Title Page

Vibration Diagnostic of Rotor Mechanisms in Ships

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Declaration

Here with, I certify that the work included in the Thesis in part or whole, has not been submitted for any other academic qualification at any institution.

UOM Verified Signature

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ABSTRACT

In ships, there are so many sources of noise and Vibration such as propulsion engines and electric generators in restricted spaces and structures of ships, which are made of steel, transmit vibration well. By the reasons, noise and vibration of ships are very big by nature and reduction of noise and vibration is important subject for ships. Regarding noise reduction, reduction of noise cause by vibration has difficulty and the major part of such noise is structure born noise.

"***Vibration***" is not a problem. It is a physical manifestation of machinery imperfection. It is used to help find obvious and subtle deviations in machines. No machine runs perfect. "***Diagnosis***" is the Method of Detection. If, a fault develops and goes undetected, then, at best, the problem will not be too serious and can be remedied quickly and cheaply; at worst, it may result in expensive damage and down-time, injury, or even loss of life. There is no reason or excuse to have machinery operate unprotected. The areas of interest in vibration measuring in plant maintenance are general measurement, analysis, and corrective.

All rotor mechanisms in ships consist of shafts, bearings, couplings, gears etc. These machinery operate under various load conditions from light to heavy. Ship propulsion system comparatively works under very heavy load conditions with rolling and pitching of the ship which may tend to cause overstressing of shafts.

Objective of the Research:

The aim of the project is to identify the vibration analysis of a ship transmission system. *A ship transmission system* is the link between the crank shaft (or thrust block) end and the propeller of the vessel. As it contains number of shafts, couplings and bearings it tends to cause severe vibrations due to various running and incipient defects. These defects can be diagnosed by measuring the level of vibration to the extent they excited.

Methodology Adopted: A Test Rig:

The test rig is a model of the transmission system of the ship "M/V Lanka Mahapola" made in to a scale of 1:10. Level and condition of lubrication maintained. Accelerometers are mounted over the bearing casings to trace the excitement of individual bearings.

Diagnosis of the misaligned and unbalanced shafts and defected sleeve (fluid film) bearings are done by using the "**AUTOVIB**" software package which is a vibration monitoring method introduce by this project.

Final Outcome of this research :

Although spectrum analysis method is not in use, similar demodulation techniques, will be practical, for the diagnostics of Sleeve (Fluid Film) bearings.

Measurement of the vibrations excited by bearing friction forces present all the necessary information for Diagnostics of bearing condition including installation problems and the quality of lubrication.

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CHAPTER I

dBsv	Decibel shock value
dBi	Initial shock value
dB_N	Normalized shock value

CHAPTER II

v	impact velocity
dB(A)	Vibration energy measurement
L	Length of the structure
M	Function of the mass at the structure and its distribution
I	Second moment of area of the material of the structure about its neutral axis.
f	Frequency of applied force
fn	Frequency of Natural Structure

CHAPTER IV

m	Mass or inertia (in Spring-mass system) (kg)
J	Mass or inertia (in Torsional system) (kg m^2)
K_m	Spring (in Spring-mass system) (Nm)
K_T	Spring (in Torsional system) (Nm/rad)
c_m	Damping (in Spring-mass system) (Ns/m)
c_T	Damping (in Torsional system) (Nms/rad)
a	Acceleration (in Spring-mass system) (m /s^2)
ö	Acceleration (in Torsional system) (rad/s^2)
v	Velocity (in Spring-mass system) (m /s)
ò	Velocity (in Torsional system) (rad/s)
y	Displacement (in Spring-mass system) (m)
θ	Displacement (in Torsional system) (rad)

CHAPTER VII

$F(t)$	Fourier Transform – Time response function
T	Periodic time
ω_T	Angular velocity
t	Time
a_0, a_n, b_n	Fourier transform coefficients
n	Integral multiplier
f_0	Fundamental frequency (first harmonic)
Δf	Frequency interval
$f(t)$	Fourier time response
N	Number of discrete values
Δt	Sampling interval
f_s	Sampling rate
f_{Ny}	Nyquist frequency
$F(f)$	Fourier Transform – Frequency response function
$u_{T/2}(t)$	Boxcar time response function
$U_{T/2}(f)$	Boxcar frequency response function
ΔN	Number of padded zeros
N'	Number of data values in time series
$\Delta f'$	Frequency Increment
B_e	Resolution bandwidth
f_{max}	Highest frequency
$X_{(f)}$	Fourier transform
$x_{(t)}$	Inverse fourier transform
k	Integral coefficient
a_k, b_k	Fourier transform coefficients
$f_{(x)}$, $g_{(x)}$	Original functions
$F_{(s)}$, $G_{(s)}$	Function after convolution
$X(mF)$	Discrete frequency transform function

