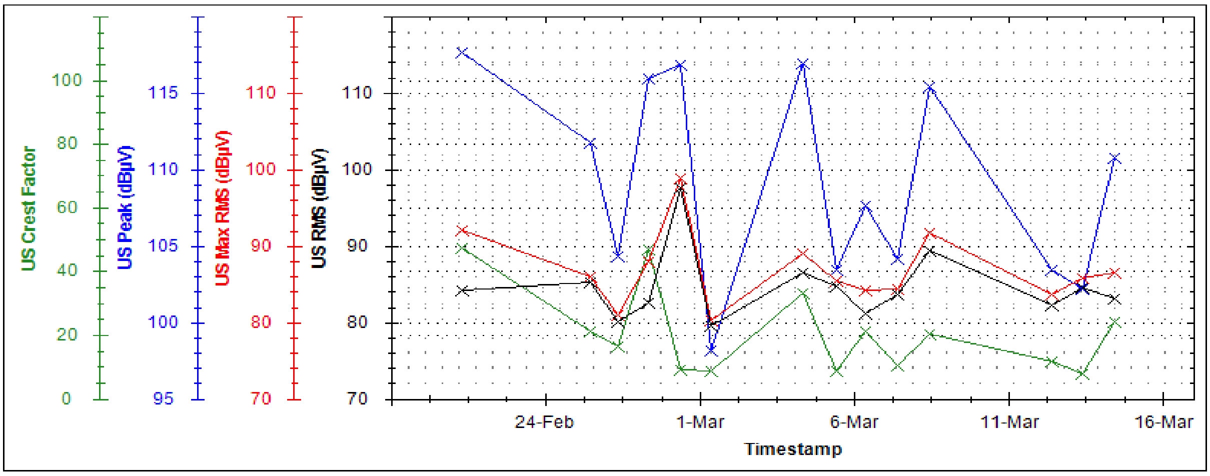
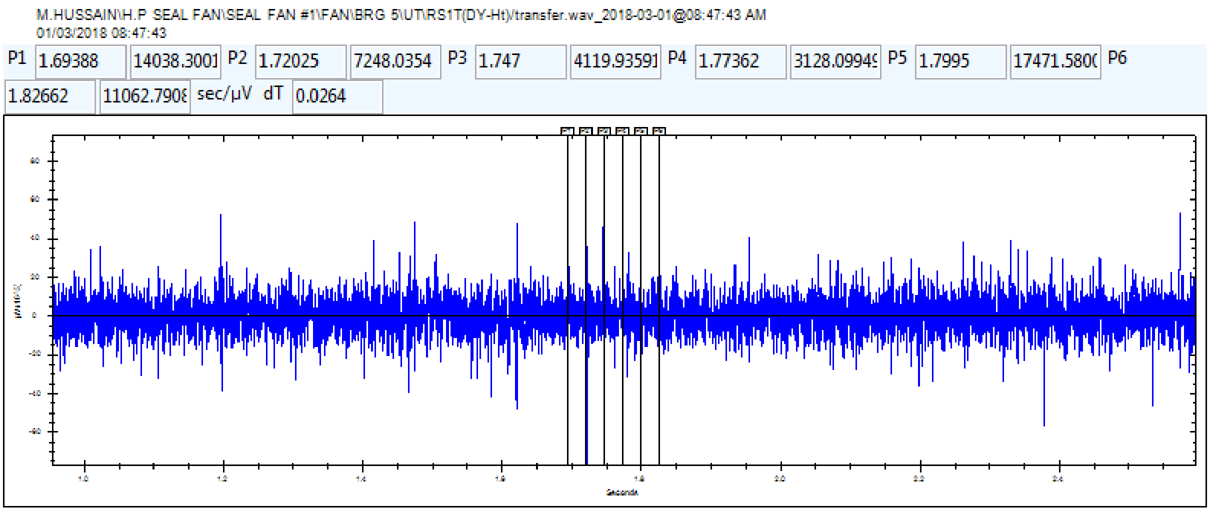


Figure (4.9) Ultrasound trend for BRG-5 of H.P.S (1)

According to table (3.7) and figure (4.9) The RMS readings for BRG-5 of H.P.S (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-5 of H.P.S (1) beaing defective.



Figure(4.10) Time domin for BRG-5 of H.P.S (1)

According to figure (4.10) dt= 0.0264 s , the freqeuency =1/dt = 1/0.0264 = 37.88 Hz. The frequency 37.88 Hz not found between the frequencies of this bearing this detect the defect outside bearing which indicates that BRG-5 of H.P.S (1) in case of loseness.

4.2.1.6 Ultrasound analysis for BRG - 6 (fan)

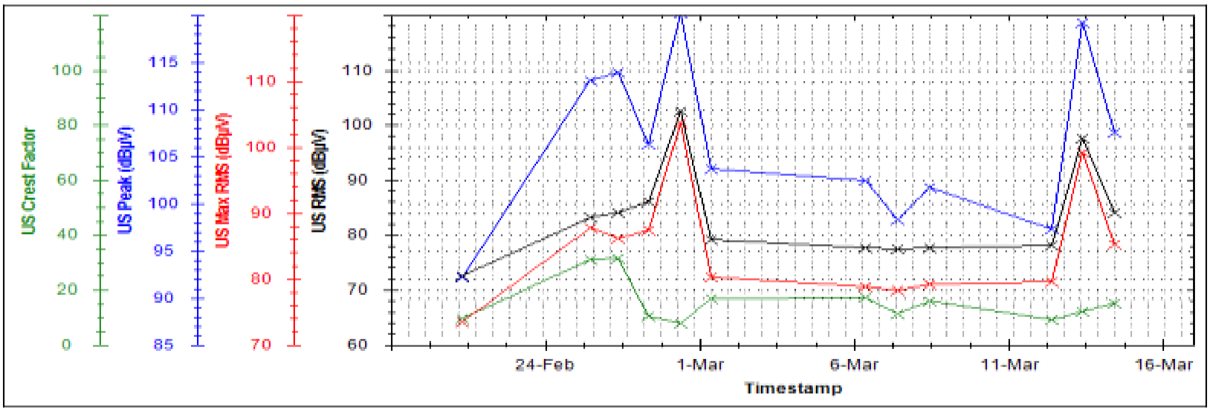


Figure (4.11) Ultrasound trend for BRG-6 of H.P.S (1)

According to table (3.8) and figure (4.11) The RMS readings for BRG-6 of H.P.S (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-6 of H.P.S (1) beaing defective.

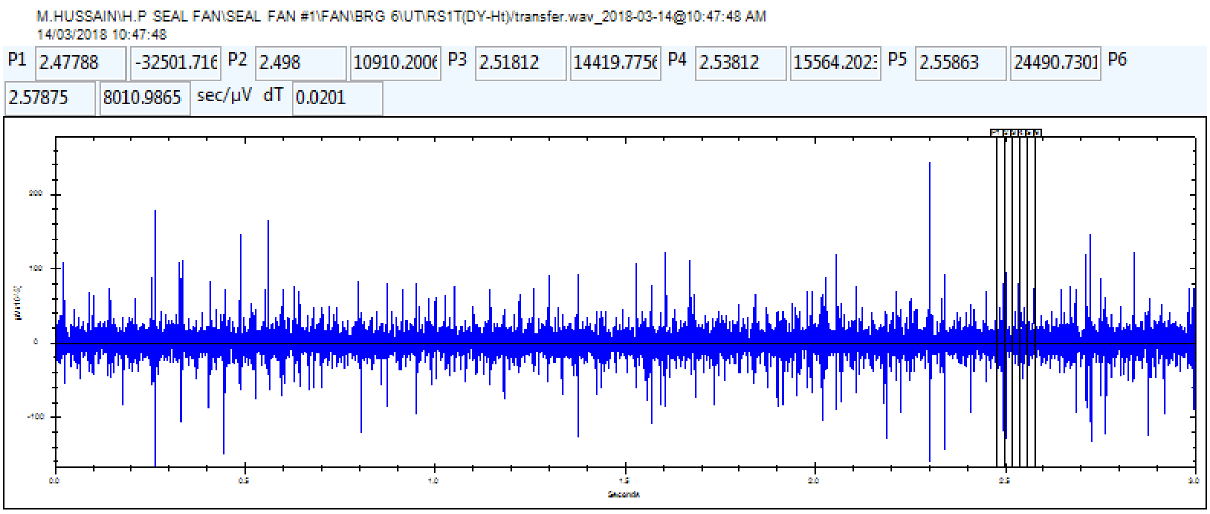


Figure (4.12) Time domin for BRG-6 of H.P.S (1)

From figure (4.12) dt= 0.0201 s , frequeency =1/dt = 1/0.0201 = 49.75 Hz. Accorging to appendix 1 this frequency 49.75 Hz detect the defect in rolling element about its own axis.

4.2.2 Ultrasound Analysis for High pressure seal blower (2)

4.2.2.1Ultrasound analysis for BRG-1 NDE Motor:

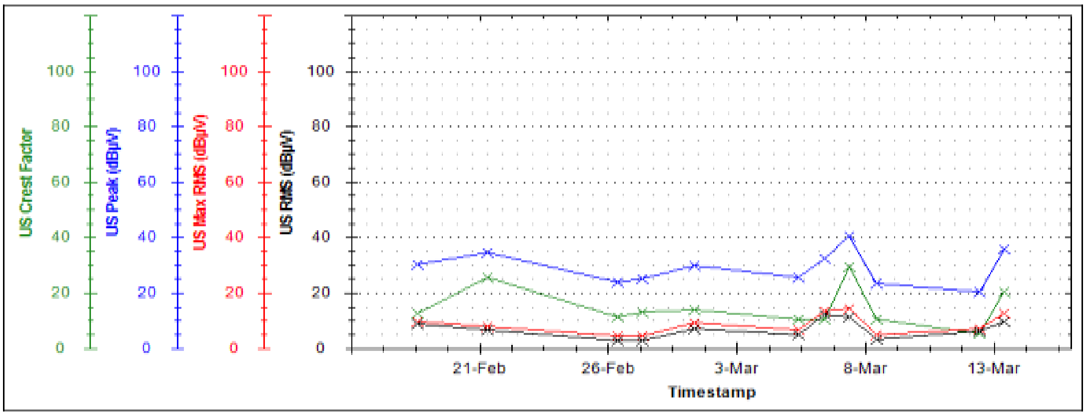


Figure (4.13) Ultrasound trend for BRG-1 of H.P.S (2)

According to table (3.9) and figure (4.13) The RMS readings for BRG-1 NDE motor of H.P.S (2) are in accepted limits in addition to non-appearance of upnormal sounds and the ultrasound trend is stable which indicates that BRG-1NDE motor of H.P.S (2) beaing healthy without defects.

4.2.2.2 Ultrasound analysis for BRG-2 DE Motor

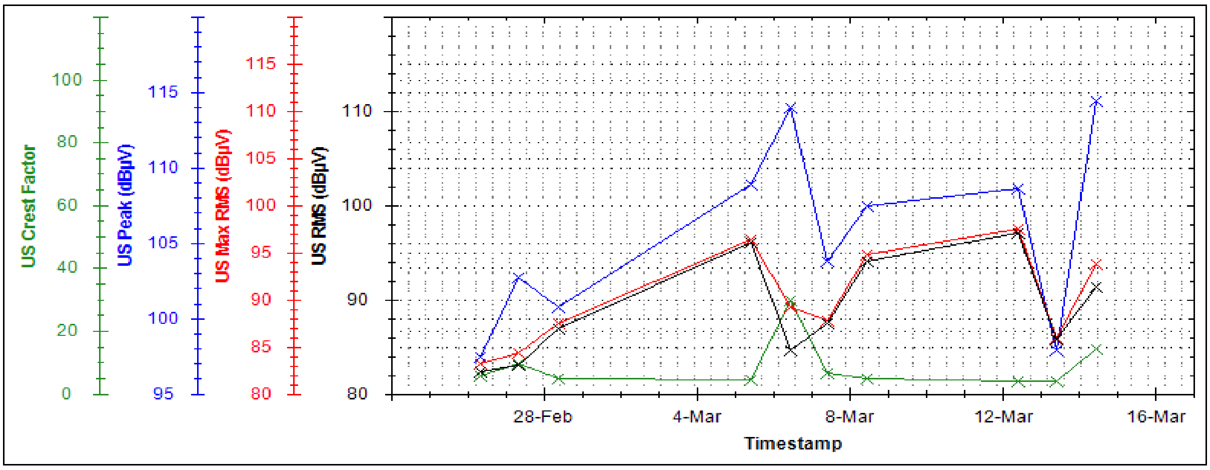


Figure (4.14) Ultrasound Trend for BRG-2 of H.P.S (2)

According to table (3.10) and figure (4.14) The RMS readings for BRG-2 DE motor of H.P.S (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-2 DE motor of H.P.S (2) beaing defective.

