MEASUREMENT AND EVALUATION OF CAM CHAIN NOISE AND VIBRATION OF MOTORCYCLE ENGINE

A thesis

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MASTER OF ENGINEERING

IN

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DALVEER SINGH

Certificate

I hereby certify that the work which is being presented in this thesis entitled " **MEASUREMENT AND EVALUATION OF CAM CHAIN NOISE AND VIBRATION OF MOTORCYCLE ENGINE**", in partial fulfillment of the requirements for the award of degree of Master of Engineering in Production Engineering Submitted in Mechanical Engineering Department of Thapar University , Patiala, is an authentic record of my own work carried out under supervision of **Dr. AJAY BATISH** and **Dr. S.P. NIGAM** and refers other researcher's works which are duly listed in reference section.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

Purpose

Majority of the motor cycle engine suffer from the problem of noise from cam chain after running for few thousand kilometers. This engine noise also known as whine noise accounts for major engine noise. Also the vibration induced in engine due to timing system of automobile engine is severe threat to engine life. This work was based on measurement and evaluation of cam chain noise. Also the vibrations induced in the system were studied for fault diagnosis.

Design/ Methodology/ Approach

This work of cam chain noise evaluation was based on measurement of cam chain noise by separating the noise of cam chain from noise of rest of the engine. As timing system is integral part of internal combustion engine and system cannot work without timing system/ cam chain, hence a system was prepared that includes crankshaft and camshaft sprockets, camshaft, and motor to rotate the chain at required RPM. Further frequency spectrum study and analysis was done along with fault diagnosis for vibration.

Findings and Results

Measurements were made on the system using SOUND LEVEL METER and frequency spectrum were obtained at different set of conditions by varying RPM , chain lubrication and chain wear.

1/1 octave band analysis of the perceived chain noise to find out the major disturbing frequencies and corresponding decibel values was done. Process parameters were analyzed using ANOVA and frequency spectrum for vibration was studied for fault diagnosis.

Maximum noise level was found to be 86 dB(A) and at condition of 1500 RPM , old chain and without lubrication. Minimum noise level was 66 dB(A) obtained for conditions of new chain at 800 RPM and with lubrication. For each condition of varying process parameters dominant frequencies remained same i.e. 2000, 4000 and 8000 Hz with corresponding dB(A)peak values ranging from 66 dB(A) to 86 dB(A). Trends in noise level with changing conditions were

obtained. Noise is more annoying as major frequencies lies in higher range only. All the process parameter were found of effective to chain noise. Process parameters were ranked using ANOVA.

A typical behavior was observed at a speed of 1250 RPM, where effect of wear of chain and effect of lubrication was very insignificant on noise generation. This RPM corresponds to frequency of nearly 130 Hz and needs further investigation.

From frequency spectrum of vibration, dominant frequencies were identified at each operating condition of RPM that lies between 20Hz to 60Hz in almost all cases with peak values ranging from 90dB to 110dB. Trend of increasing dB values with increasing RPM was obtained for measured data.

Troubleshooting vibration of system, rotating members out of balance, misalignment and bent shaft, hysteresis whirl, mechanical looseness, electrically induced vibrations were found factors for induced vibration using fault diagnosis.

Originality of the work

Uniqueness of present approach for MEASUREMENT AND EVALUATION OF CAM CHAIN NOISE OF MOTORCYCLE ENGINE is that it follows the methodology of separating cam chain noise from noise of rest of engine. Though the similar work has been done for diesel engines but motorcycle engine were not studied using this technique. Earlier work done on motorcycle engine was based on the assumption that 2000 RPM major noise from engine is of cam chain only and evaluation was performed at 2000 RPM of motorcycle engine.

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CHAPTER 1

Introduction

1.1 Chain Drive

Chain drive is system for transmitting power with interlocked metal links those are driven by sprockets. Chain drive consists of two sprockets and a chain loop. Chain drive is extensively used in all industries that range from machine tool, aerospace industries to motorcycles and valve timing for automobile engines [24].

1.2 Cam chain drive

A timing chain or cam chain is part of an internal combustion engine used for synchronizing the rotation of the crankshaft and the camshaft so that the engine's inlet and outlet valves open and close at the proper timing during each intake and exhaust strokes of cylinder arrangement [25].

1.3 Functions of timing chain

1.3.1 Transmission

A timing chain works as the link between the crankshaft and the camshaft of automobile engine [25].

1.3.2 Speed

The timing chain in an automobile engine works for transferring energy from the crankshaft to the camshaft. The size of the gears used is adjusted accordingly for reduction of rotational speed [25].

1.3.3 Timing

The timing chain works for controlling when the intake and exhaust valves has to open or close in relation to the position of the crankshaft [25].

1.3.4 Tension

Chains wear and slacking in the chain increases and this in turn disturbs the valve timing of the engine. These slacked chains need to be replaced or adjust tension accordingly [25].

1.4 Working principle

For each cylinder in an automobile engine cam shaft first opens the inlet valve to let the fuel in and air to be burned. Next cam shaft opens the exhaust valve to remove the burned gases which pass out from the engine from exhaust pipe. The above discussed coordination of crankshaft with the camshaft for proper opening and closing of inlet and outlet valves for each engine is termed as valve timing [23].

For example in a four-stroke automobile engine, the intake and exhaust valves are supposed to open and close for every other revolution of the crankshaft, so the camshaft of engine is made to turns only at half engine speed. That is why camshaft have big gears attached to it and crankshafts have smaller gears. The drive ratio for this system two to one, so at 4000 rpm the cam is turning at 2000 rpm.

1.5 Fundamentals of noise

Sound is vibratory disturbance that is produced by a moving or vibrating source. As the source moves or vibrate, surrounding atoms or molecules are temporarily displaced from their normal configuration thus forming a disturbance that moves away from the sound source [19].

1.5.1 Frequency spectrum

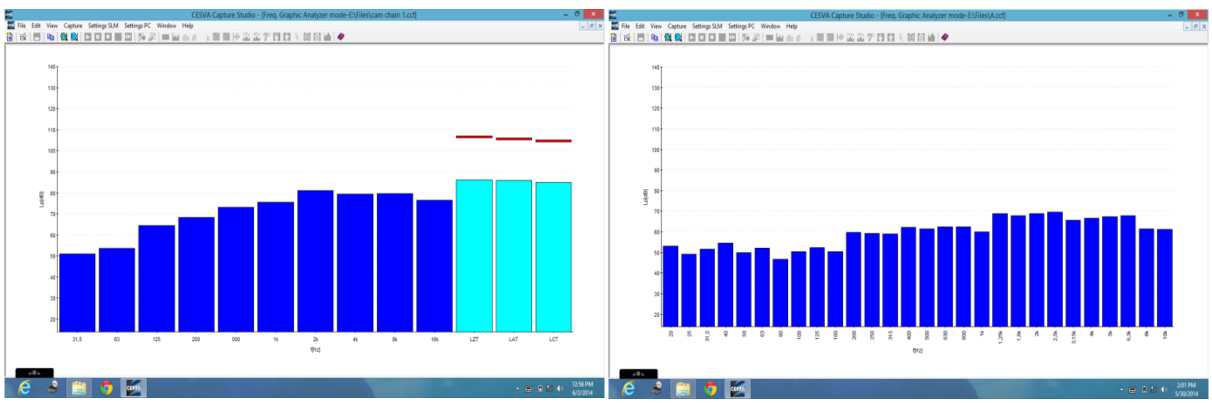
Usually sound have components at several frequencies and the characteristics of a steady sound are determined by pressure amplitudes at different frequency components. Describing sound by frequency against amplitude, that is termed as frequency spectrum of sound [19].

1.5.2 Frequency analyzers

The frequency range of 20Hz to 20kHz can be split into sections or bands. These bands have a band width of 1/1 octave or1/3 octave. An octave band is a frequency band where the highest frequency is twice the lowest frequency. For example 1/1 octave filter with a centre frequency of 1kHz has a low frequency of 707 Hz and upper frequency of 1.414 kHz. Any frequency below and above these limits are rejected. A 1/3 octave band has a width of 1/3 of that of an octave band [19].

For 1/1 octave band $f_{upper} = 2f_{lower}$

For 1/3 octave band $f_{upper} = 2^{1/3}f_{lower}$



(i) (ii)

Fig 1.1(i) 1/1 octave band analysis (ii) 1/3 octave band analysis

1.5.3 A-weighted sound level

To describe sound levels in a manner which closely approximates normal human hearing the actual sound level measurement is modified by applying A-weighting. Different weight is assigned to each frequency which is related to the sensitivity of the ear at that frequency. This dB(A) is internationally accepted to measure the environmental noise. Other type of weighing curves are B and C[19].

1.5.4 Background noise

Background noises are those noises that are due to some other conditions or parameters that are not being considered while measuring noise. It is important that for carrying out the noise results there should be low background noise. The background noise must be subtracted from total noise to obtain the sound produced by machine alone [19]

- If difference between two readings is less than 10dB than the measurement should be stopped till the difference is more than 10dB.
- If the difference is greater than 10 dB then background noise could be separated using logarithmic subtraction or correction factor could be applied as discussed in chapter 3

1.6 Noise and vibration in timing chain

Noise perceived from cam chain of motorcycle engine is considered to be due to meshing phenomenon of chain and sprockets and due to chordal action of the chain movement [22].