$x(n\mathrm{T})$	Time response function
realOut	Array of coefficients of cosine waves in the Fourier formula.
imagOut	Array of coefficients of sine waves in the Fourier formula.
$h(t)$	Impulse response
$x(t)$	Input time domain
$y(t)$	Output time domain
$\mathrm{X}(f)$	Input frequency domain
$\mathrm{Y}(f)$	Output frequency domain
$\mathrm{H}(f)$	Impulse frequency domain
$f(w)$	Fourier transform function
$f(x)$	Continuous time function
$\mathrm{E}(x)$	Even part of function $f(x)$
$\mathrm{O}(x)$	Odd part of function $f(x)$
$f^*(-x)$	Imaginary Function
$F^*(-s)$	Complex Conjugate of Function f(x)
$\mathrm{F}(s)$	Fourier Transform function of f(x)
$\wp_c$	Cosine Transform
$\wp_s$	Sine Transform
i	Numerous
x_0	A Real constant
β	$= (x - x_0)$
B	A frequency in Hz
H_n	Discrete Fourier transform of N-points
W	A Complex Number
h_k	A Vector
F_k	k^{th} component of fourier transform
F^e_k	k^{th} Component of Fourier transform of length $n/2$
$data[1]$	Real part of f_0
$data[2]$	Imaginary part of f_0

CHAPTER IX

L_{10}	Basic rating life of bearing

CHAPTER XII

f_n	Undamped natural (resonant) frequency (Hz)
f	Frequency at any given point of the curve (Hz)
a_o	Output acceleration
a_b	Mounting base or reference acceleration
Q	Factor of amplitude increase at resonance
C_t	Transducer capacitance
C_c	Cable capacitance
C_r	Range (or feedback) capacitor
R_t	Time constant resistor (or insulation of range capacitor)
R_i	Insulation resistance of input circuit (cable and transducer)
q	Charge generated by the transducer
V_o	Output voltage
A	Open loop Gain
TC	Time Constant
q	Charge generated by piezoelectric element
V_i	Input signal at gate
C_q	Transducer capacitance
C_G	MOSFET GATE capacitance

CHAPTER XIII

F	Force
m	Mass
a	Acceleration

CHAPTER XIV

T1, T2, T3	Accelerometers
EM	Electric motor
B1, B2, B3	Bearings
TS	Tail shaft
IS	Intermediate shaft
C1, C2	Couplings

CHAPTER XVII

N	Motor speed (rps)
n	Number of balls
d	Ball diameter
D	Pitch diameter
B	Contact angle of ball
Z	Number of polls
F_L	Line frequency
N_s	Synchronous speed
F_{rot}	Rotational frequency
F_s	Slip frequency
F_p	Pole frequency
F_z	Slot frequency
$F_z \pm F_{rot}$	Side bands
$F_z - 2F_L \pm F_{rot}$	Side bands
F_m	Main supply frequency
EMO	Characteristics of electric motor at 0 rpm
ECUP	Characteristics of electric motor running with attached coupling only
EMR	Characteristics of electric motor running with shafting and propeller