4.2.2.3 Ultrasound analysis for BRG-3 (fan):

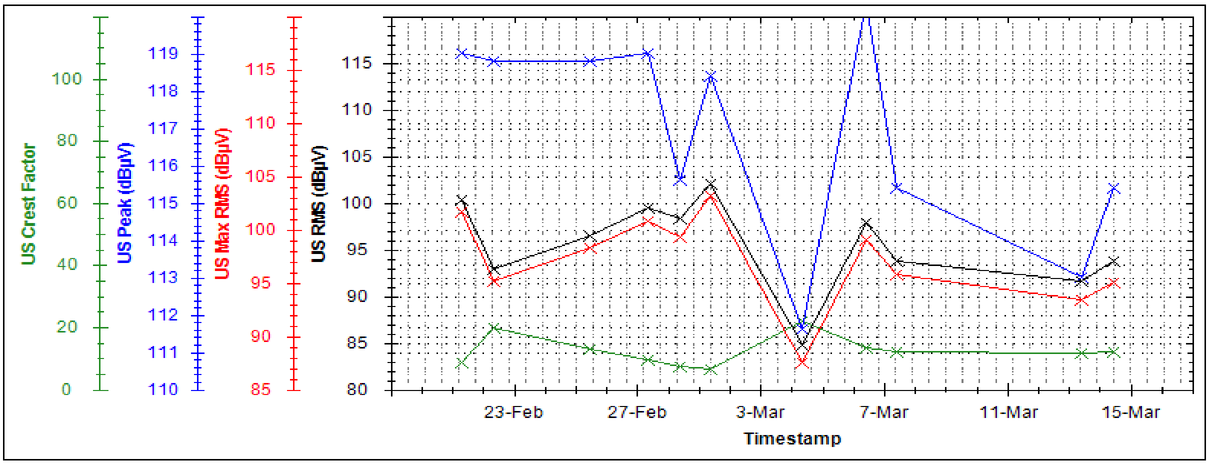
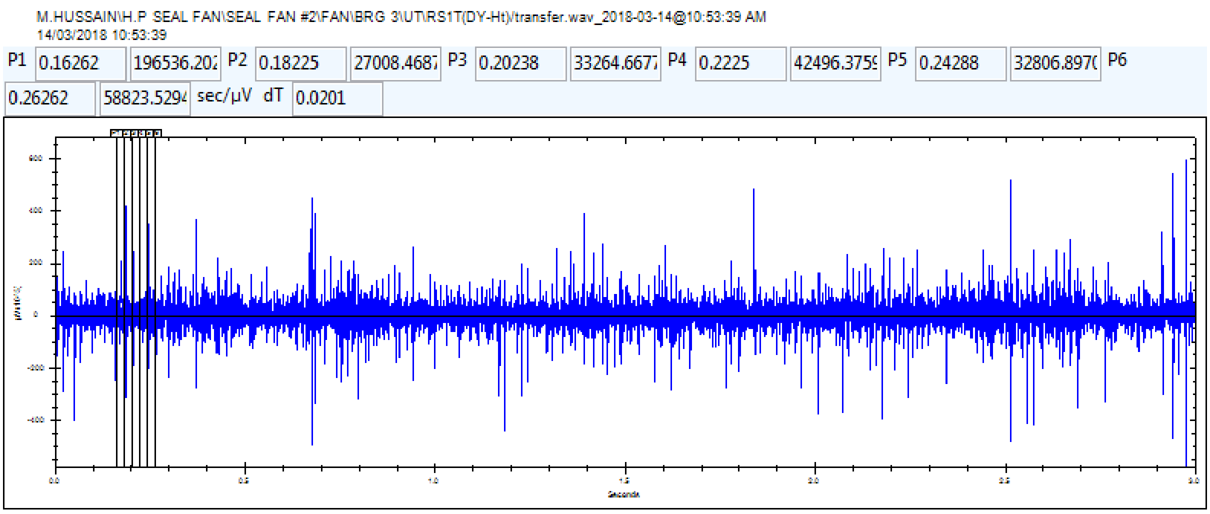


Figure (4.15) Ultrasound trend for BRG-3 of H.P.S (2)

According to table (3.11) and figure (4.15) The RMS readings for BRG-3 of H.P.S (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-3 of H.P.S (2) beaing defective.



Figure(4.16) Time domin for BRG-3 of H.P.S (2)

From figure (4.16) dt= 0.0201 s , frequeency =1/dt = 1/0.0201 = 49.75 Hz. Accorging to appendix 1 this frequency 49.75 Hz detect the defect in BRG 3 of H.P.S (2) in rolling element about its own axis.

4.2.2.4 Ultrasound analysis for BRG-4 (fan):

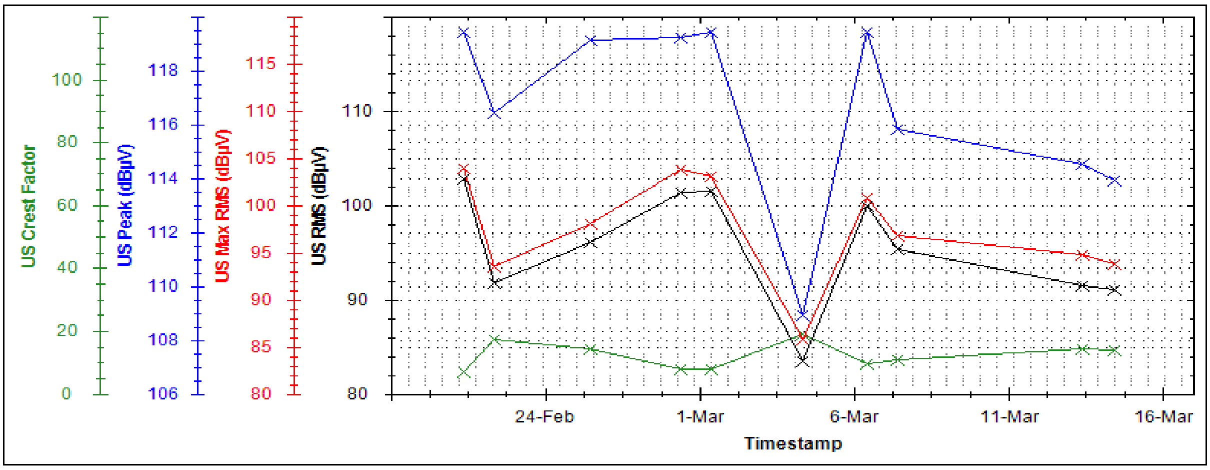


Figure (4.17) Ultrasound trend for BRG-4 of H.P.S (2)

According to table (3.12) and figure (4.17) The RMS readings for BRG-4 of H.P.S (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-4 of H.P.S (2) beaing defective.

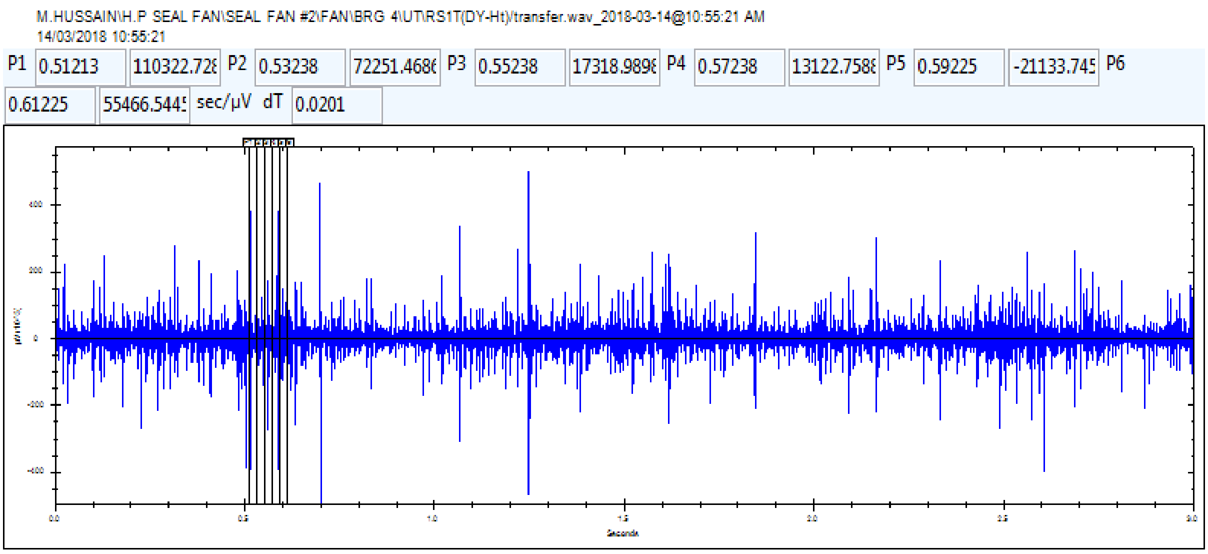


Figure (4.18) Time domin for BRG-4of H.P.S (2)

From figure (4.18) dt= 0.0201 s , frequeency =1/dt = 1/0.0201 = 49.75 Hz. Accorging to appendix 1 the frequency 49.75 Hz detect the defect in BRG-4 of H.P.S (2) in rolling element about its own axis.

4.2.2.5 Ultrasound analysis for BRG-5 (fan):

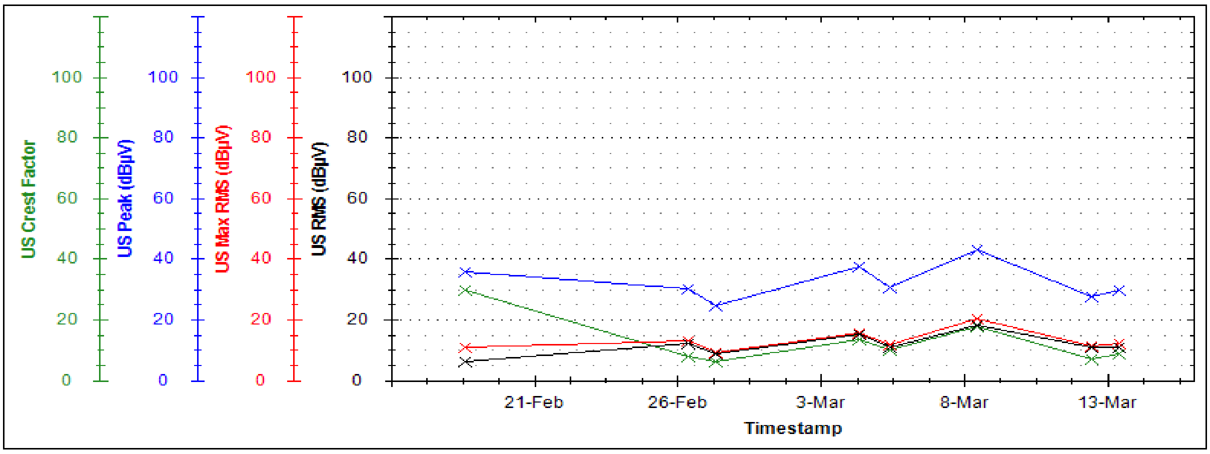


Figure (4.19) Ultrasound trend for BRG-5 of H.P.S (2)

According to table (3.13) and figure (4.19) The RMS readings for BRG-5 of H.P.S (2) are in accepted limits in addition to non-appearance of upnormal sounds and the ultrasound trend is stable which indicates that BRG-5 of H.P.S (2) beaing healthy without defects.

4.2.2.6 Ultrasound analysis for BRG-6 (fan) :

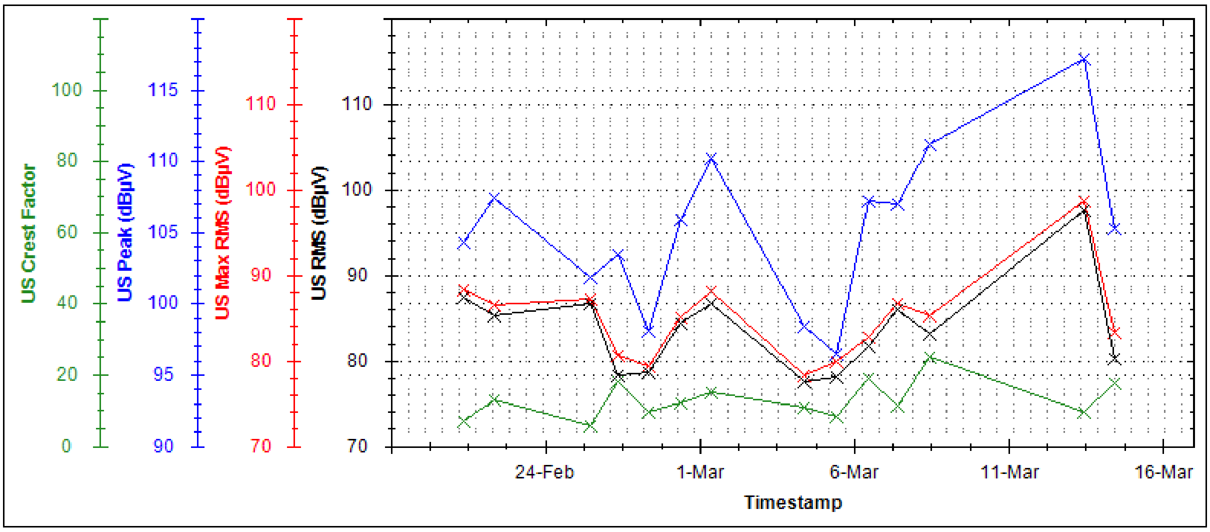


Figure (4.20) Ultrasound trend for BRG-6 of H.P.S (2)

According to table (3.14) and figure (4.20) The RMS readings for BRG-6 of H.P.S (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-6 of H.P.S (2) beaing defective.