Following are the factors that are responsible for noise and vibration in chain

- When chain roller strikes the sprocket tooth bottom
- Meshing noise between chain and sprocket
- Chordal action
- Roller makes noise due to its elastic vibration as there is space between roller and the bushing
- Sprocket may vibrate
- Shock sounds produced due to fluid present between various parts
- Misalignment or bent shaft
- Worn sprocket or chain

1.7 Chordal action

Vibration induced in chain due to fluctuation in position at which chain and sprocket engage is termed as chordal action. Reason behind the chordal action is the pitch length in chain, and chain can bend only at pitch points [22].

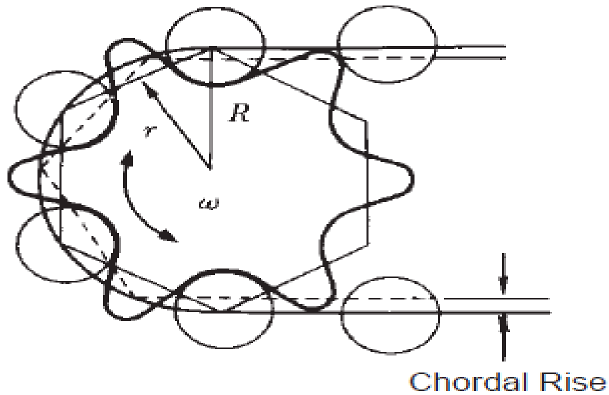


Fig 1.2 Variation of radius (when chain engages tangent position and when it engages in chord.)

(courtesy A complete guide to chain handbook[22])

Therefore even when the sprocket rotates at constant speed, speed of chain is not steady and chordal action is based on number of teeth in the sprockets.

- Negligible stretch that is much more in case of belt transmission system.
- Chain drive requires comparatively less physical space than a belt driven system

CHAPTER 2

Literature review

2.1 Review of literature

This chapter covers the detailed review of literature on the various aspects of CAM CHAIN noise and vibration measurement and evaluation. The literature review includes the research carried out on noise from cam chain, effect of various parameters in chain noise, methods for measuring noise and remedies for eliminating the cam chain noise.

A noisy cam was analyzed to identify the noise source by approach of noise source localization by using sound quality. Noise measurements were made on cam chain sets on a motorcycle to characterize noise in terms of amplitude and frequency. Further the measured objective data was correlated with the subjective perception using sound quality tools and testing by jury to identify the major frequencies attributable to perceived chain noise. From subjective analysis and objective data it was concluded that 5800 Hz that corresponded to second natural frequency of larger sprocket was attributed as major source of perceived chain noise. Also observation was made that noisy chain have higher centre distance and thus all the noisy cam chain have slack or elongation owing to its use. Slack in chain and its links riding over the sprocket was basic cause of impulsive excitation on the sprockets. That is why chain / sprockets are rejected after running for few thousand kilometers [1].

A measuring device was designed in a camshaft drive chain sprocket for detecting torque fluctuation with minimum change in the dynamical characteristics of valve drive system. In order to realize these functions, the disc portion in a chain sprocket that connects the teeth of sprocket and camshaft was carved so as to make thin plate area such that the strain gauges placed on that carved area have enough sensitivity to torque fluctuations[2].

The torque measuring device's performance was evaluated by studying a model cylinder head unit of an in-line four cylinder engine driven by a variable speed electric motor. The measured waveforms from the system were compared with ones calculated by multi-body dynamics simulation software[2].

A chain guide mounting assembly was invented that will be helpful in reduction chain related noises in a chain driven timing system of an automobile engine having overhead cam. The assembly includes means of vibration isolation for mounting of chain guide to the engine[3].

Allen invented that a roller chain timing drives noise can be reduced by thinning the teeth and hence elongating the root land that is in between each pair of teeth on the sprocket. Through detailed calculations, the root land was elongated resulting in a reduced thickness of the teeth as measured across itself from a drive face to a coast face. The result of the alteration was the maintained contact of all the rollers wrapped around sprocket throughout the entire design life of the chain and sprockets which reduces noise [4].

A roller chain and sprocket drive system was invented that reduces noise levels normally associated with chain drives by reducing the chain-sprocket engagement impact energy as the sprocket collects the rollers from the span. This invention achieved this object by providing a sprocket having an asymmetrical tooth profile, each sprocket tooth comprising an engaging flank (which is also the drive flank for a driving sprocket), a disengaging flank (or coast flank for the same driving sprocket) opposite to the engaging flank of an adjacent tooth and an inclined root surface tangent to root radii that are disposed between the engaging and disengaging flanks of adjacent sprocket teeth [5].

An adaptive and active control strategy was presented for reduction of noise and vibration in cam chain drives of automobile engine and also examined the effect of active control on reduction of noise. Experiments performed shows that the average vibration amplitude of chain is reduced as much by 90% from low to moderate conditions of tension in timing chain and hence the noise level was reduced by 3 decibels. The experimental set up for the purpose was a low cost equipment and was readily applicable to industrial environment [6].

A system was developed to measure the load to which a timing chain is subjected. The system prepared consists of a special sprocket transducer and telemetry equipment. The conventional sprocket that is attached to cam shaft of automobile engine was replaced by specia; transducer sprocket which can sense the torque available at the shaft and transmit it by electronic means to recording equipment. System was helpful in investigating the parameters that affect the life of chain and hence results helps in improving chain design [7]

Liu studied that the impact resulting from meshing phenomenon between chain and sprocket is major source of noise in timing system of automobile engine. Further studies revealed that this impact noise results from velocity difference between the individual chain links if the timing chain and sprocket at engagement point. This velocity difference generates a local impact whose magnitude varies with the engagement frequency is dependent on parameters of system such as load, mass, tension etc. An experimental and analytical modeling method was developed and was used to examine impact noise characteristics of timing system of automobile engine. Purpose of the analysis was to evaluate comparatively between various system parameters and operating conditions. Analytical model developed was capable of finding chain sprocket engagement impact intensity. Hence the work concentrated on the complementary testing of timing system of automobile engine to understand the effect of system parameters on impact noise and meshing noise phenomenon from experiment point of view. Experimental work was performed on a specially designed test stand that was used to examine the sound produced by meshing impact [8].

A vibration isolation system was developed for timing chain guides of automobile engine. It was studied through testing that timing chain guides are significant path through which the chain / sprocket impacts are transmitted to other power trains. It was found that isolation of chain guides produced a significant reduction in radiated sound levels hence reduced mesh frequency and amplitude and hence improved quality [9].

Wang stated that the torsion oscillations of cam shaft of automobile engine induced due to valve train loads cause significant tension fluctuation in timing chain and also magnifies the chain vibrations that in turn increases undesirable impact noise from meshing of chain and sprocket and also the knocking noise from interaction between chain guide and vibrating chain. Thus a generic mode of engine timing system was developed that couples the sprocket motion with vibration of chain spans. Hence effect of cam shaft torsional loads upon the total system was investigated based on model developed. It was observed that cam shaft oscillations caused longitudinal vibration in chain and induce tension changes. The periodic tension variation of chain destabilized the system and caused large transverse vibration. Parametric resonances were identified and instability zones were derived through analysis using multiple scale method. It was concluded that sub harmonic type and summation type parameter resonance existed. Also contribution of system parameters to chain response and stability were quantified [10].

The proposal of replacement of metallic timing chain cover with plastic timing chain cover was presented. In order to improve fuel efficiency in automobile industry, light weighting is main objective. But designing parts of light weight i.e. by replacing metal with plastic, these redesigns give noise, vibration and harshness issue due to difference in part mass and material stiffness. Due to these issues many parts were not converted to plastic [11].

Engine parts like cylinder head cover, air intake manifold etc made of metal were replaced by plastic but timing chain has not been replaced. Key aspects of plastic timing chain cover as well as advantages of using plastic timing chain cover were discussed [11].

Young presented a design and development of a new sprocket tooth form for roller chain for engine camshaft drives as an effort to reduce the noise levels from chain-sprocket meshing. The crankshaft sprocket was also incorporated with inclined plane. Nitrile damper rings for further damping and reduce meshing impact noise levels. As roller impact during meshing is a dominant source of noise in roller chain drives [12].

Sopouch reported that due to durability and lifetime requirements, the timing drive systems of modern automotive engines are equipped with chain drives now. But Chain driven systems are generally more critical in aspect of NVH as compared to belt-drives. Mainly the polygonal effect and the phenomena, like impact forces caused by the meshing between the chain-links of timing chain and impacts between the engagement/disengagement regions of guides and sprockets, leads to an increased excitation of the automobile engine's structure. Since the polygonal effect occurs due to the meshing frequency, the excited vibrations of engine are basically narrow banded and can be well recognized as an annoying whine-noise from engine. This work described the modeling of the entire timing chain drive system containing a bushing chain drive, camshafts and connected single valve trains. The investigations carried were mainly focused on the dynamics of the chain drive and the forces those were transferred to the engine's structure [13].

A simulation technology was developed that was helpful in predicting holding limit of chain tensioner used in the system and effect of tensioner on chain was clarified. Multibody dynamics was used to develop the simulation model. Link by link method was used for analysis and hybrid model of tensioner was created using multiple masses and oil. Different types of tensioners i.e. spring type and hydraulic tensioners were compared. Analysis clarified the effect of tensioner on chain load and chain behavior. Hence it was made possible to predict the optimum system design of chain [14].