CAP1_B11	Characteristics of bearing no. 1 with loosen cap no.1
CAP1_B21	Characteristics of bearing no. 2 with loosen cap no.1
CAP1_B31	Characteristics of bearing no. 3 with loosen cap no.1
CAP1_EM1	Characteristics of electric motor with loosen cap no.1
CAP2_B11	Characteristics of bearing no. 1 with loosen cap no.2
CAP2_B21	Characteristics of bearing no. 2 with loosen cap no.2
CAP2_B31	Characteristics of bearing no. 3 with loosen cap no.2
CAP2_EM1	Characteristics of electric motor with loosen cap no.2
CAP3_B11	Characteristics of bearing no. 1 with loosen cap no.3
CAP3_B21	Characteristics of bearing no. 2 with loosen cap no.3
CAP3_B31	Characteristics of bearing no. 3 with loosen cap no.3
CAP3_EM1	Characteristics of electric motor with loosen cap no.3
LB1_B11	Characteristics of bearing no. 1 with loosen bearing no.1
LB1_B21	Characteristics of bearing no. 2 with loosen bearing no.1
LB1_B31	Characteristics of bearing no. 3 with loosen bearing no.1
LB1_EM1	Characteristics of electric motor with loosen bearing no.1
LB2_B11	Characteristics of bearing no. 1 with loosen bearing no.2
LB2_B21	Characteristics of bearing no. 2 with loosen bearing no.2
LB2_B31	Characteristics of bearing no. 3 with loosen bearing no.2
LB2_EM1	Characteristics of electric motor with loosen bearing no.2
LB3_B11	Characteristics of bearing no. 1 with loosen bearing no.3
LB3_B21	Characteristics of bearing no. 2 with loosen bearing no.3
LB3_B31	Characteristics of bearing no. 3 with loosen bearing no.3
LB3_EM1	Characteristics of electric motor with loosen bearing no.3
LC1_B11	Characteristics of bearing no. 1 with loosen coupling no.1
LC1_B21	Characteristics of bearing no. 2 with loosen coupling no.1
LC1_B31	Characteristics of bearing no. 3 with loosen coupling no.1
LC1_EM1	Characteristics of electric motor with loosen coupling no.1
LC2_B11	Characteristics of bearing no. 1 with loosen coupling no.2
LC2_B21	Characteristics of bearing no. 2 with loosen coupling no.2

LC2_B31	Characteristics of bearing no. 3 with loosen coupling no.2
LC2_EM1	Characteristics of electric motor with loosen coupling no.2
UM_B11	Characteristics of bearing no. 1 with unbalance mass
UM_B21	Characteristics of bearing no. 2 with unbalance mass
UM_B31	Characteristics of bearing no. 3 with unbalance mass
UM_EM1	Characteristics of electric motor with unbalance mass
NOL1_B11	Characteristics of bearing no. 1 without lubrication
NOL2_B21	Characteristics of bearing no. 2 without lubrication
NOL3_B31	Characteristics of bearing no. 3 without lubrication
ECUP	Characteristics of electric motor with coupling attached
AL_B11	Characteristics of bearing no. 1 with shaft aligned
AL_B21	Characteristics of bearing no. 2 with shaft aligned
AL_B31	Characteristics of bearing no. 3 with shaft aligned

PREFACE

PREFACE

A ship is the home of the crew for months at a time and of her passengers perhaps for weeks. The influence of vibration upon comfort is therefore extremely important and will be a factor in the reputation of any passenger ship.

Vibration Problems on ships such as mast, foundation, and propeller shaft vibration excited by propulsion system frequencies can lead to structural fatigue, damage to machinery, and can be annoying, uncomfortable, and dangerous for persons on the ship.

Vibration has been a matter of concern to ship designers since the end of the 19th century although its presence in ship characteristics was known long before that time and its importance has become much emphasized over the last half century. Some sailing warships, particularly the lightly-built frigates, suffered from serious vibration aft when driven hard, probably as a result of flow interaction while there are accounts of mast/sail combinations causing such severe vibration that crewmen were thrown from their feet or, worse, from their mast-top positions.

Today, an increasing number of new or alternative ships is launched - very large and very fast container ships, cruise ships, tankers with modern propulsion systems. Due to little experience with such ships, living conditions can be adversely affected by vibration if the frequencies of major excitations are close to a natural frequency of the superstructure or a part of it.

In ships, there are so many sources of noise and Vibration such as propulsion engines and electric generators in restricted spaces and structures of ships, which are made of steel, transmit vibration well. By the reasons, noise and vibration of ships are very big by nature and reduction of noise and vibration is important subject for ships.

Effect of Vibration :

One can distinguish two areas, where standards have been developed to assess the effect of vibration, applied to the human body: vibration passing to hand and whole body. The vibration passes to hand, can cause the disease, called as "white finger disease," the latter can lead to variety of health problems, ranging from motion sickness to tissue damages. It should be noted, that the relationship between exposure and the disease is complex and many questions in this area, remain unanswered. A number of standards incorporating the latest state of knowledge have been introduced over the last few years with the object of giving guidance to those, who required to assess the importance of human vibration exposure.

It is now generally believed that vibration causes damage to blood vessels, which are thus made incapable of circulating blood to the extremities. There is no known cure and symptoms, which are irreversible. So it is clearly important to establish the levels of vibration and the duration of exposure, which are statically likely to cause the disease and to take precautions.