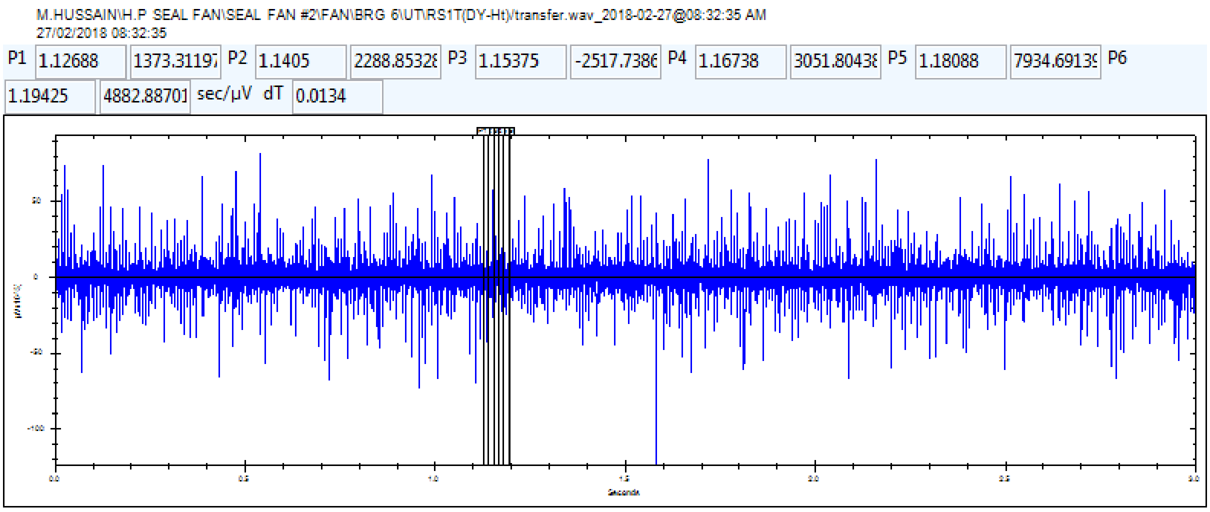


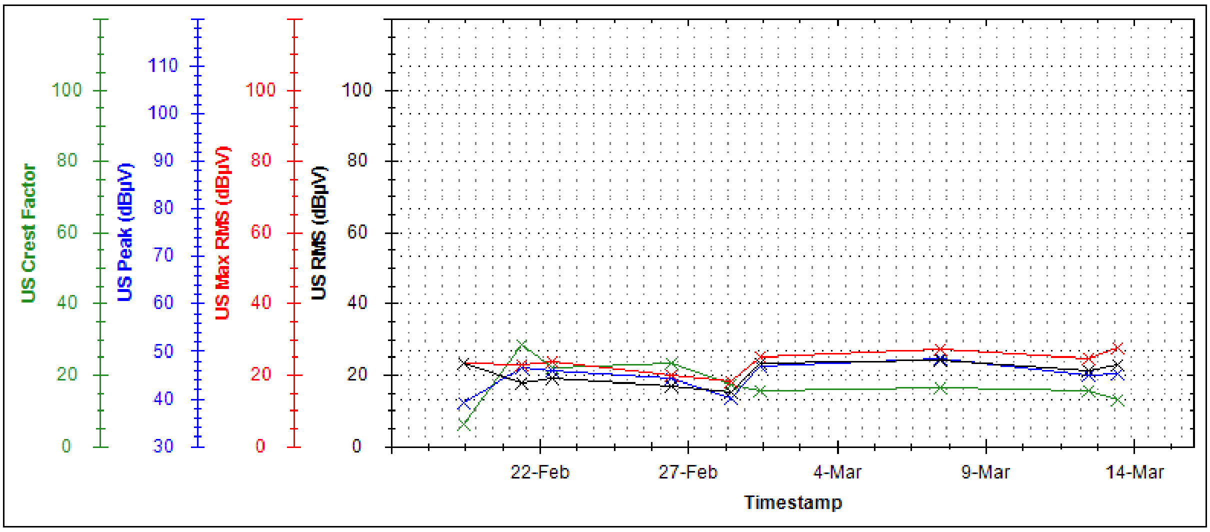
Figure (4.21) Time domin for BRG-6 of H.P.S (2)

From figure (4.21) dt = 0.0134 s , frequeency =1/dt = 1/0.0134 = 74.63 Hz. the frequency 74.63 Hz not found in between the frequencies of bearing this detect the defect out side bearing which indicates that BRG-6 of H.P.S (2) in case of loseness**.**

4.3 Ultrasound analysis for condensate extraction pumps

4.3.1 Ultrasound analysis for condensate extraction pump (1)

4.3.1.1 Ultrasound analysis for BRG -1 NDE Motor



Fgure (4.22) Ultrasound trend for BRG-1 of C.E.P (1)

According to table (3.15) and figure (4.22) The RMS readings for BRG-1 NDE motor of C.E.P (1) are in accepted limits in addition to non-appearance of upnormal sounds and the ultrasound trend is stable which indicates that BRG-1 NDE motor of C.E.P (1) beaing healthy without defects.

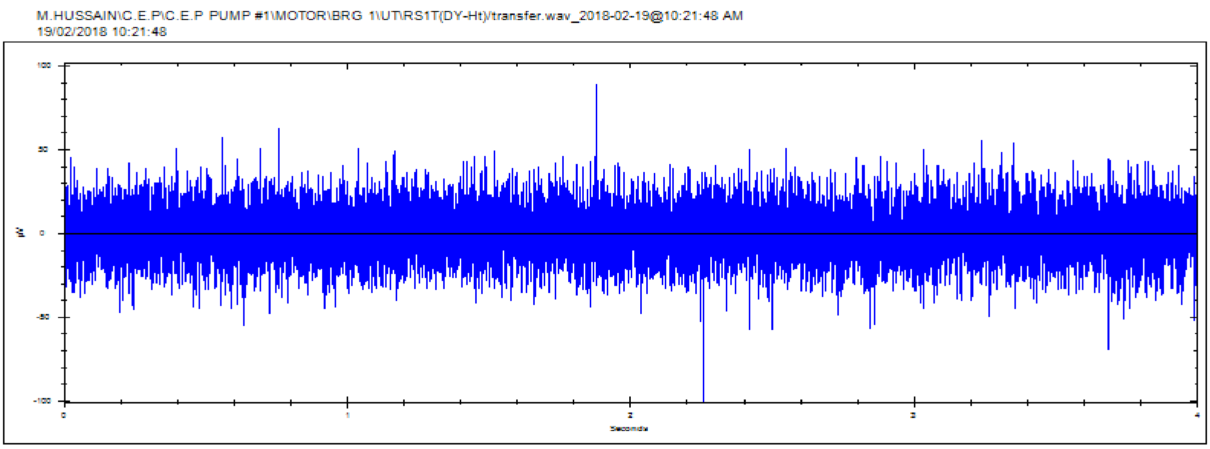
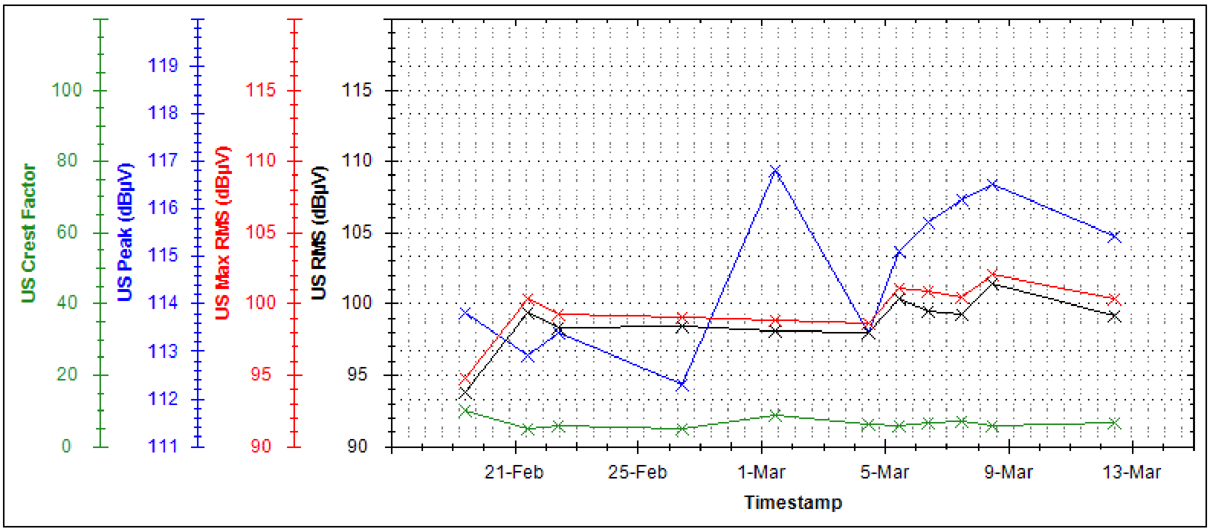


Figure (4.23) Time domin for BRG-1 of C.E.P (1)

Figure (4.23) shows that BRG-1 NDE motor of C.E.P (1) is healthy without defects.

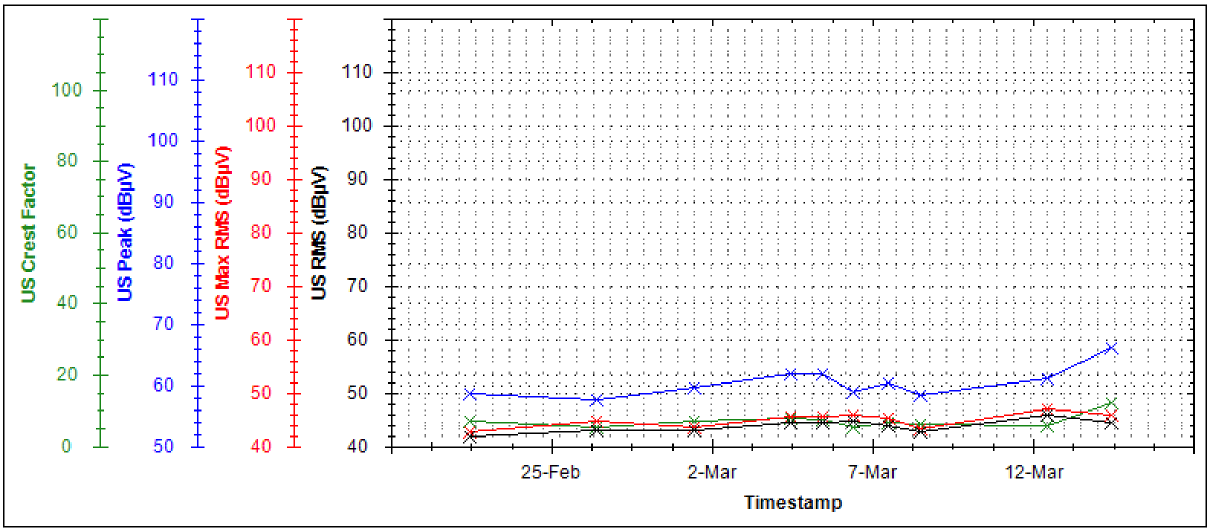
4.3.1.2 Ultrasound analysis for BRG-2 DE Motor



Fgure (4.24) Ultrasound trend for BRG-2 of C.E.P (1)

According to table (3.16) and figure (4.24) The RMS readings for BRG-2 DE motor of C.E.P (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-2 DE motor of C.E.P (1) beaing defective.