Hayashi analyzed the cam chain noise which occurs in transfers using silent chain system, analysis considering the energy of the noise source was proved effective by experiment. Chain noise can be simulated by calculating a dimensionless coefficient of chain noise energy that consists of two contributing factors ,the energy of the collision when the chain meshes with the sprocket and fluctuation in the chain speed [15].

In this work, performance of different types of lubricants on engine timing life time were studied. Lubricants used were minerals, semi synthetic and synthetic. Chains were regularly measured during tests in order to find the trend in wear elongation. Chains were also applied to tear down inspections at end of test [16].

The method of reducing friction in the engine timing system was investigated when timing chain is used by multibody dynamics simulation. Also known as link by link model was employed for the simulation on order to represent the behavior of each individual link of the timing chain and its friction due to contact. For prediction of friction under actual operating conditions of engine, model was created that takes camshaft torque fluctuation and rotational speed fluctuation of crank shaft rotation into account [17].

This simulation was used to verify the distribution of friction in every part of timing chain system as well as change in friction in domain of time. It was found that sliding friction between the chain tensioner guide and chain guide was comparatively larger than in other location. Based on this method of reducing friction was established that took into account mechanism and structure and do not rely upon low friction materials [17].

Basic principles of the characteristics of sound and the mechanism of human hearing were described. Some simple experiments which demonstrated the relationship between intensity were explained. Author also pointed out the difficulties of analyzing accurately sound electronically, and the importance of combining the finest electronic equipment with sharp and attentive human faculties. Five basic ways to reduce noise and the mechanics of each were described. The effect of those 5 methods on the work of the sound engineer were indicated [18].

2.2 Summary

After studying literature it can be concluded that work has been done in the field of cam chain noise reduction, in one way or another. Some investigators have focused on modal analysis of the timing chain system to identify major frequencies. Various methods have been introduced in order to reduce or mitigate the noise perceived from cam chain. Some investigators worked on finding new methods to measure the actual noise and vibration generating from cam chain.

2.3 Gaps in literature

It can be concluded from literature review that though the work has been done on the cam chain noise, factors responsible for noise generation from chain need to be studied. Factors like increasing RPM, lubrication of the chain and chain wear are responsible for chain noise generation and needs to be studied.

Work done on cam chain noise was based on assumption that at 2000 RPM, noise from engine is from cam chain only. This aspect needs further investigation.

Also vibration of the cam chain needs to be studied for its causes.

CHAPTER 3

Experimentation

3.1 Objective

In an automobile engine noise and vibration have been the major threat to the engine performance and quality characteristics. Noise and vibration in an engine is produced from various rotating and reciprocating parts. Studies revealed that major part of the engine noise and vibration is due to timing system of automobile engine. Because metallic cam chains are used in motorcycle engines for operating timing system of engine, there is noise due to movement of this chain, meshing phenomenon of chain with the sprocket and vibration due to moving chain. This noise from cam chain causes severe threat to engine and user often complains the rattling noise from engine after few thousand kilometers. Hence this cam chain noise needs to be studied and evaluated for causes and mitigation.

There was no method to measure the noise of cam chain only from running engine and engine cannot be operated without cam chain. So a method was developed to measure the noise of cam chain only separating the noise of rest of engine.This work of cam chain noise evaluation is based on separating the noise of cam chain from noise of rest of the engine noises i.e. noise from reciprocating piston and rotating crankshaft etc.

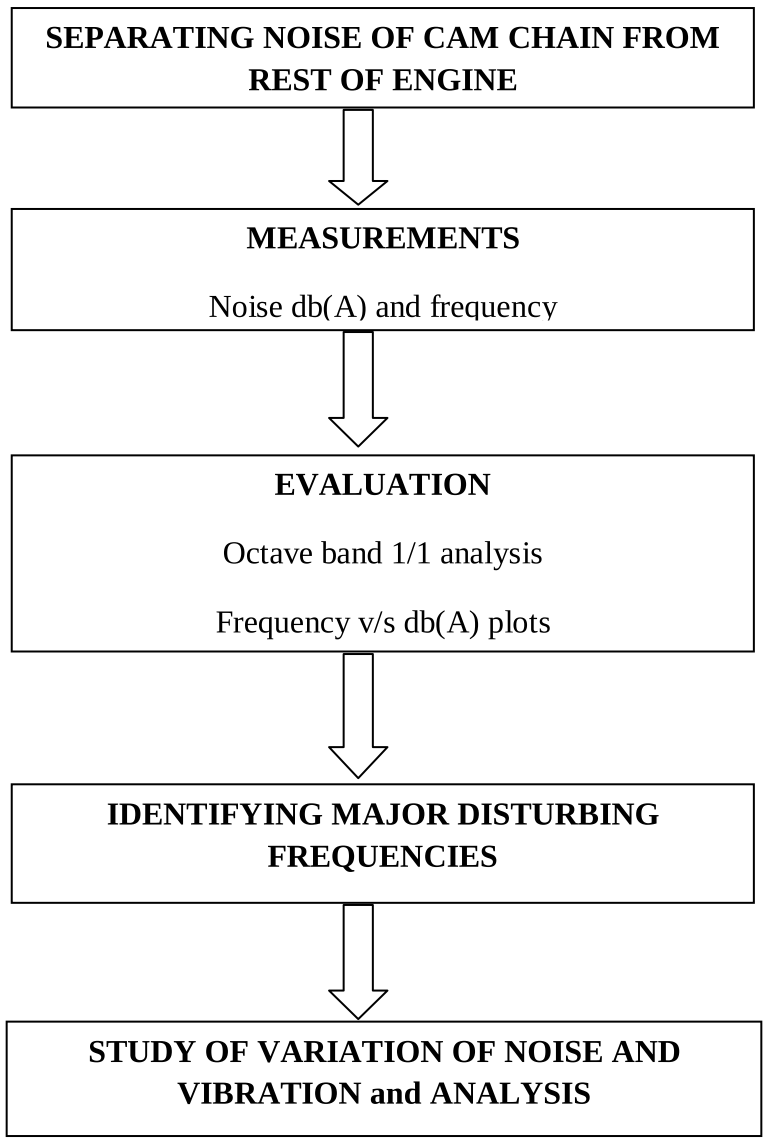
Further major disturbing frequencies are identified at different set of operating conditions of RPM, chain wear and lubrication.Also effect of various parameters on noise from Cam chain was studied and condition monitoring technique for engine timing system was performed for fault diagnosis.

3.2 Methodology

Present work is based on technique of separating noise of cam chain from noise of rest of engine by preparing a set up for rotating chain at required RPM using a motor and providing adequate tension to the chain.

Further noise dB(A) and frequencies will be measured from perceived chain noise. Evaluation of noise will be done using 1/1 octave band analysis and plots between frequency and decibels of noise and vibration will be obtained. Further major disturbing frequencies will be identified and vibration of noise and vibration with changing parameters will be studied.

- ❖ **Methodology of work is as depicted in block diagram**



Analysis of data was done using ANOVA and process parameters accounting for cam chain noise and vibration i.e. RPM, lubrication and chain wear were rated accordingly using ANOVA.

3.2.1 Separating noise of cam chain

Purpose of the experiment is to measure and evaluate the cam chain noise. As cam chain is integral part of any automobile engine and engine cannot run without cam chain, so there exists a problem of how to measure the noise of cam chain only, separating the noise of rest of engine.

Studies revealed that experiments have been done on measuring cam chain noise but all the experiments are based on neglecting the noise of rest of engine parts. This work is based on measuring noise of cam chain only.

For this purpose cam chain was rotated at the required speed using AC motor whose rpm was controlled using voltmeter. System was set using engine head that has cam shaft and sprocket attached to cam shaft, AC motor to give required rpm to the chain and assembly for providing adequate tension to the chain.

Measurement includes both noise of cam chain as well as motor and other background noise. Therefore background noise and noise from motor will be eliminated/ subtracted. There are two methods to eliminate or subtract the background noise and noise of motor from cam chain noise.

3.2.3 Set up

In order to measure the noise of cam chain only, it needs to be separated from noise of rest of engine parts and other background noises. For this purpose a system was set as shown in picture below that was used for measuring the noise of cam chain only and constitute following parts

- Engine cylinder head
- Cam chain
- AC motor
- Voltmeter for variable input voltage
- Welded angles and nut bolts for providing adequate tension
- Larger sprocket (cam shaft sprocket) Number of teeth 28

Fig 3.1 Cam shaft sprocket

- Smaller sprocket (crank shaft sprocket) Number of teeth 14

Fig 3.2 Crank shaft sprocket

Sprocket attached to crank shaft was fitted over shaft of motor and above that lies engine head having sprocket of cam shaft at adequate distance to provide required tension to the chain. Required rpm could be given with the help of motor by adjusting input voltage to the motor. Welded angles and nut bolts are used in such a way that cam chain tension could be adjusted as per requirement.

Fig 3.3 Set up for measuring cam chain noise

3.2.4 Subtracting back ground noise

Measurements from system include noise of both chain and motor, hence noise of motor needs to be subtracted from the total noise in order to obtain the noise of cam chain only.

There are two ways of separating noise from the background noise as discussed below

3.2.5 Subtracting correction factor

The table below shows the correction factors for differences between noise levels up to 15 dB apart.

Table 3.1 Correcting factor to be subtracted for given difference between two noises [21].