Noise:

Noise has been recognized as a nuisance (in the legal sense) for many years. Nuisance can be either public or private. A private nuisance is commonly defined as an unlawful interference with a person's use or enjoyment of land or of some right over it or in connection with it. A public noise is an unlawful act or omission causing interference with the health and safety of the public at large. A noisy operation can be both a public and a private nuisance. It is not always easy to answer the question of whether the nuisance complained of is a public or a private one. If the noise nuisance affects just one person or a household, it is clearly a private nuisance. If it affects a class of the public, such as the residents of a community or of the passers-by of a noisy factory, it is likely to be a public nuisance.

A private action can only be brought by the occupier of the land or by someone who has a legal interest in the land, and he can only take action against the person who cause the nuisance. A public nuisance is a crime, and proceedings can be taken by public bodies such as the local authority or Attorney-General or both. All the criminal sanctions are available to the court, an in addition it has power to issue an abatement order, which may take the form of restricting the noise to certain hours, or levels, or to cease entirely.

It is well known that much of modern technology is derived from projects ordered by the military industry of the developed countries. The deepest research of machines and equipment vibration is done initially in countries with strong naval forces, which have important needs to minimize noise and vibration. A number of naval research centers that deal with using and developing analytical tools for vibration measurement and reduction exist in Developed Countries. These centers are equipped with modern instrumentation for measurement and analysis of signals ,mostly using instruments produced by Bruel & Kjaer (Denmark) and Kistler (Norway). A number of highly qualified experts work in these centers and prepare specialists for navy and shipbuilding industry.

The greatest advances can make in the condition diagnostics of machines using vibration., The AUTOVIB monitoring method for condition diagnostics of machines using vibration can be successfully used in a number of civil industries including energy, nuclear power plants, paper and pulp, metallurgy, transport including ships, aviation and railways.

One of the main problems in Sri lanka is a great shortage of specialists who can efficiently use condition monitoring and diagnostics systems, including those with expert systems that are supplied by the leading Western companies. To prepare these specialists would take too much time. This fact has defined the main peculiarities of the vibration diagnostics in Sri lanka. The strategy of AUTOVIB, is to develop a system for condition diagnostics of sleeve bearings (fluid film bearings) that can be applied equally for ball bearings as well.

The main problems peculiar to the Sri lankan market

The changes associated with the introduction of market relations in the number of industries in Sri lanka were started at the end of the 1956 and after 1980s with the introduction of Open economy. Plans for restructuring the economy included plans to decrease production costs and excess labour energy. The drawbacks prevail in improving of the efficiency of production processes is based on three main assumptions:

- The absence of financial resources in the country to renew the machinery and equipment in the majority of industries for at least five to ten years. The natural wear of the equipment should significantly increase its maintenance costs and the introduction of the condition diagnostics systems is likely to be the most practical way to decrease these costs.
- Relatively high investments over high level diagnostic systems (Automatic Condition monitoring Systems) prevent owners by utilizing such a system.
- Significant limitations of existing condition diagnostic technologies from leading Western companies.

The following reasons that limit the use of modern condition monitoring and diagnostics systems of American and West-European production in Sri lanka

- The absence in most regions of qualified personnel who can use these systems, despite the existence of a number of scientific centers with experts of higher qualification. The problem is that to prepare a person to be a qualified expert takes several years and would require significant financial resources.
- The high relative price of the common monitoring and diagnostic systems in Importing. For example, in the West the price of the diagnostic instrumentation needed for an expert to work on the enterprise is less than or equal to compared to the labor costs of an expert for the enterprise during a year. In Sri lanka, taking into account the tax policy, the price for the diagnostic equipment equals the income of an expert for about ten years. This makes the survival of small companies specialized in diagnostic services impossible.

- One more reason, which is also economic is the high costs of mounting permanent transducers on existing equipment. Typically, the construction of units should be redesigned to assure appropriate mounting and protection of the transducers so as not to destroy them in the process of standard maintenance of the equipment.
- The last reason is connected to the existence of various standards and regulations that differ in each industry that define the requirements for different parameters of the main equipment and methods for their control. These regulations do not allow making a decision for maintenance and repair of the equipment without conducting standard measurements that usually require the shutdown of the equipment and partial disassembly of the units. That's why these regulations make it impossible to use modern condition monitoring systems and use condition based maintenance.

This analysis of the current situation led to a recommendation to speed up the development of the methods for mass condition diagnostics that can be carried out by a user with no special training in condition diagnostics. These methods were developed over a period of several years based on the analysis of machine vibrations in the shipbuilding industry and the resultant extraction of diagnostic information signals. The methods developed were intended to be used for condition diagnostics of supplementary machines and equipment the maintenance of which was not governed by the existing standards and regulations.