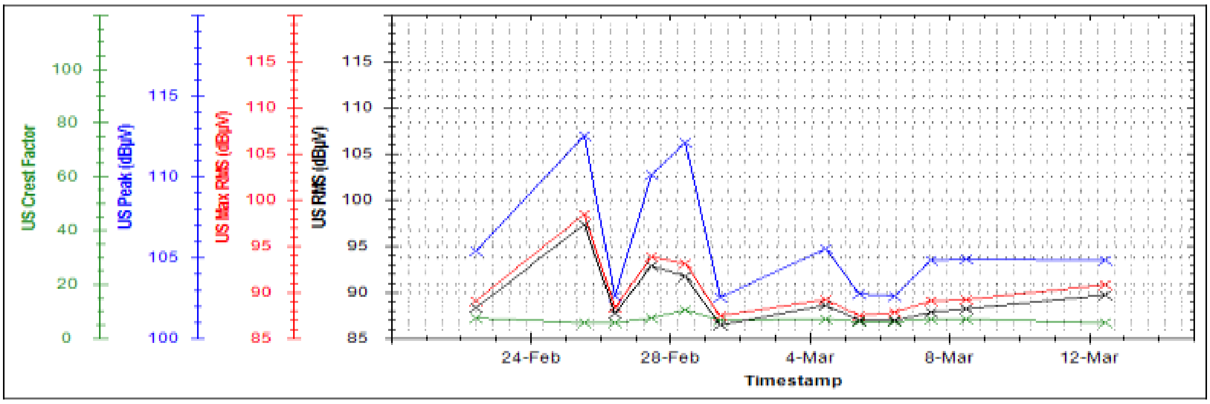
4.3.1.3 Ultrasound analysis for BRG-3 DE pump



Fgure (4.25) Ultrasound trend for BRG-3 of C.E.P (1)

According to table (3.17) consider that the value RMS = 44 as base line which indicates that RMS readings for BRG-3 of C.E.P (1) DE fan are stable in = 44 without any apperence for upnormal sounds, also from figure (4.25) BRG-3 of C.E.P (1) DE fan is healthy without defects .

4.3.1.4 Ultrasound analysis for BRG-4 NDE pump

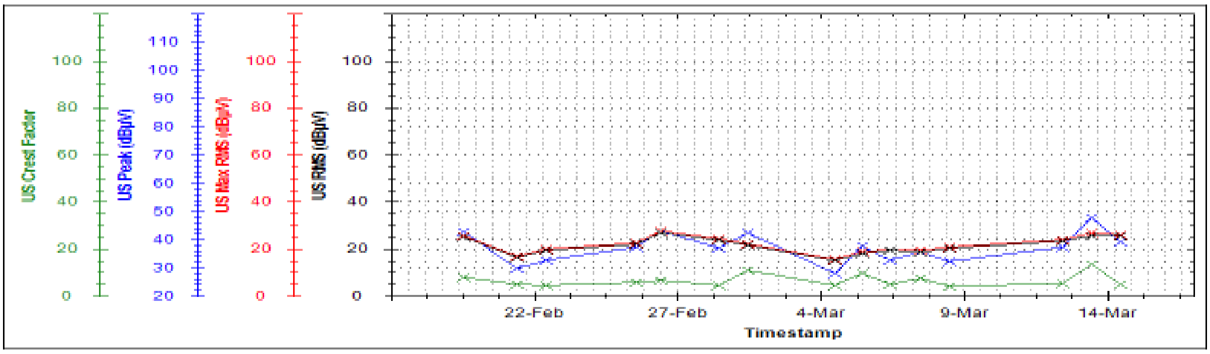


Fgure (4.26) Ultrasound trend for BRG-4 of C.E.P (1)

According to table (3.18) and figure (4.26) The RMS readings for BRG-4 NDE of C.E.P (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-4 NDE of C.E.P (1) beaing defective.

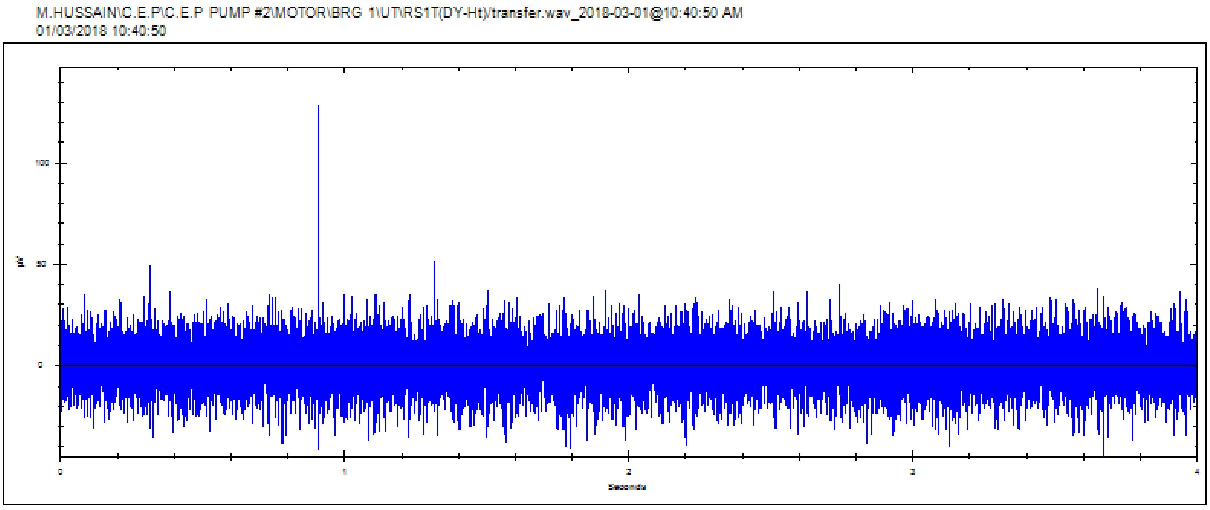
4.3.2 Ultrasound analysis for condensate extraction pump (2)

4.3.2.1 Ultrasound analysis for BRG -1 NDE Motor



Fgure (4.27) Ultrasound trend for BRG-1 of C.E.P (2)

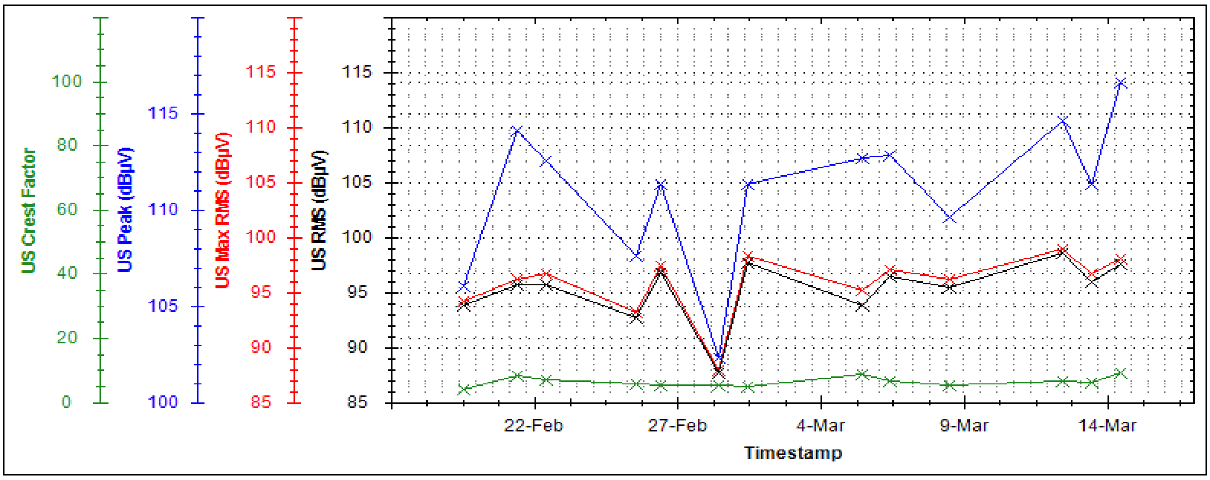
According to table (3.19) and figure (4.27) The RMS readings for BRG-1 NDE motor of C.E.P (2) are in accepted limits in addition to non-appearance of upnormal sounds and the ultrasound trend is stable which indicates that BRG-1 NDE motor of C.E.P (2) beaing healthy without defects.



Figure(4.28) Time domin for BRG-1of C.E.P (2)

Figure (4.28) show that BRG-1 NDE motor of C.E.P (2) is healthy without defects.

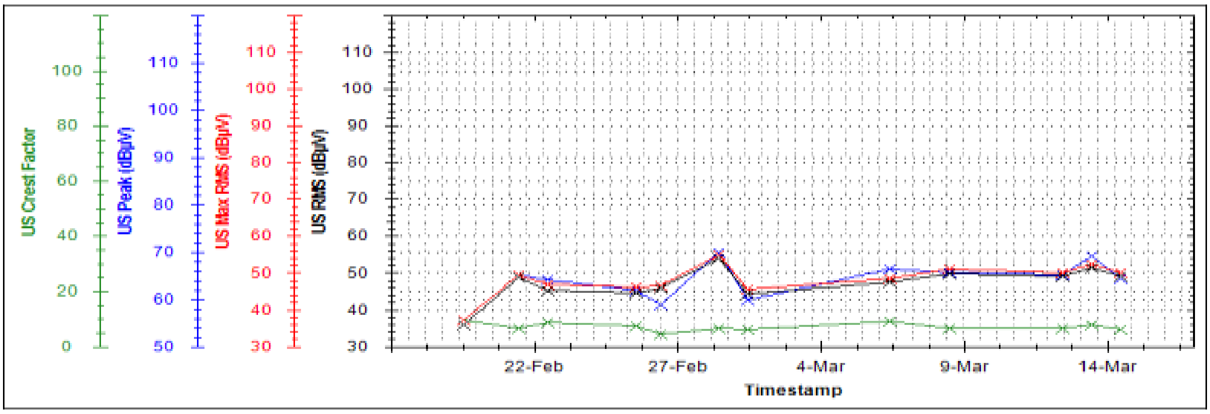
4.3.2.2 Ultrasound analysis for BRG -2 DE Motor



Fgure (4.29) Ultrasound trend for BRG-2 of C.E.P (2)

According to table (3.20) and figure (4.29) The RMS readings for BRG-2 DE motor of C.E.P (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-2 DE motor of C.E.P (2) beaing defective.

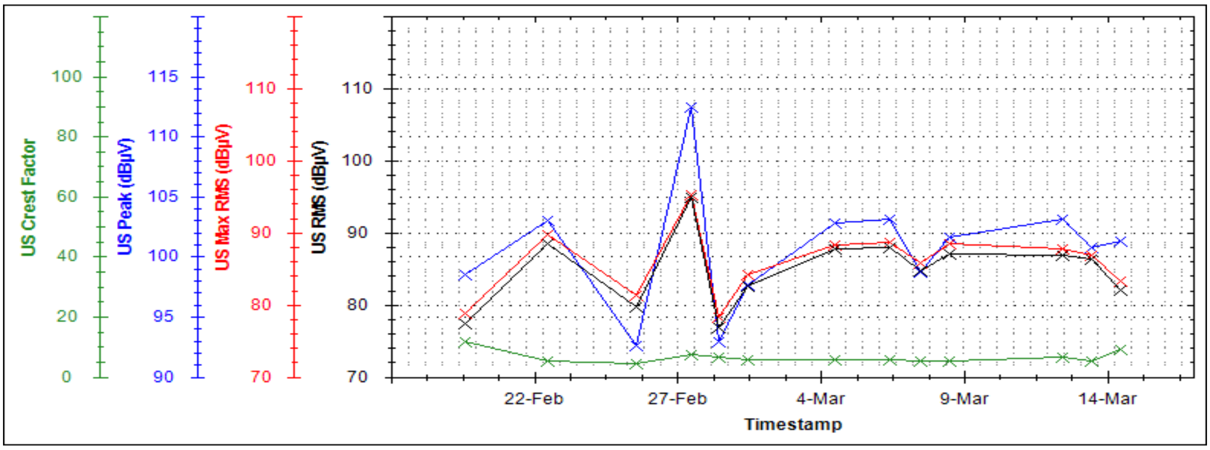
4.3.2.3 Ultrasound analysis for BRG- 3 D E pump:



Fgure (4.30) Ultrasound trend for BRG-3 of C.E.P (2)

According to table (3.21) and figure (4.30) The RMS readings for BRG-3 DE of C.E.P (2) are in accepted limits in addition to non-appearance of upnormal sounds and the ultrasound trend is stable which indicates that BRG-3 DE of C.E.P (2) beaing healthy without defects.

4.3.2.4 Ultrasound analysis for BRG-4 NDE Fan



Fgure (4.31) Ultrasound trend for BRG-4 of C.E.P (2)

According to table (3.22) and figure (4.31) The RMS readings for BRG-4 NDE of C.E.P (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-4 NDE of C.E.P (2) beaing defective.