Difference between two noise levels (dB)	**Correction factor to be subtracted from higher of the levels (dB)**
0	At least 10
1	6.9
2	4.3
3	3.0
4	2.2
5	1.7
6	1.3
7	1.0
8	0.7
9	0.6
10	0.5
11	0.4
12	0.3
13	0.2
14	0.2
15	0.1

3.2.6 Logarithmic subtraction

Logarithmic subtraction can also be used to subtract the background noise from the noise of system to be measured. If difference between noise to be measured and background noise is more than 10 decibels, background noise can be subtracted using following logarithmic formula [19].

$$L = 10\log(10^{0.1L_c} - 10^{10L_b})$$

L_c = combined sound pressure level of the noise source and the background noise

L_b =sound pressure level of the background noise

For example background noise is 60 dB(A) and noise of system including background noise is 80 dB(A). Here the difference between two is more than 10 decibels and hence background noise can be separated from total noise using logarithmic subtraction.

3.3 Measurement of cam chain noise

After set up is prepared for cam chain noise separation, next step is to measure the noise of cam chain. Following are equipments used for the measurement of cam chain noise

3.3.1 Sound level meter

Sound level meter is a device used to measure the intensity of noise, music or any other sound source. A typical sound level meter consists of a microphone that picks the sound signals and convert them into electrical signals that is followed by electronic operation on these signals in order to measure the desired characterstics of perceived sound.

Some of the basic applications of CESVA SC310 sound level meter are listed below

- Measuring sound insulations
- Environmental noise measurements
- Measurement of industrial Hygiene
- Noise measurements for air conditioning (HVAC)

- Measuring community noise
- Measuring sound power (machinery)
- Measuring vibrations

Sound level meter was held stationary at distance of about 300mm from the experimental set up in plane of cam shaft rotation. Simultaneously sound level meter was connected to PC having capture studio software and readings of the system were stored alongside in PC.

Sound level meter was used in 1/1 graphical mode for working.

Fig 3.4 Sound level meter CESVA 310 (courtesy CESVA acoustic products)

3.3.2 Stroboscope

A stroboscope is an instrument that is used to make a cyclically moving object to appear slow-moving or stationary. The principle of stroboscope is used for the study of rotating, reciprocating, oscillating or vibrating objects. Machine parts and vibrating strings are common examples studied by stroboscope.

- ❖ Firstly the object whose rpm or speed is to be measured should be visible for all 360° of rotation (e.g. the end of any shaft).
- ❖ Second, the object to be inspected should have some unique part on it, like any bolt, a keyway or any imperfection to use this as a reference point. If it does not have ant unique part on it, then the user is required to mark the rotating object with a piece of tape or paint in a single location, to use that as a reference point.

If the speed of rotation to be measured is within the range of the stroboscope, stroboscope should be started at the highest flash rate and adjusted the flash rate down. At some point we will stop the motion where only a single image of the object is in view. As we approach the correct speed, we may see three or more images at harmonics of the actual speed. The first SINGLE image that we see is the true speed.

(i)

(ii)

Fig 3.5 (i) and (ii) Stroboscope

3.3.3 Software capture studio

CAPTURE Studio is complete software application that allows to configure

- All the parameters of the acoustic instrument on one screen,
- Download readings from the instrument memory to PC, can also erase the instrument memory so as to empty the instrument and hence user will have the full capacity to save the new measurements/ readings,
- Capture studio provides user with a convenient, easy to use environment for the purpose of obtaining in digital format the data acquired by the instrument when measurements are taken.

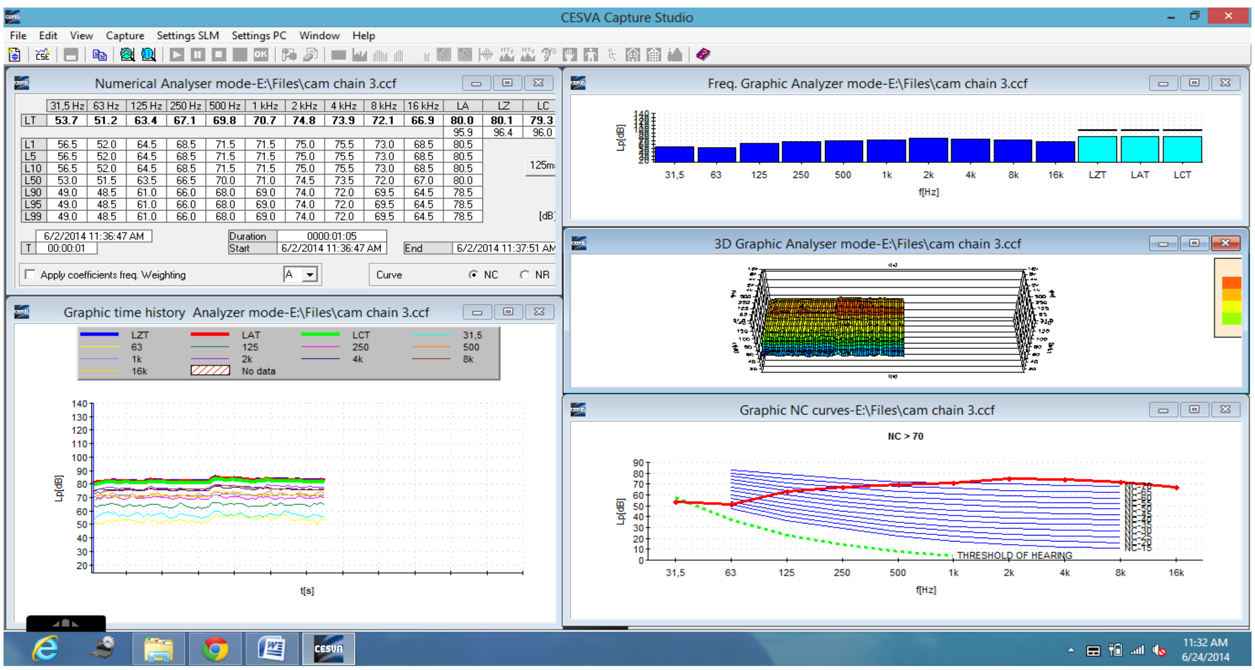


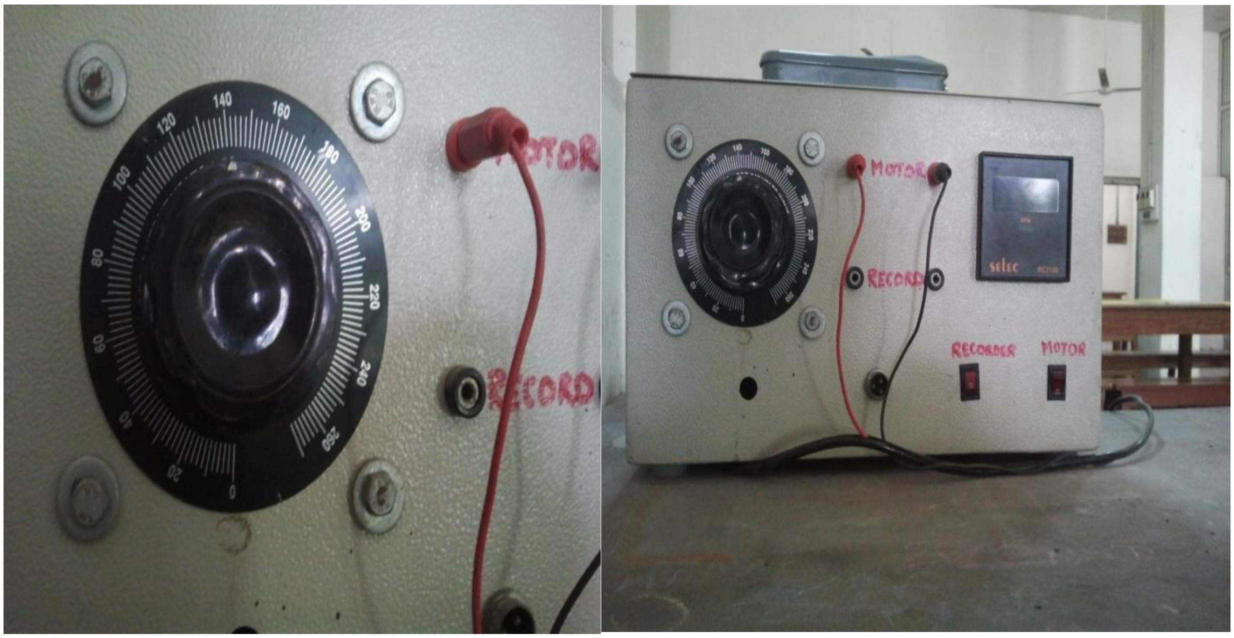
Fig 3.6 CAPTURE studio screen

3.3.4 AC motor

AC motor was used in the system for providing adequate RPM to the cam chain sprockets. Motor used for the experiment is able to give maximum of 8000 RPM and minimum of 600 RPM could rotate the cam chain system.

3.3.5 Voltmeter to adjust input voltage

AC motor used for the experiment was connected to a voltmeter to vary the input voltage for carrying out experiment at different RPM. Everytime after adjusting the voltage, RPM were measured using stroboscope.