This analysis was the base of this project. At the same time, a number of problems became evident during the detailed market research stage:

- The first problem was the need for application software based on the developed methods that would efficiently replace a qualified expert. The system should ask the customer to describe the equipment for diagnostics, define what data should be measured, process the measured data, make condition diagnostic and prediction for the machines and equipment under control.

- The second problem occurred after the start of the exploitation by the customers of the automatic diagnostic systems consisting of the measurement device, personal computer and the application software . This was the problem of the customers support in those rare situations when the automatic diagnostics did not answered the question of what is the defect in the machine and how dangerous it is.

Noise Generated From Machine Vibrations

If you want to reduce maintenance costs you must improve equipment maintainability and reliability. The premise being, if the equipment does not fail as often, it costs less to repair. When equipment does fail, longer life can be achieved if proper repairs are made. Proper repairs means the cause of failure must be identified and eliminated. If this is not done the equipment will fail again. These objectives can be accomplished during the acquisition phase of new equipment, the purchase of spare parts, and accurate diagnosis of all rotating machinery problems. If either of these items are not properly managed the objectives may not be achieved. Executive evaluations, payment of bonuses, production objectives and other brownie point systems tend to focus management's attention on the short term instead of the long term. This can also affect maintainability and reliability.

In field balancing machines with high vibrations, the use of common methods of determining balance weights often does not yield satisfactory results. An analysis of the reasons for this shows that there are two main groups of constraints on the balancing efficiency: The forces of different nature from simple unbalance that excite vibration at the rotating frequency and the existence of certain defects in the machine that can change the mechanical properties of the machine.

The technology on how to diagnose problems in rotating machinery is equally unparalleled. The technology has progressed from amplitude measuring and trending to using the time domain signal, phase, and frequency domain spectra for accurate diagnosis of specific problems. In fact, it may be time to progress to the next step beyond predictive maintenance to equipment maintainability and reliability.

Consideration of the reliability and service life of a machine suggests that low frequency vibrations present the greatest source of danger to a machine. For machines with rotating parts (rotors), this is typically a vibration at the rotation frequency. This vibration may significantly increase during the machine operation. Usually, when the vibration level exceeds certain limits, the users conduct maintenance of the machine. The inertial forces due to the unbalance of the rotating parts relative to the rotation axis are typically considered to be the reasons for the vibration increase. That's why the users try field balancing the machine when possible. Unfortunately, attempting to balance the machine may not always produce acceptable results. The main reasons for this are other problems of the machine or of its supports. To eliminate additional expenses and delays, the customer should have the information about the various possible defects of the machine that can be responsible for the machine vibration at the rotating frequency and this information should be available before or at least during the balancing.

The factor, the vibration still remains as an actual problem with increase in speed and load of machines in ships. The technical diagnostic is the process of testing the machine, in order to test the condition of it. Therefore the technical diagnostic helps to detect the faults of machines while they operate. The change in condition of vibration of machines may cause the change in technical condition of ship machinery then the condition of the ship.

The term **Diagnostic** is a Greek word, and means the ability to discern. It is used in Medical Science. That is the section, which indicates the symptoms of diseases and methods using to identify the diseases.