4.4 Ultrasound analysis for circulating water pumps

4.4.1 Ultrasound analysis for circulating water pump (1)

4.4.1.1 Ultrasound analysis for BRG-1 NDE Motor

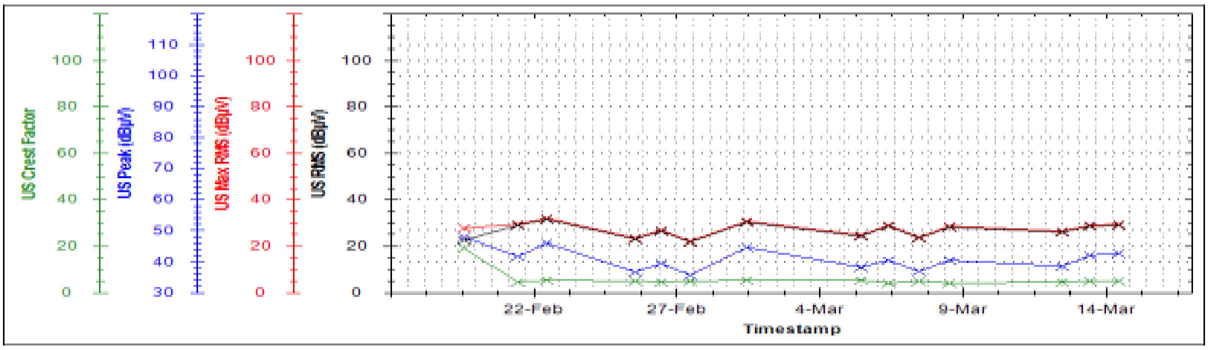
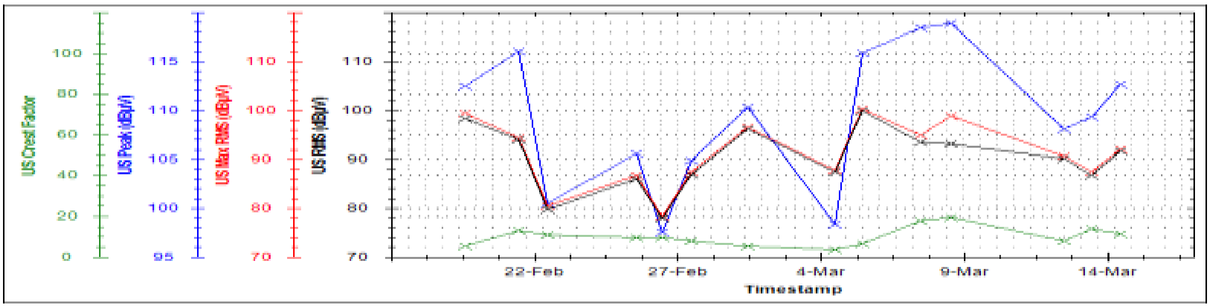


Figure (4.32)Ultrasound trend for BRG-1of C.W.P (1)

According to table (3.23) and figure (4.32) The RMS readings for BRG-1 NDE motor of C.W.P (1) are in accepted limits in addition to non-appearance of upnormal sounds and the ultrasound trend is stable which indicates that BRG-1 NDE motor of C.W.P (1)beaing healthy without defects.

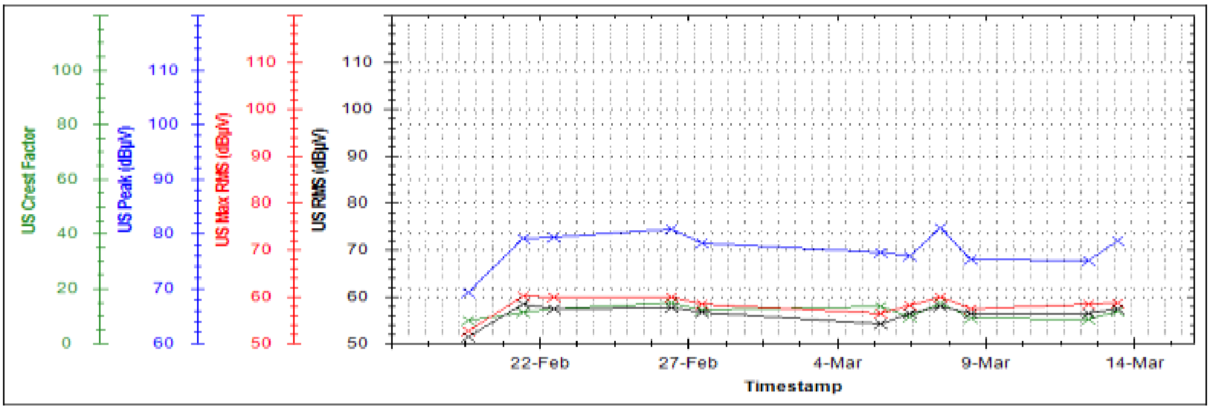
4.4.1.2 Ultrasound analysis for BRG -2 DE Motor



Figure(4.33)Ultrasound trend for BRG-2 of CWP (1)

According to table (3.24) and figure (4.33) The RMS readings for BRG-2 DE motor of CWP (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-2 DE motor of CWP (1) beaing defective.

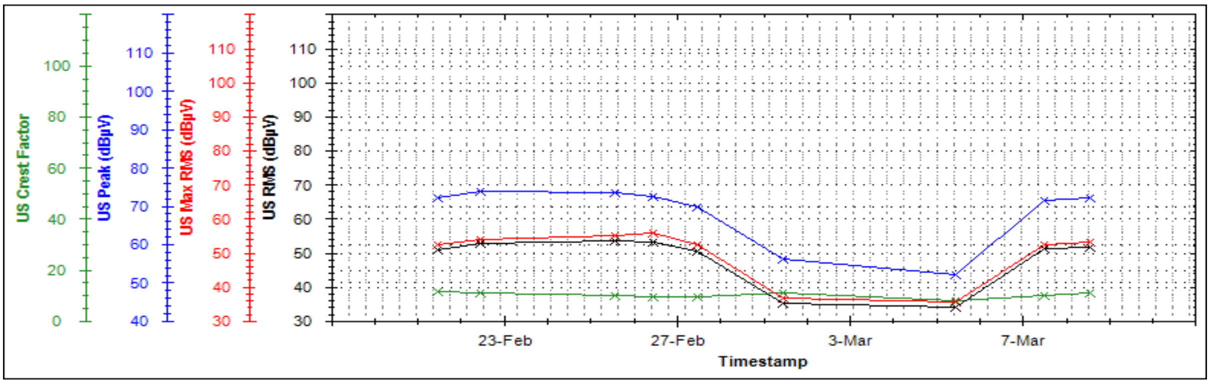
4.4.1.3 Ultrasound analysis for BRG - 3 DE pump



Figure(4.34)Ultrasound trend for BRG-3 of C.W.P (1)

According to table (3.25) and figure (4.34) The RMS readings for BRG-3 DE of CWP (1) are higher than accepted limits in addition to appearance of upnormal sounds which indicates that BRG-3 DE of CWP (1) beaing defective.

4.4.1.4 Ultrasound analysis for BRG-4 NDE pump



Figure(4.35)Ultrasound trend for BRG-4 of C.W.P (1)

According to table (3.26) and figure (4.35) The RMS readings for BRG-4 NDE of CWP (1) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-4 NDE of CWP (1) beaing defective.

4.4.2 Ultrasound analysis for circulating water pump (2)

4.4.2.1 Ultrasound analysis for BRG-1 NDE Motor

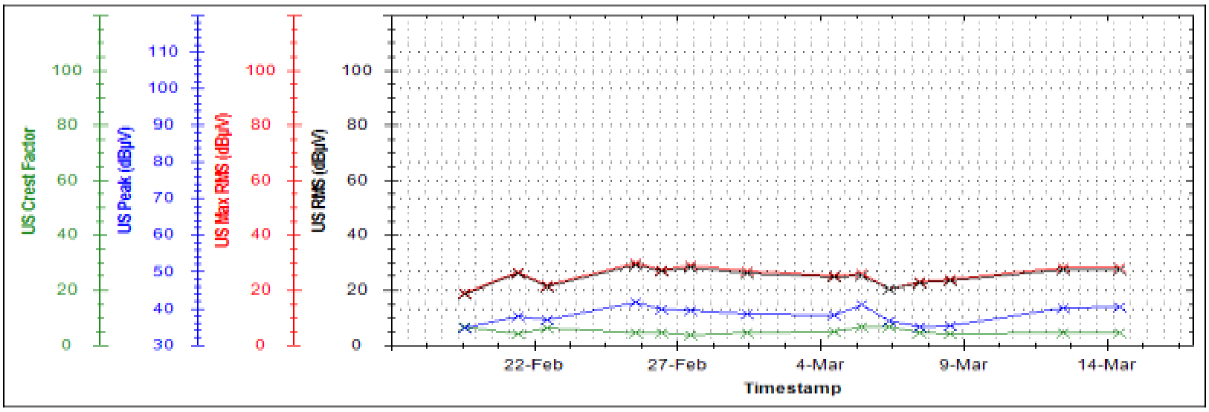
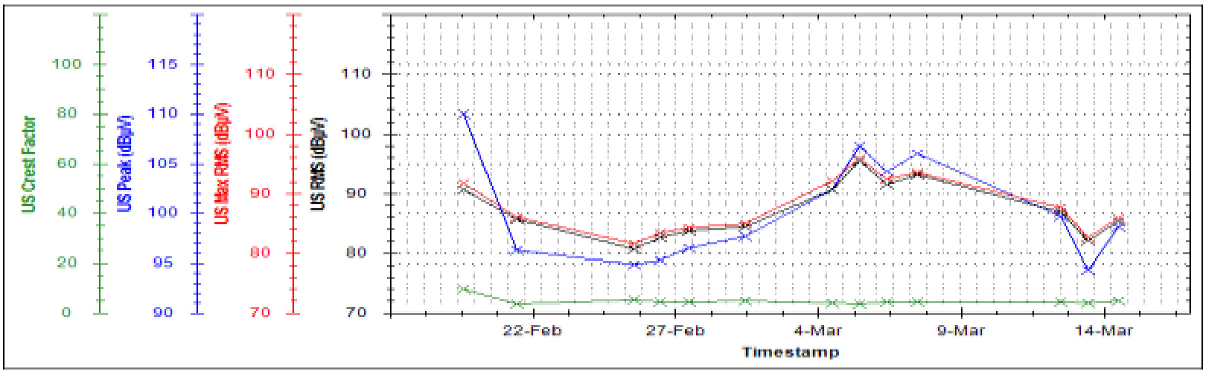


Figure (4.36) Ultrasound trend for BRG-1of C.W.P (2)

According to table (3.27) and figure (4.36) The RMS readings for BRG-1 NDE motor of C.W.P (2) are in accepted limits in addition to non-appearance of upnormal sounds and the ultrasound trend is stable which indicates that BRG-1 NDE motor of C.W.P (2) beaing healthy without defects.

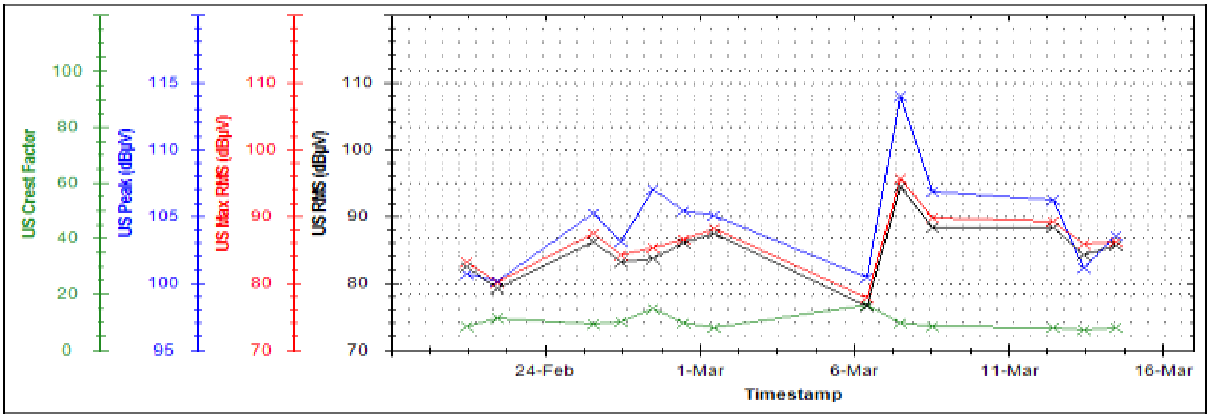
4.4.2.2 Ultrasound analysis for BRG -2 DE Motor



Figure(4.37) Ultrasound trend for BRG-2 of C.W.P (2)

According to table (3.28) and figure (4.37) The RMS readings for BRG-2 DE motor of CWP (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-2 DE motor of CWP (2) beaing defective.

4.4.2.3 Ultrasound analysis for BRG - 3 DE pump



Figure(4.38)Ultrasound trend for BRG-3 of C.W.P (2)

According to table (3.29) and figure (4.38) The RMS readings for BRG-3 DE of CWP (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-3 DE of CWP (2) beaing defective.