(i) (ii)

Fig 3.7(i) and (ii) Voltmeter used for variable input

3.4 Instrumentation used for noise measurements

Measurements were made in large size room satisfying the condition of noise measurement i.e. background noise or environmental noise differs from system noise by atleast 10 decibels, thus making environment favourable for chain noise measurements.

Instrumentation set used is as described below

- ❖ System was placed at height of 3m from the ground in order to eliminate the reflections of noise from ground

- Mounting -system was fixed over the block as shown in picture below, using nut bolts. In order to avoid the vibration due to mounting, a thermocol sheet was used between the block and system and tighten by using nut bolts.
- A heavy hand vice was used for holding the system in which the system was tightened
- In order to further reduce the vibration and noise rubber pieces were used between the contacting area of system and vice as shown in picture.
- AC motor used in the system was connected to a voltmeter to vary the input voltage to the motor that inturn controls the rpm of motor of AC motor used.
- Laser stroboscope was used everytime to measure the rpm of the sprocket attached to motor.
- Sound level meter was held still at distance of 300 mm (approx) in plane of sprocket attached to cam shaft.
- Keeping the same system, for every set of condition cam chain was changed and rpm varied.
- Data recorded from sound level meter was collected in PC having capture studio software placed near the system and connected to sound level meter using USB cable.
- Test conditions established were maintained throughout the test for ensuring repeatibility and reliability of measured data under every set of conditions.
- Time history of decibels and frequency was recorded in PC using capture studio software

Fig 3.8 Instrumentation for the experiment

3.5 Design of experiment

Based on different conditions of chain wear, lubrication and RPM, number of experimental runs were performed. There were 20 conditions for the experiment varying 3 parameters

Process parameters for the experiment were-

- Chain wear (new chain and old chain)
- Lubrication (with and without lubrication)
- RPM (800 , 1000 , 1250 , 1350 , 1500)

Conditions for the experiment are tabulated below

Table 3.2 Conditions for different experimental runs

Sr. no.	**Chain**	**Lubrication**	**RPM**
1	**Old**	**No**	**800**
2	**Old**	**No**	**1000**
3	**Old**	**No**	**1250**
4	**Old**	**No**	**1350**
5	**Old**	**No**	**1500**
6	**Old**	**Yes**	**800**
7	**Old**	**Yes**	**1000**
8	**Old**	**Yes**	**1250**
9	**Old**	**Yes**	**1350**
10	**Old**	**Yes**	**1500**
11	**New**	**No**	**800**
12	**New**	**No**	**1000**
13	**New**	**No**	**1250**
14	**New**	**No**	**1350**
15	**New**	**No**	**1500**
16	**New**	**Yes**	**800**

17	**New**	**Yes**	**1000**
18	**New**	**Yes**	**1250**
19	**New**	**Yes**	**1350**
20	**New**	**Yes**	**1500**

There were 20 experimental runs conducted and dB(A) v/s frequency graphs were obtained for 20 different set of conditions on of which is shown below

The graph obtained contains the following variables

- On X axis – frequency in hertz
- On Y axis-decibel values of noise measurement i.e. dB(A)

Hence the major disturbing frequencies could be depicted from the graph and results will be compared between different set of conditions.

For example in this graph major disturbing frequency is 2000, 4000 and 8000 Hz as it has the highest decibel value among all other frequencies.

Graph shows the peak values corresponding to dominant/ major frequencies and hence results could be compared for dB(A) peak values for different set of conditions.

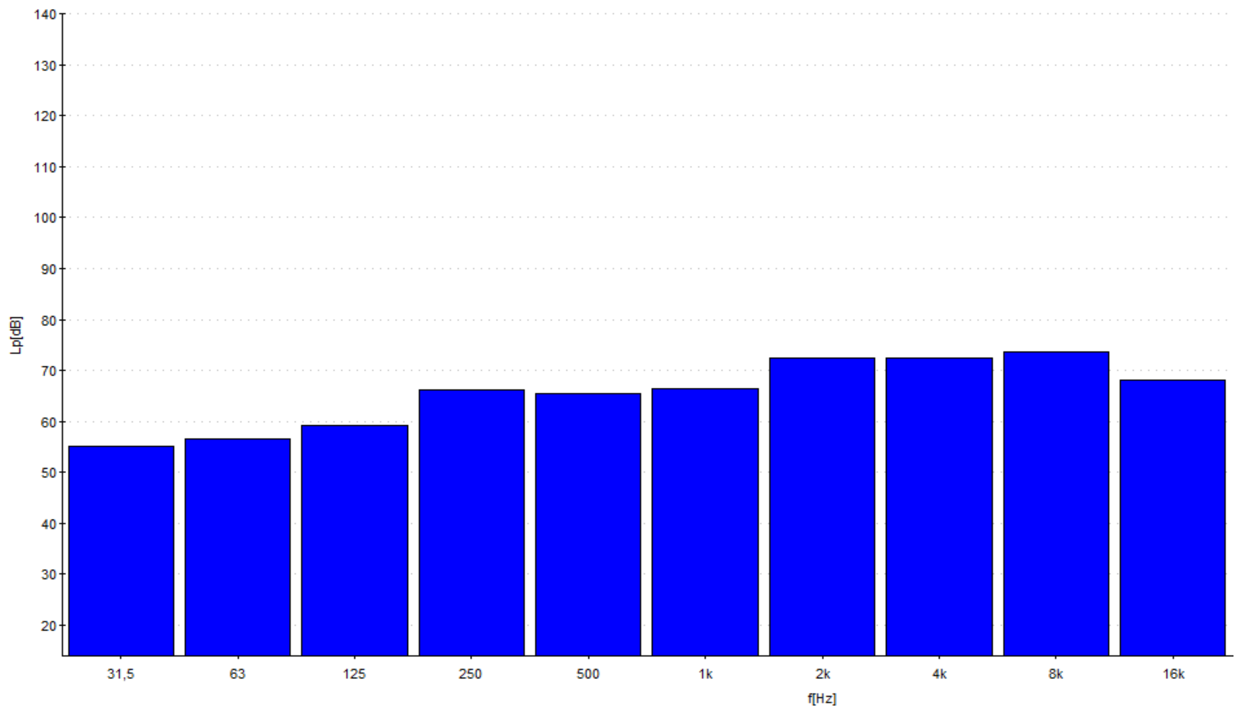


Fig 3.9 Graph obtained from capture studio

3.6 Analysis of result

ANOVA is a statistical technique used to achieve important conclusions based on study of the experimental data. This method is very useful for the purpose of close-fitting the level of significance of impact of process parameters and interaction of process parameters on a particular response parameter.

Depending on F value, P-value (probability of significance) is then calculated. If P-value for a factor seems to be less than 0.05 (for 95% confidence level), then it can be concluded that the effect of the factors or interaction of factors is significant on the selected response parameter. Significance of all the dependent variables has been completed using software MINITAB 15. These dependent variable studied in this study is noise.

For this experimental work the following response characteristics have been studied:-

- Response Name : Noise
  Response Type : Lower the better
  Units : dB(A)
- Response Name: : Vibration
  Response Type : Lower the better
  Units : Lt(dB) ms^{-2}

CHAPTER 4

Results and analysis for noise measurement

CESVA SC310 sound level meter was used to carry out measurements in 1/1 octave band and graphic analyzer mode, measurements were made at different 20 set of conditions as tabulated in previous chapter.

Plot between dB(A) values and frequency were obtained and hence the results were compared between different set of conditions