Accurate Diagnosis

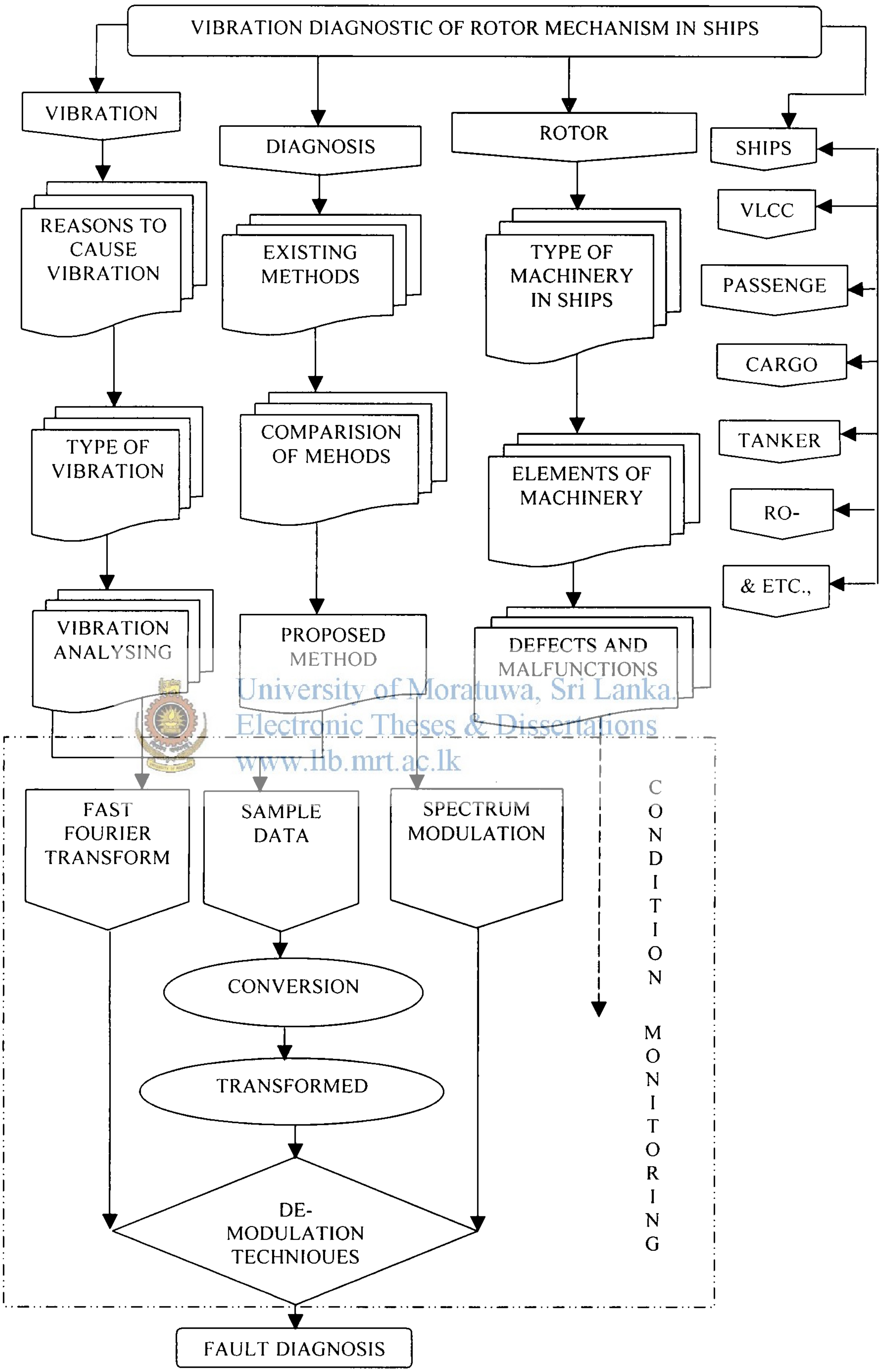
Accurate diagnosis of machinery problems provides the intelligence for new equipment acquisitions, spare parts purchasing, and necessary repairs. This is why this very important function must be part of the Equipment Maintainability and Reliability group.

Once a problem has been identified the necessary maintenance and engineering talent must be available to determine the proper fix. Accurate diagnosis of machinery problems requires a lot more than condition monitoring and trending. Accurate diagnosis requires the proper hardware, software, technology, and skilled people. This includes the use of frequency domain spectra, time domain signals, and phase relationships of frequencies. The first response is "we can't afford that." The fact is that you can't afford not to do accurate diagnosis.

If the right hardware, software, and technology are placed in the hands of skilled people, the payback period is the shortest, and the return on investment (ROI) is more than for any other investment today. These savings are realized by a reduction in maintenance cost and increased production. Managers should realize they may have to purchase new equipment analyzers and transducers. High quality personnel should be assigned to the program. These people must be trained in the best technology. People's attitude should be changed from condition monitoring and trending to accurate diagnosis with vibration analysis. If these objectives are achieved, the increase in profits for a medium plant should be at least one million dollars per year.

Imbalance is a linear problem. Linear problems behave in a linear manner. If a machine is out of balance, you should be able to balance it in three or four runs. If balancing is so simple, what is the problem? The problem is inaccurate diagnosis. There are a lot of vibration "experts" that cannot tell the difference between imbalance, looseness, bent shaft, misalignment, softfoot, broken rotor bars, and loading. All of these problems can cause a high amplitude at rotor speed, however these problems cannot be solved by balancing.

The program “AUTOVIB” gives a broad range of options to diagnose above mentioned disorders and irregularities of the machinery.


VIBRATION DIAGNOSTIC OF ROTOR MECHANISM IN SHIPS
VIBRATION
DIAGNOSIS
ROTOR
SHIPS
VLCC
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