4.4.2.4 Ultrasound analysis for BRG- 4 NDE pump

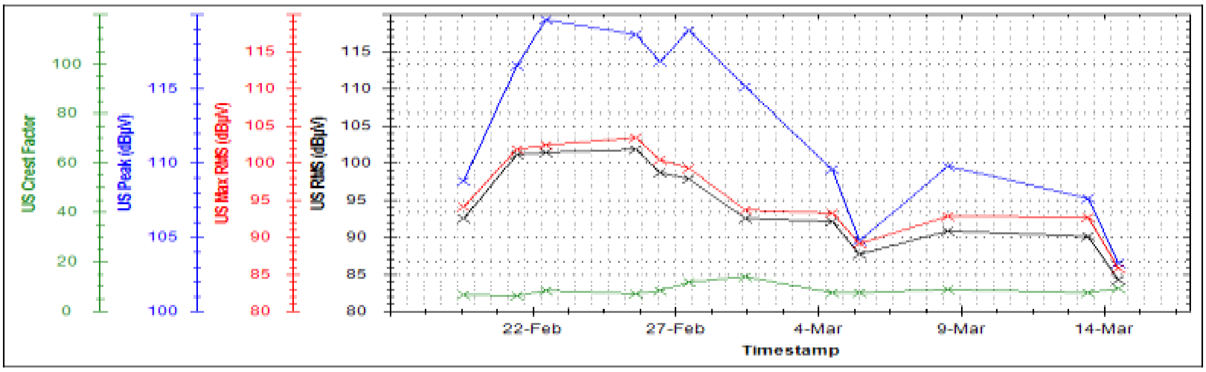


Figure (4.39) Ultrasound trend for BRG-4 of C.W.P (2)

According to table (3.30) and figure (4.39) The RMS readings for BRG-4 NDE of CWP (2) are higher than accepted limits in addition to appearance of upnormal sounds and the ultrasound trend is not stable which indicates that BRG-4 NDE of CWP (2) beaing defective.

4.5 Ultrasound analysis for pumps cavitation

All ultrasound measurements for pumps cavitation were taken by using RS1NL100 ultrasound sensor.

4.5.1 Ultrasound analysis for cavitation in condensate extraction pump (1)

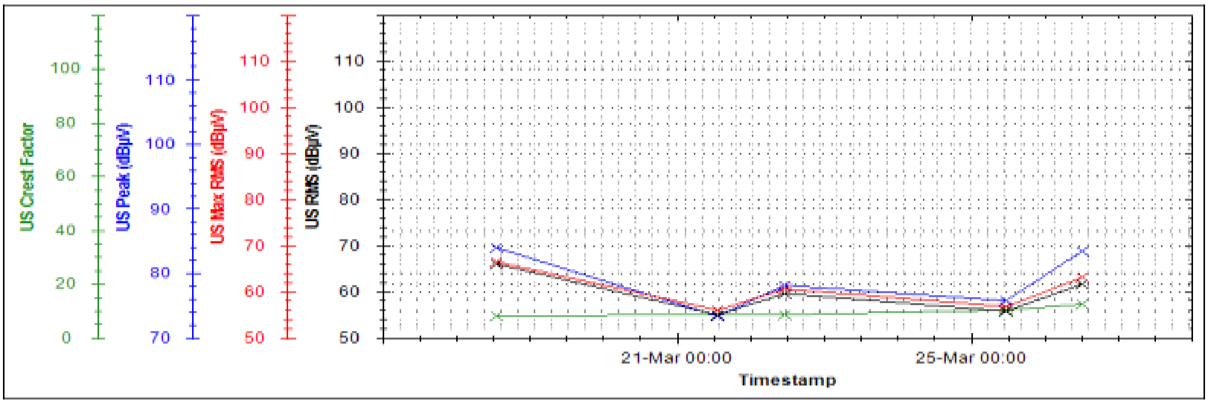


Figure (4.40) Ultrasound trend for cavitation in suction pipe of C.E.P (1)

According to table (3.31) and figure (4.40) for cavitation in suction pipe of C.E.P (1) note that the RMS readings are high which indicates that the cavitation appeared in entrance of C.E.P (1).

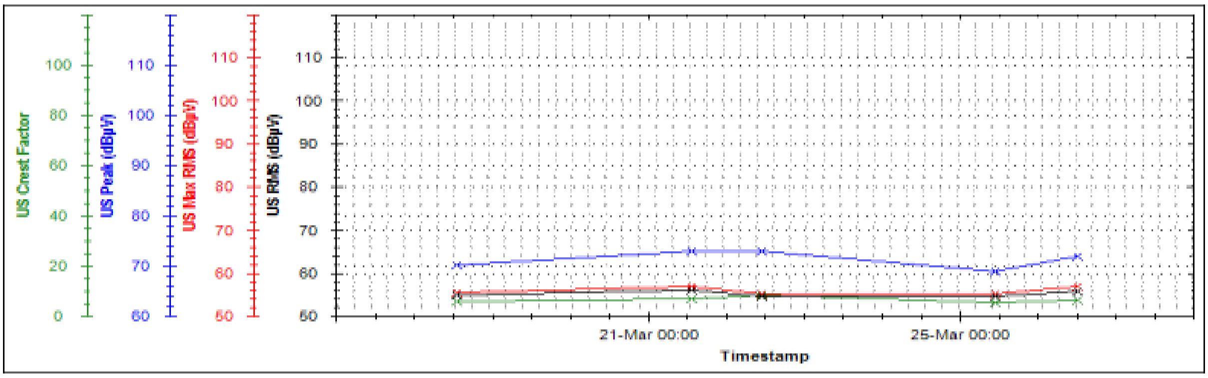


Figure (4.41) Ultrasound trend for cavitation in volute of C.E.P (1)

According to table (3.32) and figure (4.41) for cavitation in volute of C.E.P (1) note that RMS readings are high which indicates that the cavitation appeared in impeller of C.E.P (1).

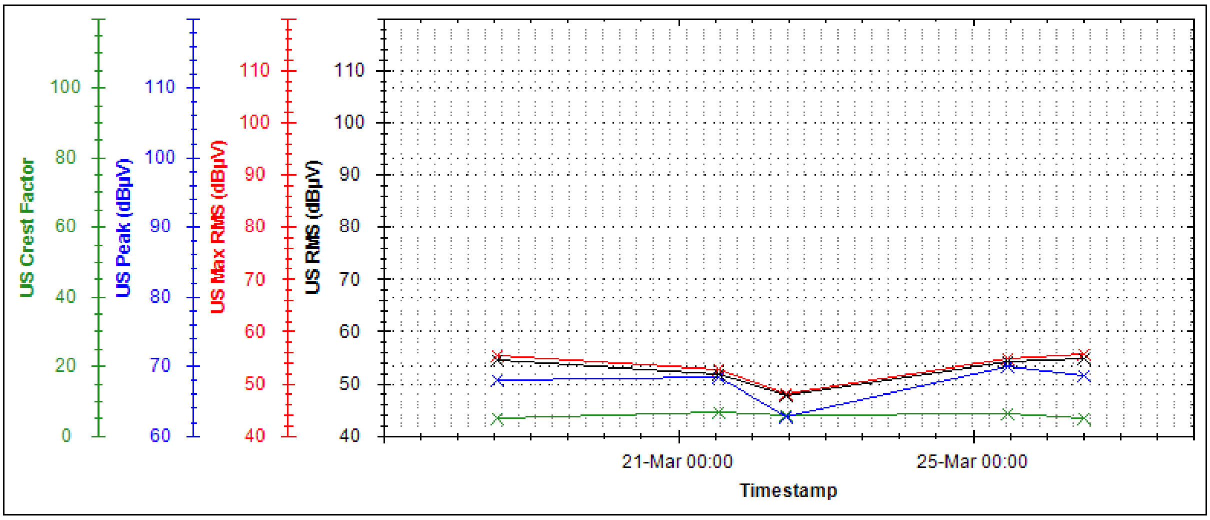


Figure (4.42) Ultrasound trend for cavitation in discharge pipe of C.E.P (1)

According to table (3.33) and figure (4.42) for cavitation in discharge pipe of C.E.P (1) note that RMS readings are high which indicates that the cavitation appeared in discharge pipe of C.E.P (1).

4.5.2 Ultrasound analysis for cavitation in condensate extraction pump (2)

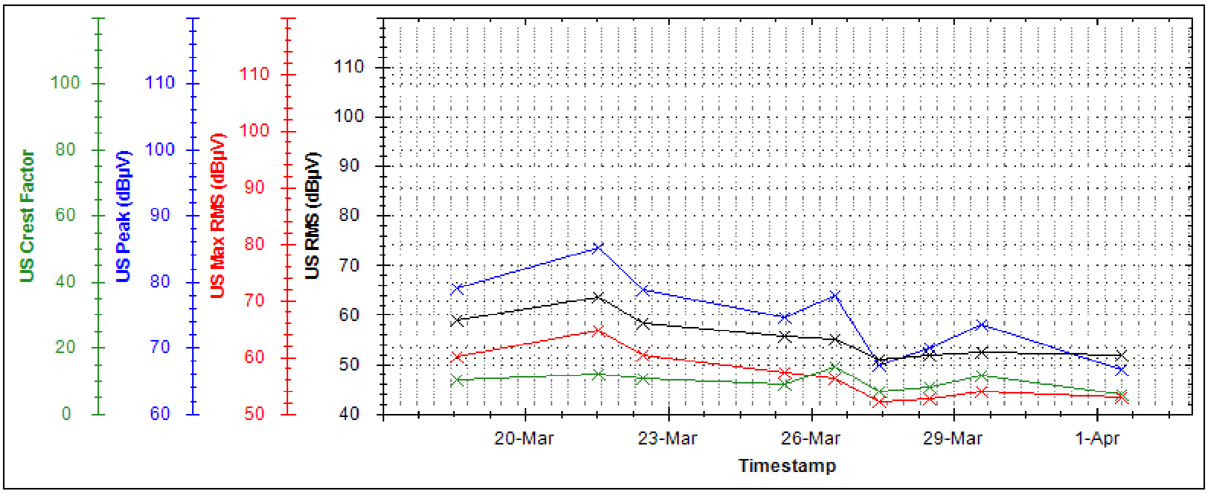


Figure (4.43) Ultrasound trend for cavitation in suction pipe of C.E.P (2)

According to table (3.34) and figure (4.43) for cavitation in suction pipe of C.E.P (2) note that RMS readings are high which indicates that the cavitation appeared in entrance of C.E.P (2).

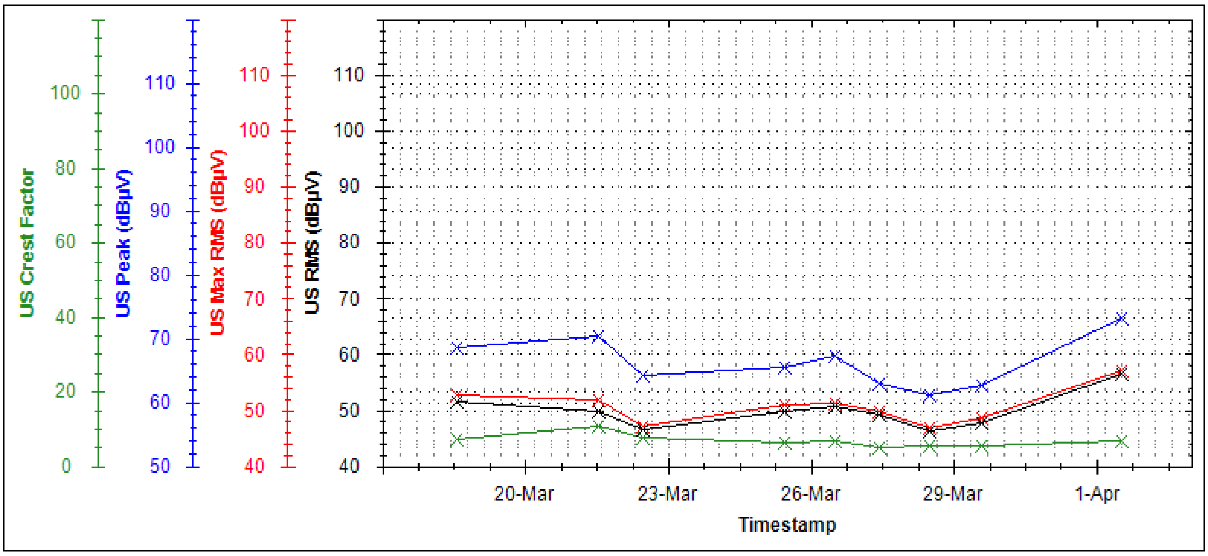


Figure (4.44) Ultrasound trend for cavitation in volute of C.E.P (2)

According to table (3.35) and figure (4.44) for cavitation in volute of C.E.P (2) note that RMS readings are high which indicates that the cavitation appeared in volute of C.E.P (2).