4.1 Frequency Spectrum for different conditions as per table 3.2

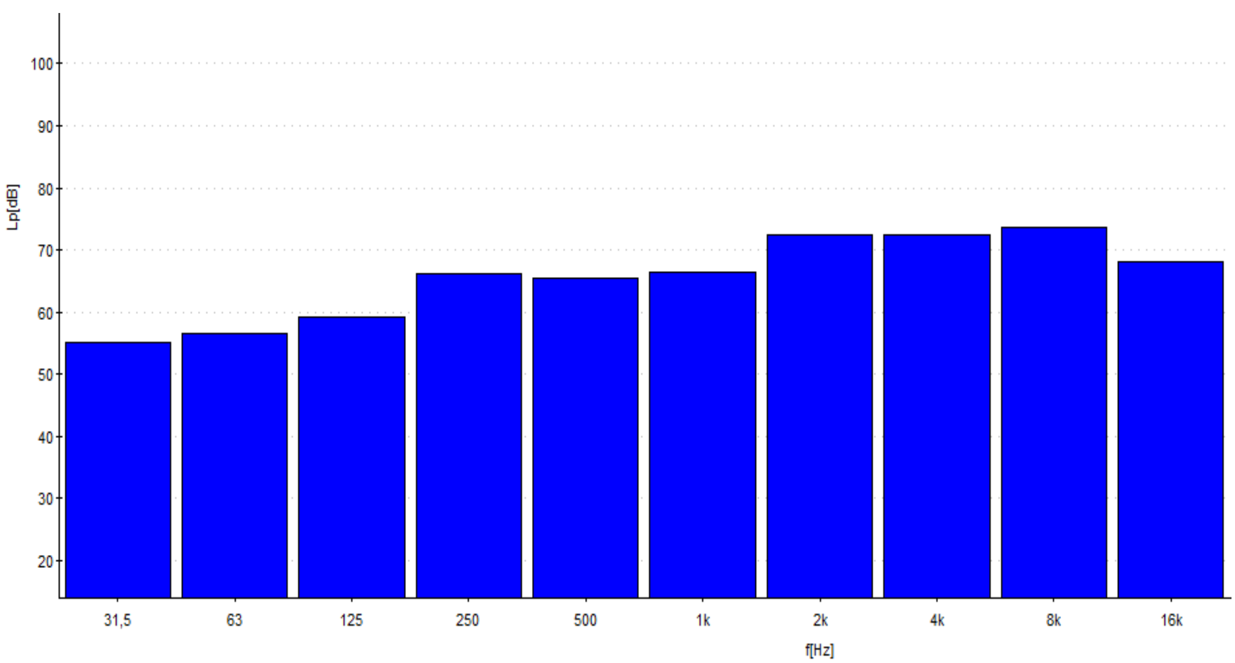


Fig 4.1 Frequency spectrum for Condition 1

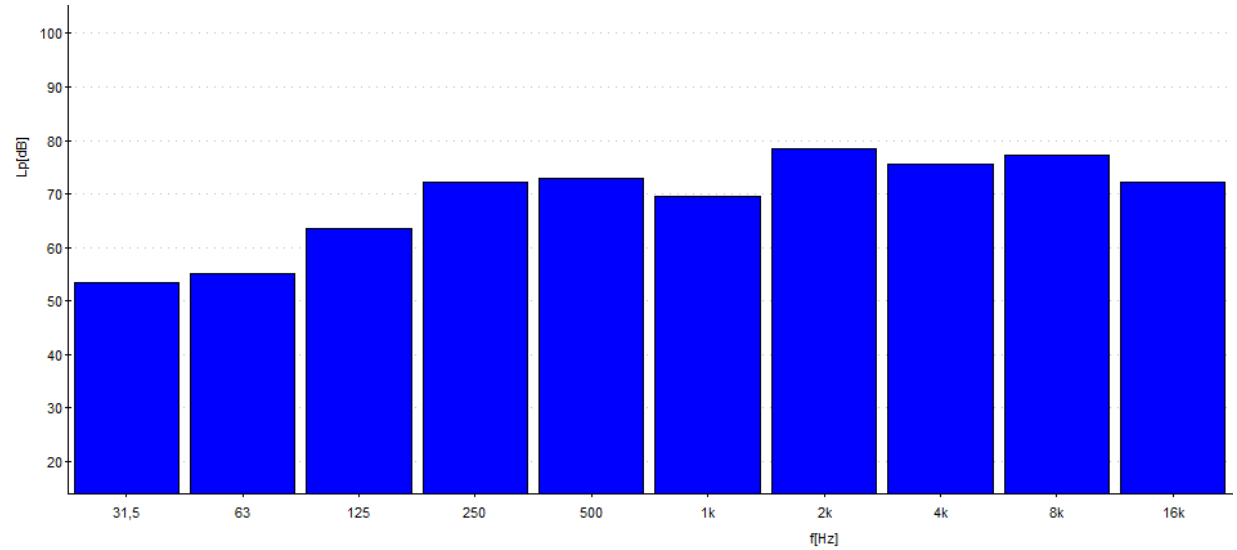


Fig 4.2 Frequency spectrum for Condition 2

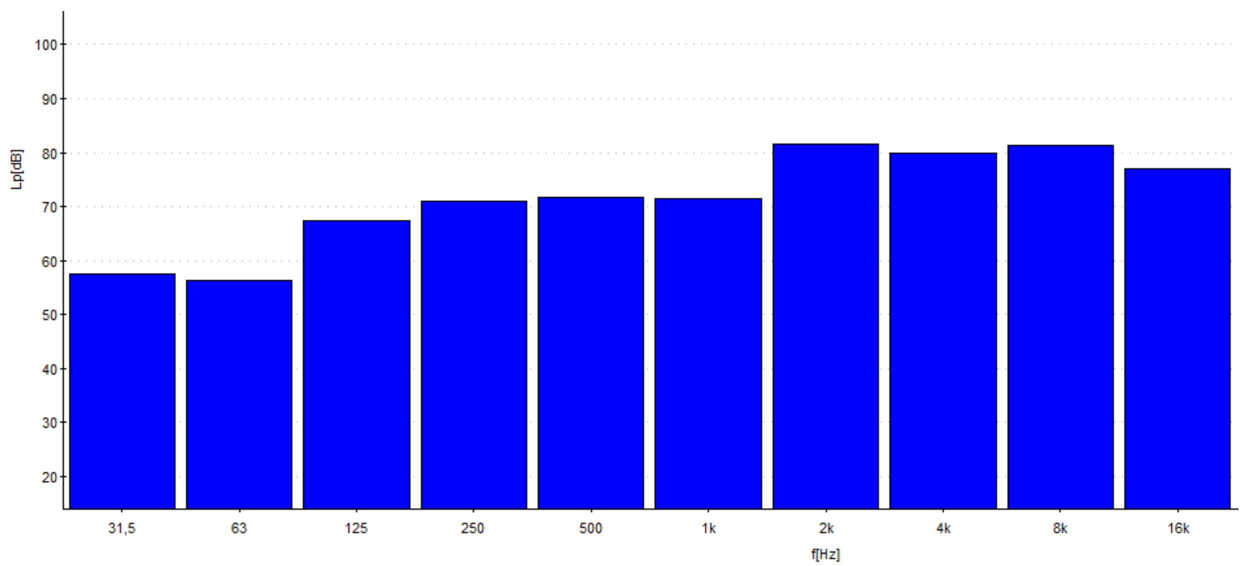


Fig 4.3 Frequency spectrum for Condition 3

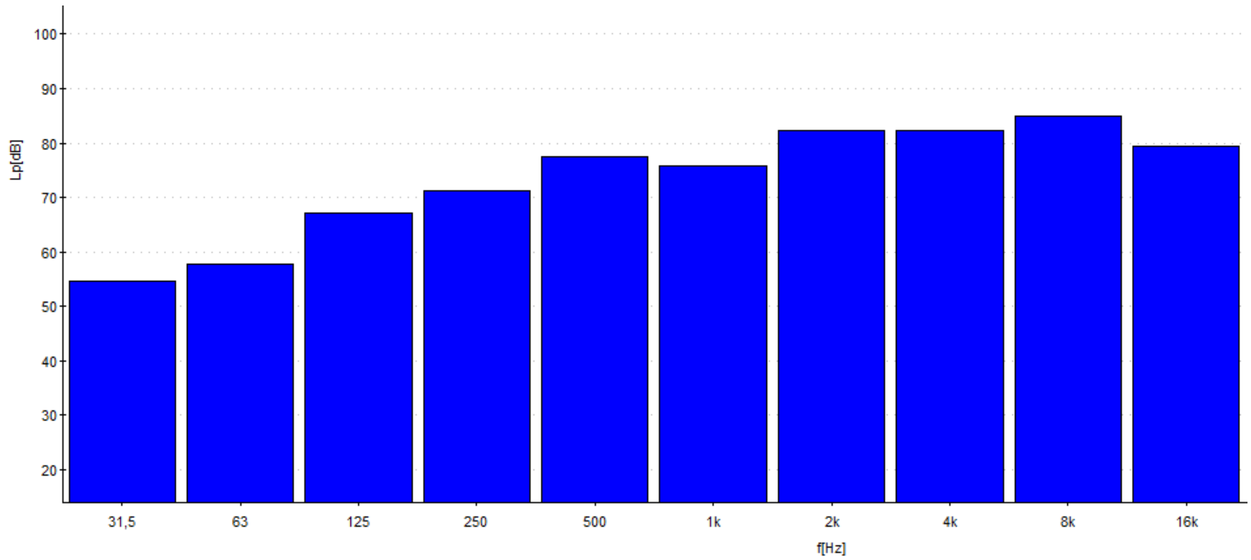


Fig 4.4 Frequency spectrum for Condition 4

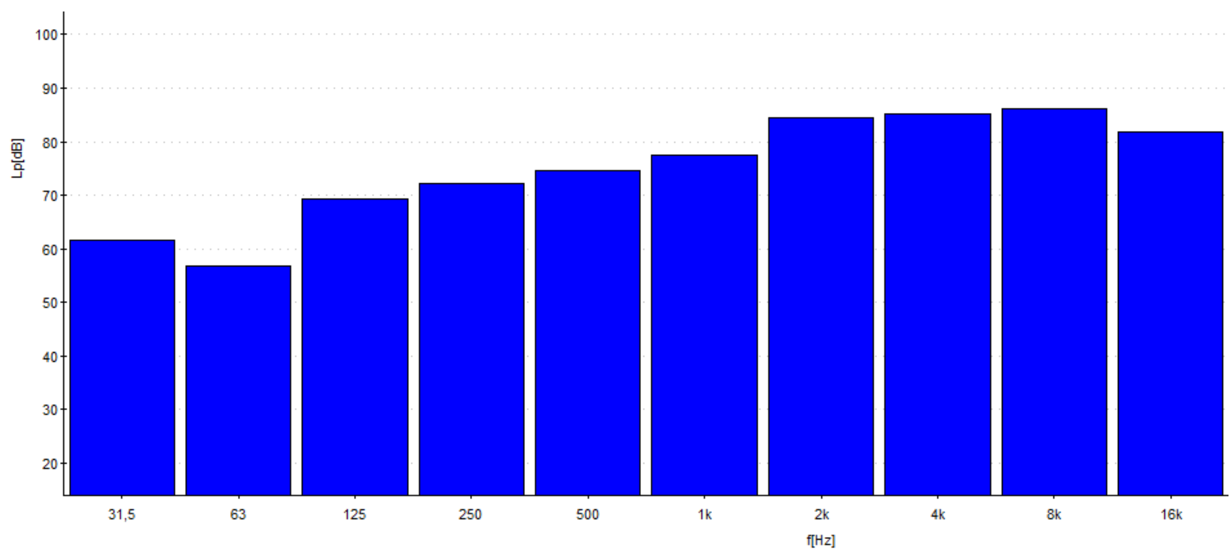


Fig 4.5 Frequency spectrum for Condition 5

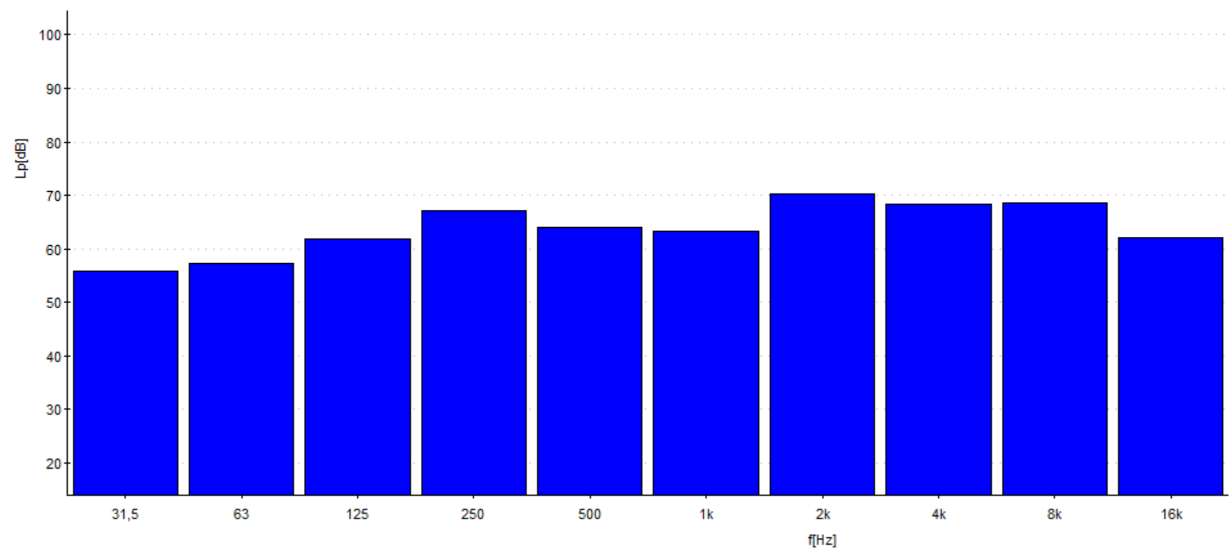


Fig 4.6 Frequency spectrum for Condition 6

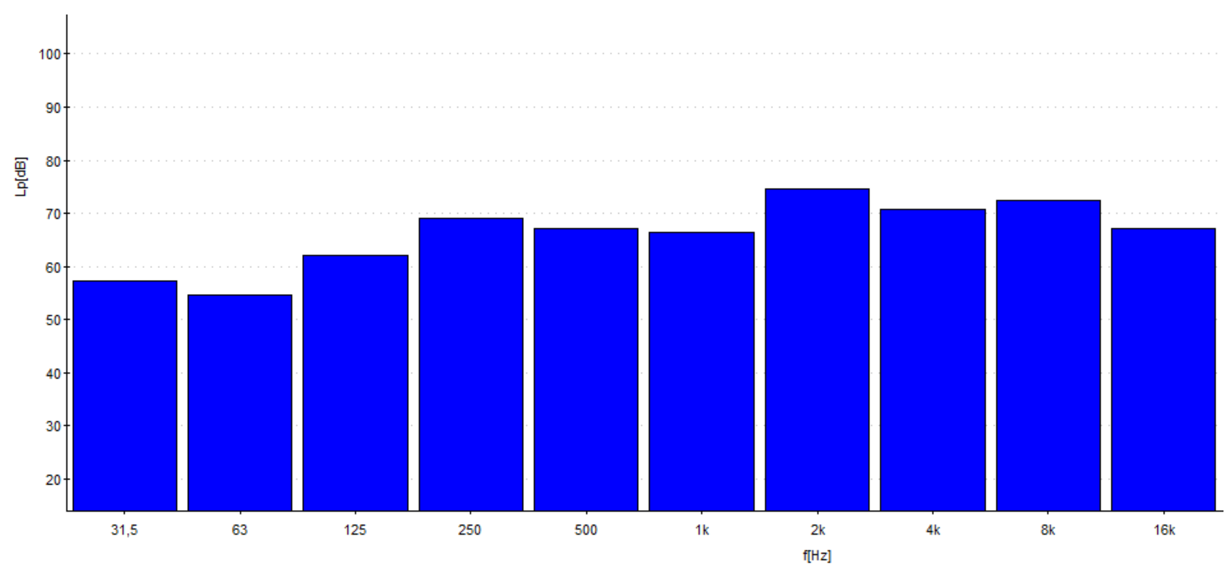


Fig 4.7 Frequency spectrum for Condition 7

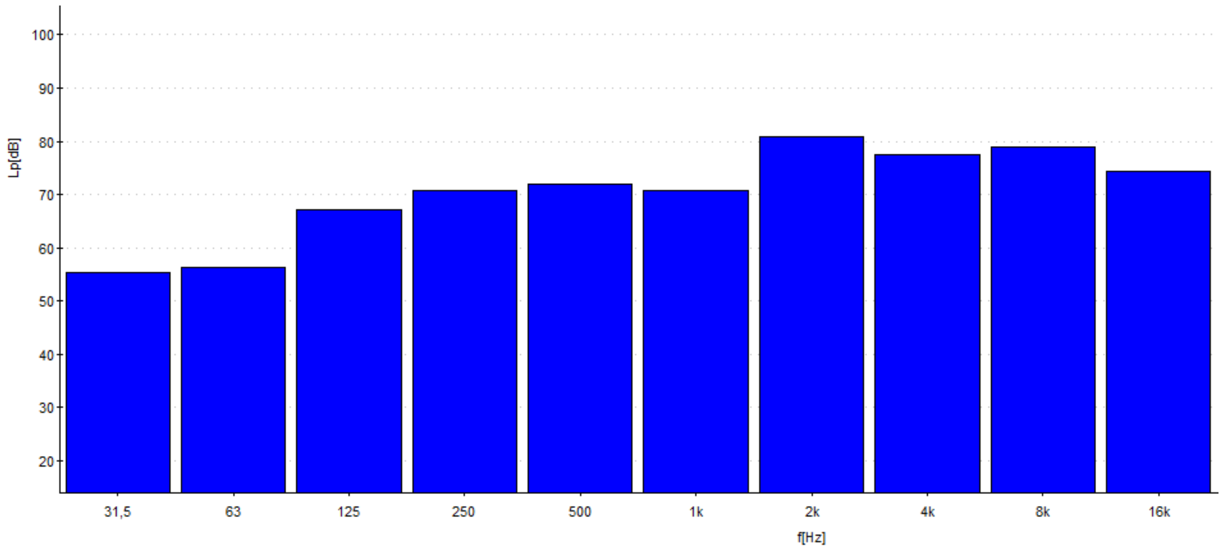


Fig 4.8 Frequency spectrum for Condition 8

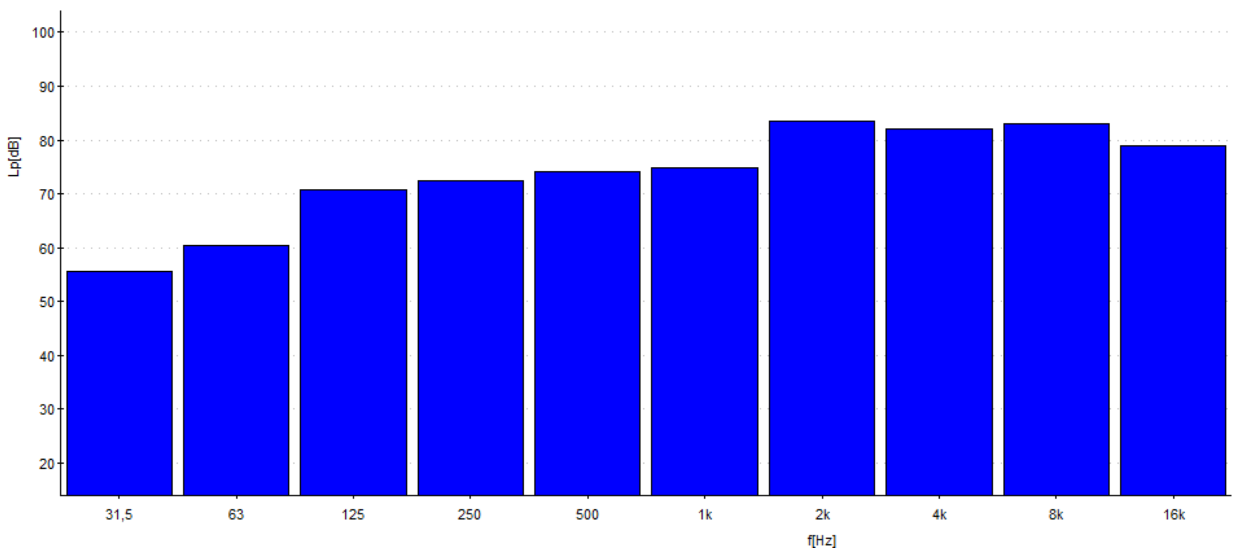