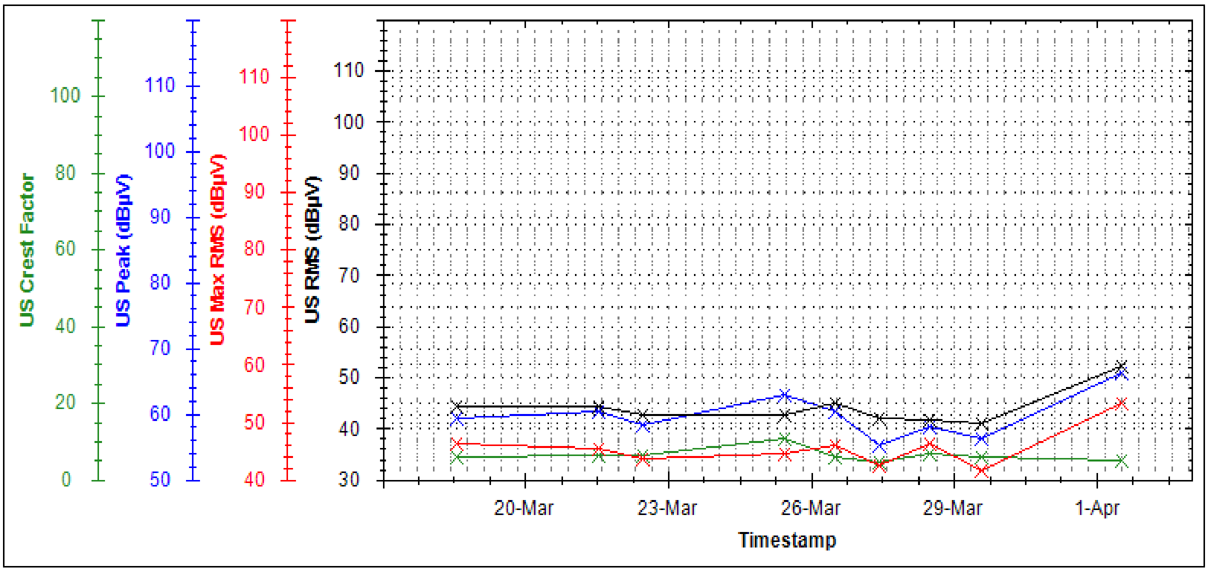


Figure (4.45) Ultrasound trend for cavitation in discharge pipe of C.E.P (2)

According to table (3.36) and figure (4.45) for cavitation in discharge pipe of C.E.P (2) note that RMS readings are in accepted limits which indicates that discharge pipe of C.E.P (2) without cavitation.

4.5.3 Ultrasound analysis for cavitation in circulating water pump (1)

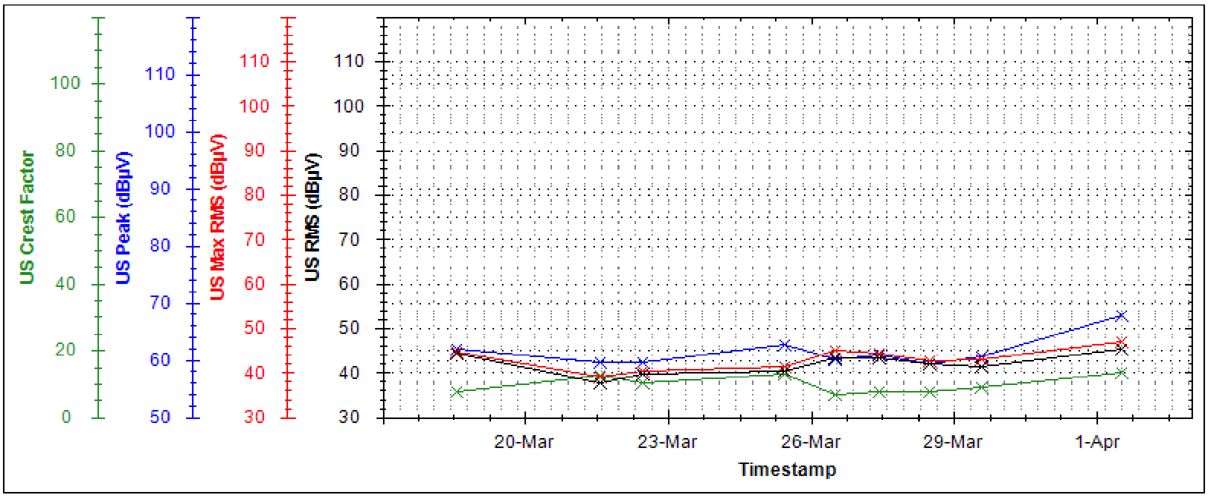


Figure (4.46) Ultrasound trend for cavitation in suction pipe of C.W.P (1)

According to table (3.37) and figure (4.46) for cavitation in suction pipe of C.W.P (1) note RMS readings are high which indicates that the cavitation appeared in suction pipe of C.W.P (1).

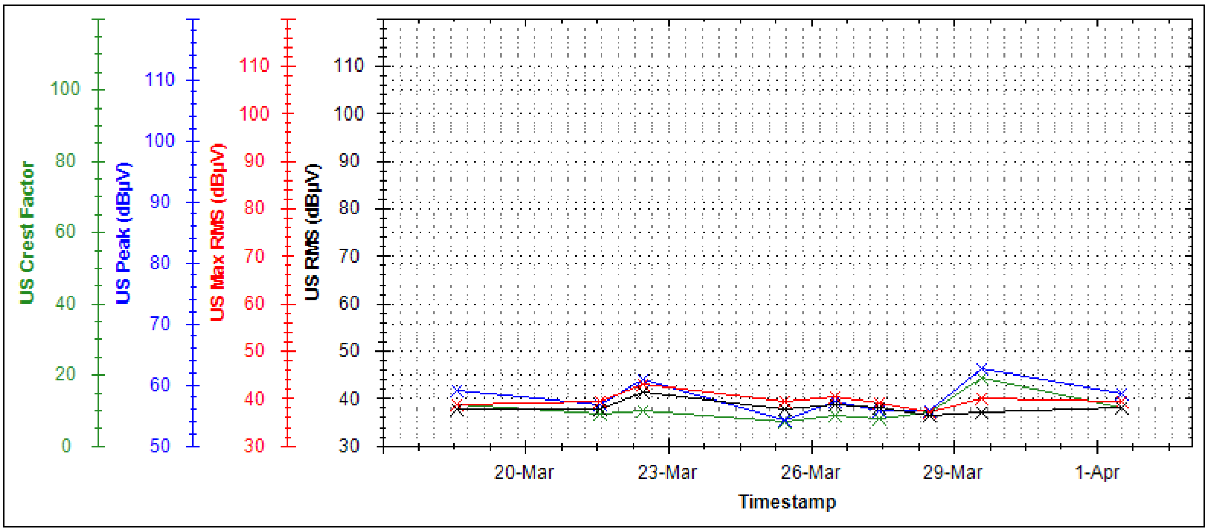


Figure (4.47) Ultrasound trend for cavitation in volute of C.W.P (1)

According to table (3.38) and figure (4.47) for cavitation in volute of C.W.P (1) note that RMS readings are high which indicates that the cavitation appeared in impeller of C.W.P (1).

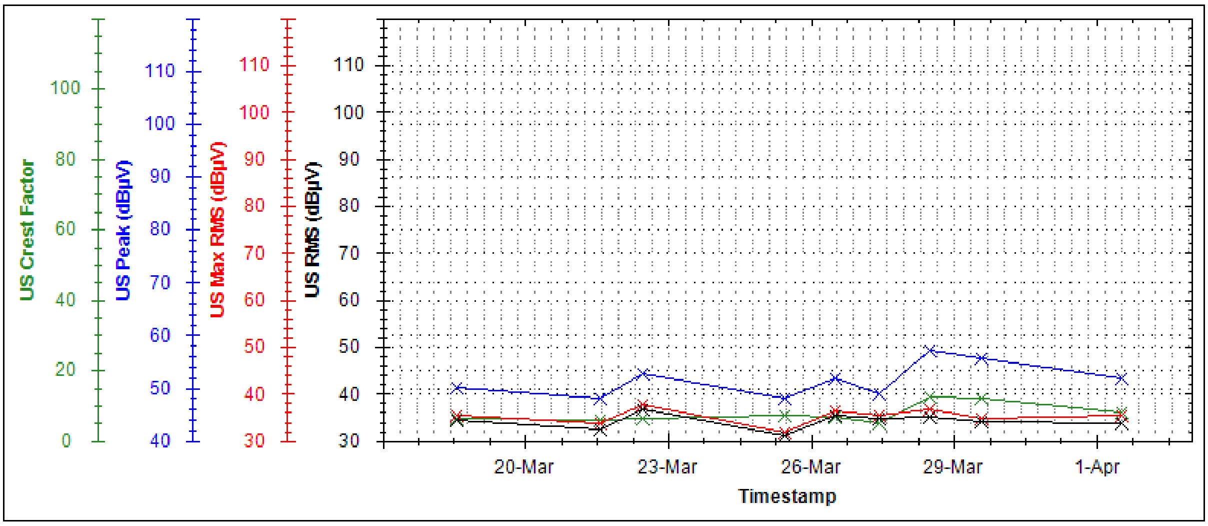


Figure (4.48) Ultrasound trend for cavitation in discharge pipe of C.W.P (1)

According to table (3.39) and figure (4.48) for cavitation in discharge pipe of C.W.P (1) note that RMS readings are in accepted limits which indicates that discharge pipe of C.W.P (1) without cavitation.

4.5.4 Ultrasound analysis for cavitation in circulating water pump (2)

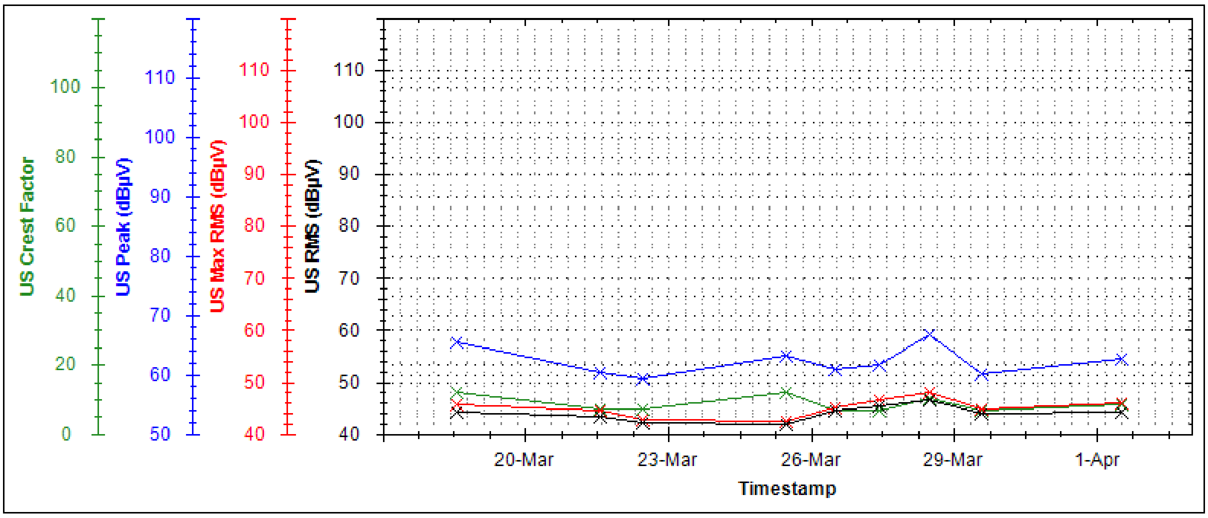


Figure (4.49) Ultrasound trend for cavitation in suction pipe of C.W.P (2)

According to table (3.40) and figure (4.49) for cavitation in suction pipe of C.W.P (2) note that RMS readings are high which indicates that the cavitation appeared in suction pipe of C.W.P (2).

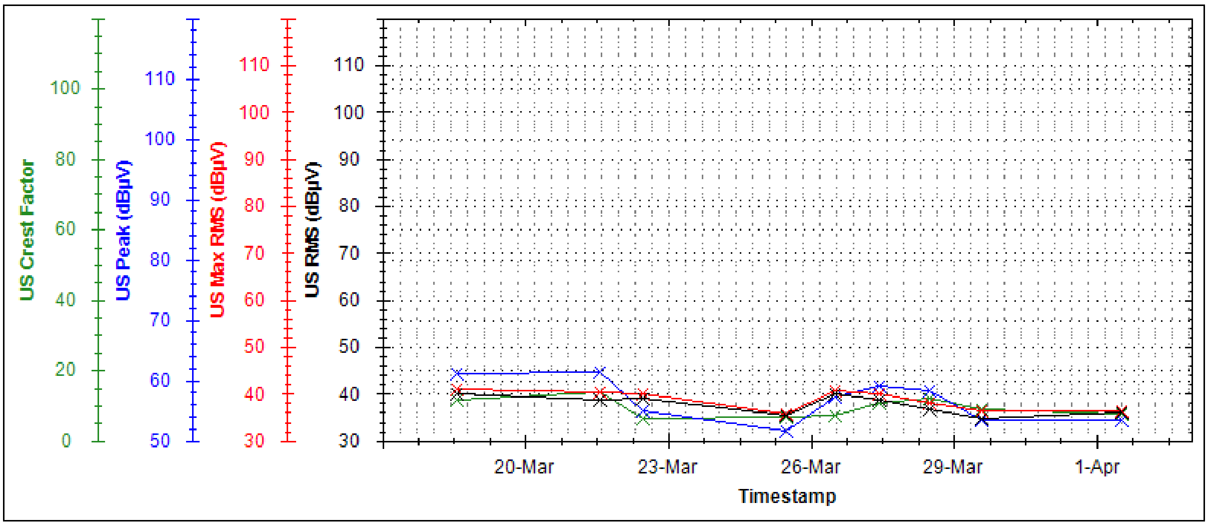


Figure (4.50) Ultrasound trend for cavitation in volute of C.W.P (2)

According to table (3.41) and figure (4.50) for cavitation in volute of C.W.P (2) note that RMS readings are in accepted limits which indicates that the volute of C.W.P (2) without cavitation.

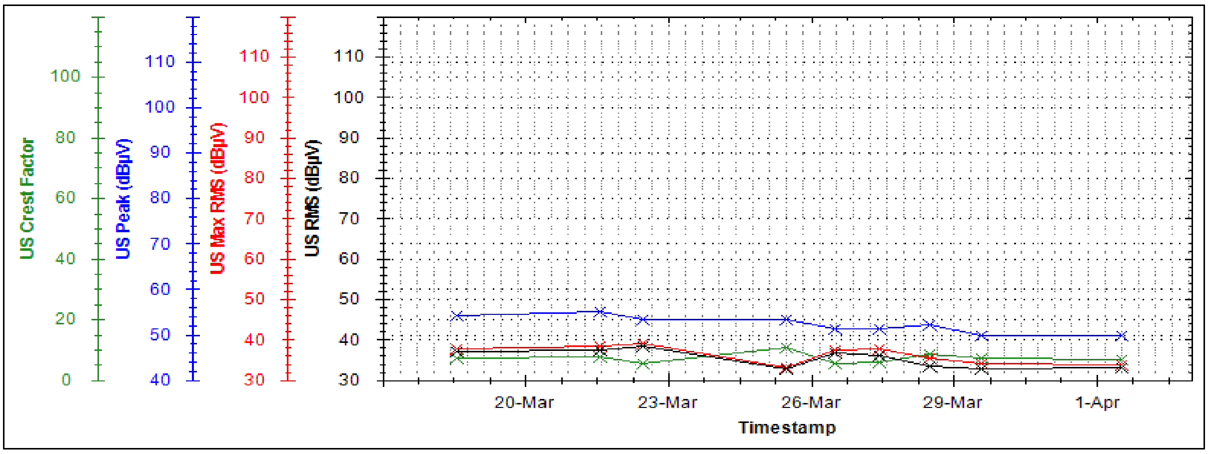


Figure (4.51) Ultrasound trend for cavitation in discharge pipe of C.W.P (2)

According to table (3.42) and figure (4.51) for cavitation in discharge pipe of C.W.P (2) note that RMS readings are in accepted limits which indicates that discharge pipe of C.W.P (2) without cavitation.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

After putting the case studies in Garri-4 power plant under monitoring by using ultrasound condition monitoring technique (SDT 270 ultrasound device) up normal sounds were detected. The ultrasound measurements were collected by using two types of sensors: RS1 Needle contact sensor and RS1 Threaded sensor. All data collected was transferred to ultranaylsis suite software to make analysis. Wrong data was excluded before analysis was completed.

For healthy bearings ultrasound measurements are in accepted limits, ultrasound trend is stable in addition to non-appearance for up normal sounds. For defective bearings ultrasound measurements are higher than accepted limits, the ultrasound trend is not stable in addition to appearance for up normal sounds.

For high pressure seal blower (1) found that BRG-1 NDE motor is healthy, BRG-2 DE motor is defective, BRG-3 is defective in outer ring, BRG-4 is defective in outer ring, BRG-5 in case of looseness and BRG-6 is defective in rolling element about its own axis. For high pressure seal blower (2) found that BRG-1 NDE motor is healthy, BRG-2 DE motor is defective, BRG-3 is defective in rolling element about its own axis, BRG-4 is defective in rolling element about its own axis,BRG-5is healthy and BRG-6 in case of looseness.

For condensate extraction pump (1) found that BRG-1 NDE motor is healthy, BRG-2 DE motor is defective, BRG-3 DE pump is healthy and BRG-4 NDE pump is defective. For condensate extraction pump (2) found that BRG-1 NDE motor is healthy, BRG-2 DE motor is defective, BRG-3 DE pump is healthy and BRG-4 NDE pump is defective.

For circulating water pump (1) found that BRG-1 NDE motor is healthy, BRG-2 DE motor is defective, BRG-3 DE pump is defective and BRG-4 NDE pump is defective. For circulating water pump (2) found that BRG-1 NDE motor is healthy, BRG-2 DE motor is defective, BRG-3 DE pump is defective and BRG-4 NDE pump is defective.

For cavitation in condensate extraction pump (1); the cavitation appeared in entrance, impeller and discharge pipe. For cavitation in condensate extraction pump (2); the cavitation appeared in entrance, impeller and disappeared in discharge pipe.

For cavitation in circulating water pump (1); the cavitation appeared in entrance, impeller and disappeared in discharge pipe. For cavitation in circulating water pump (2); the cavitation appeared in entrance, and disappeared in impeller and discharge pipe.

5.2 Recommendations

1) In this thesis the ultrasound technique was used to identify the mechanical faults in rotating machines I recommended that to be used to identify the static equipments faults.
2) Due to difficulty in determining the amount of grease inside bearings I recommended to use ultrasound technique in greasing to specify the correct quantity.

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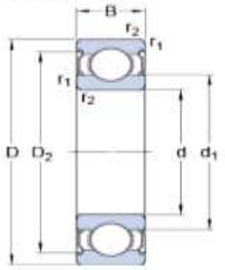
APPENDIX A

Bearing specifications for high pressure seal blowers:

6311-2Z

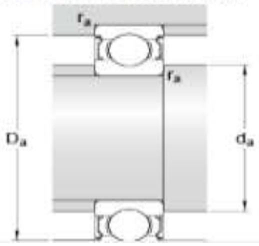
Popular item
SKF Explorer

Dimensions



d		55	mm
D		120	mm
B		29	mm
d_1		75.34	mm
D_2		103.7	mm
$r_{1,2}$	min.	2	mm

Abutment dimensions



d_a	min.	66	mm
d_a	max.	75.2	mm
D_a	max.	109	mm
r_a	max.	2	mm

Calculation data

Basic dynamic load rating	C	74.1	kN
Basic static load rating	C_0	45	kN
Fatigue load limit	P_u	1.9	kN
Reference speed		12000	r/min
Limiting speed		6300	r/min
Calculation factor	k_r	0.03	
Calculation factor	f_0	13.1	

Mass

Mass bearing	1.42	kg

Bearing frequencies for high pressure seal blowers:

Rotational frequency of the inner ring f_i	24.7 Hz
Rotational frequency of the outer ring f_e	0 Hz
Rotational frequency of the rolling element and cage assembly f_c	9.42 Hz
Rotational frequency of a rolling element about its own axis f_r	49.4 Hz
Over-rolling frequency of one point on the inner ring f_{ip}	121.9 Hz
Over-rolling frequency of one point on the outer ring f_{ep}	75.4 Hz
Over-rolling frequency of one point on a rolling element f_{rp}	98.8 Hz

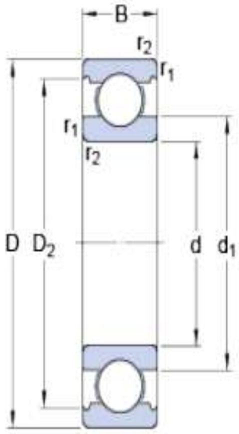
APPENDIX B

Bearing specifications for condensate extraction pumps:

6310

Popular item
SKF Explorer

Dimensions



d		50	mm
D		110	mm
B		27	mm
d_1		68.76	mm
D_2		95.2	mm
$r_{1,2}$	min.	2	mm

Calculation data

Basic dynamic load rating	C	65	kN
Basic static load rating	C_0	38	kN
Fatigue load limit	P_u	1.6	kN
Reference speed		13000	r/min
Limiting speed		8500	r/min
Calculation factor	k_r	0.03	
Calculation factor	f_0	13	

Mass

Mass bearing	1.08	kg

Bearing frequencies for condensate extraction pumps:

Rotational frequency of the inner ring f_i	49.7 Hz
Rotational frequency of the outer ring f_e	0 Hz
Rotational frequency of the rolling element and cage assembly f_c	18.9 Hz
Rotational frequency of a rolling element about its own axis f_r	98.4 Hz
Over-rolling frequency of one point on the inner ring f_{ip}	246 Hz
Over-rolling frequency of one point on the outer ring f_{ep}	151.4 Hz
Over-rolling frequency of one point on a rolling element f_{rp}	196.7 Hz

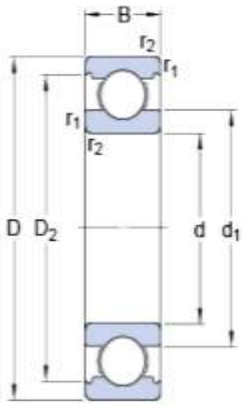
APPENDIX C

Bearing specifications for circulating water pumps (NDE):

6320

Popular item

Dimensions



d		100	mm
D		215	mm
B		47	mm
d_1		135.85	mm
D_2		183.8	mm
$r_{1,2}$	min.	3	mm

Calculation data

Basic dynamic load rating	C	174	kN
Basic static load rating	C_0	140	kN
Fatigue load limit	P_u	4.75	kN
Reference speed		6700	r/min
Limiting speed		4300	r/min
Calculation factor	k_r	0.03	
Calculation factor	f_0	13.2	

Mass

Mass bearing	7.08	kg

Bearing frequencies for circulating water pumps (NDE):

Rotational frequency of the inner ring f_i	16.3 Hz
Rotational frequency of the outer ring f_e	0 Hz
Rotational frequency of the rolling element and cage assembly f_c	6.27 Hz
Rotational frequency of a rolling element about its own axis f_r	33.3 Hz
Over-rolling frequency of one point on the inner ring f_{ip}	80.5 Hz
Over-rolling frequency of one point on the outer ring f_{ep}	50.2 Hz
Over-rolling frequency of one point on a rolling element f_{rp}	66.7 Hz

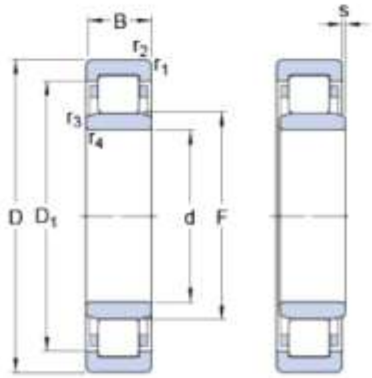
APPENDIX D

Bearing specifications for circulating water pumps (DE):

NU 320 ECM

Popular item
SKF Explorer

Dimensions



d		100	mm
D		215	mm
B		47	mm
D_1		181.1	mm
F		127.5	mm
$r_{1,2}$	min.	3	mm
$r_{3,4}$	min.	3	mm
s	max.	2.9	mm

Calculation data

Basic dynamic load rating	C	450	kN
Basic static load rating	C_0	440	kN
Fatigue load limit	P_u	51	kN
Reference speed		3200	r/min
Limiting speed		3800	r/min
Calculation factor	k_r	0.15	
Limiting value	e	0.2	
Axial load factor	Y	0.6	

Mass

Mass bearing	8.45	kg

Bearing frequencies for circulating water pumps (DE):

Rotational frequency of the inner ring f_i	16.3Hz
Rotational frequency of the outer ring f_e	0 Hz
Rotational frequency of the rolling element and cage assembly f_c	6.53 Hz
Rotational frequency of a rolling element about its own axis f_r	39.1 Hz
Over-rolling frequency of one point on the inner ring f_{ip}	127.5 Hz
Over-rolling frequency of one point on the outer ring f_{ep}	84.9 Hz
Over-rolling frequency of one point on a rolling element f_{rp}	78.1 Hz