Fig 4.9 Frequency spectrum for Condition 9

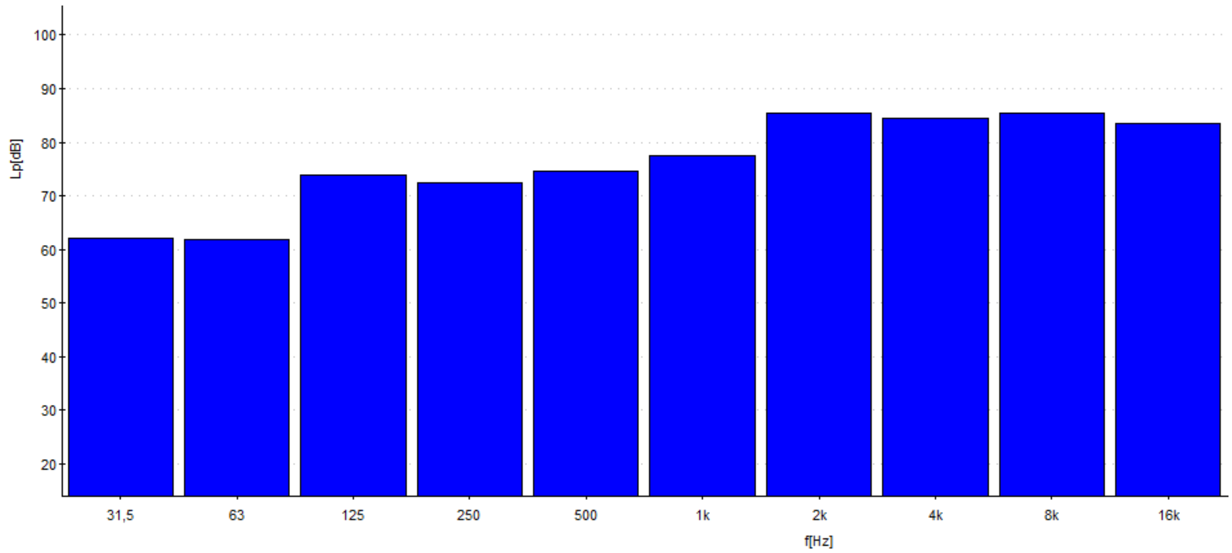


Fig 4.10 Frequency spectrum for Condition 10

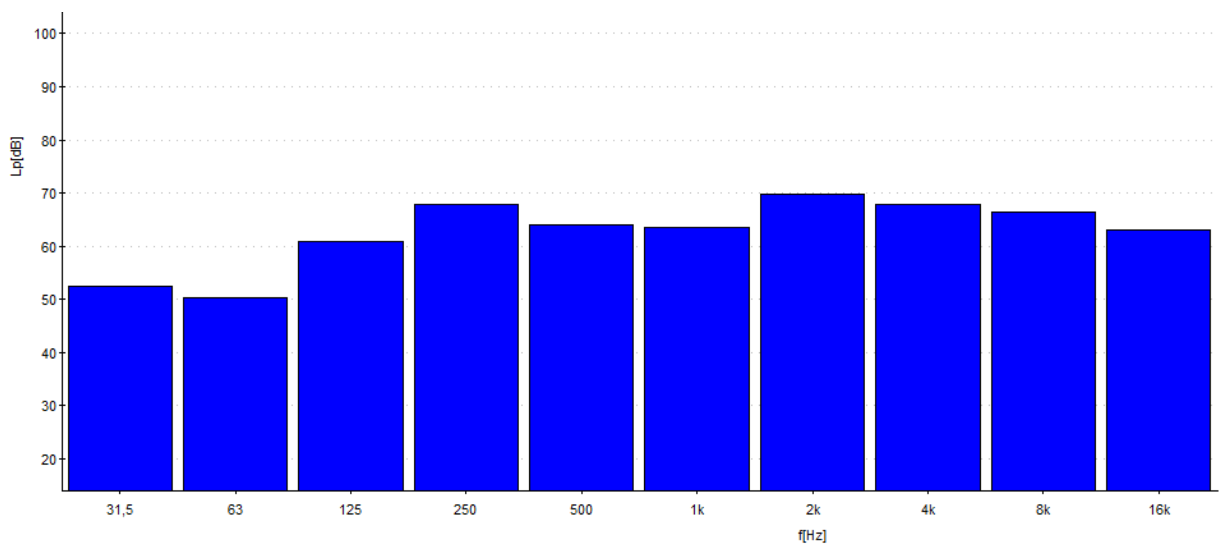


Fig 4.11 Frequency spectrum for Condition 11

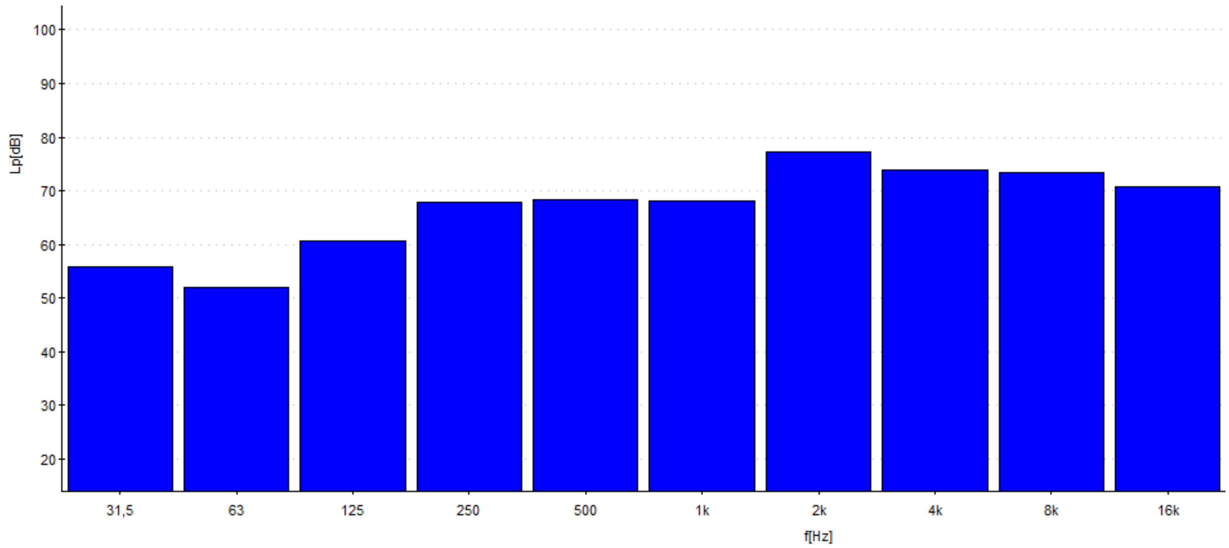


Fig 4.12 Frequency spectrum for Condition 12

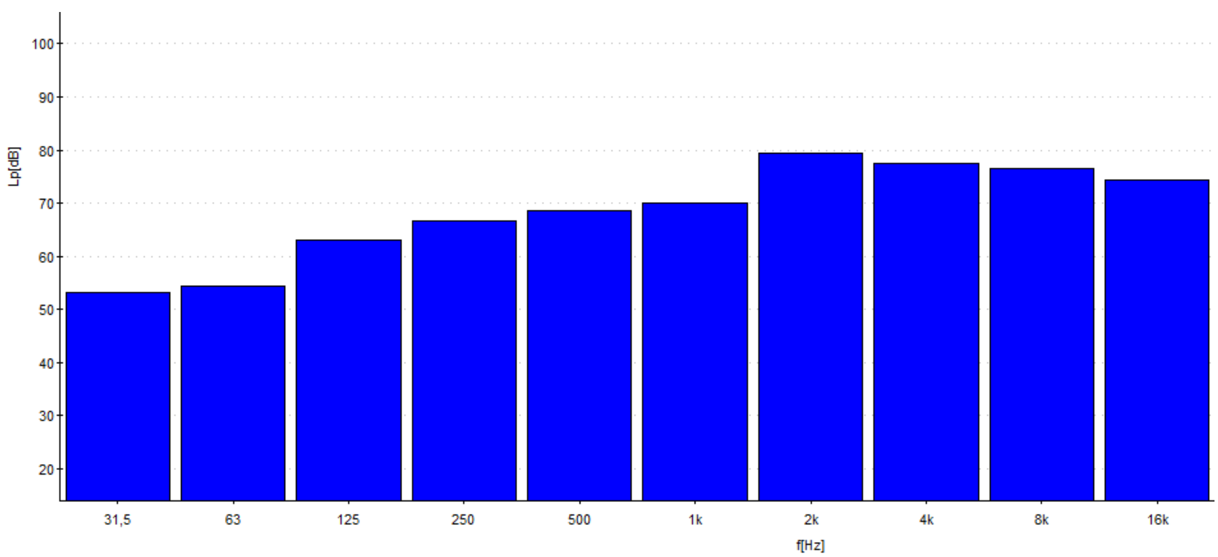


Fig 4.13 Frequency spectrum for Condition 13

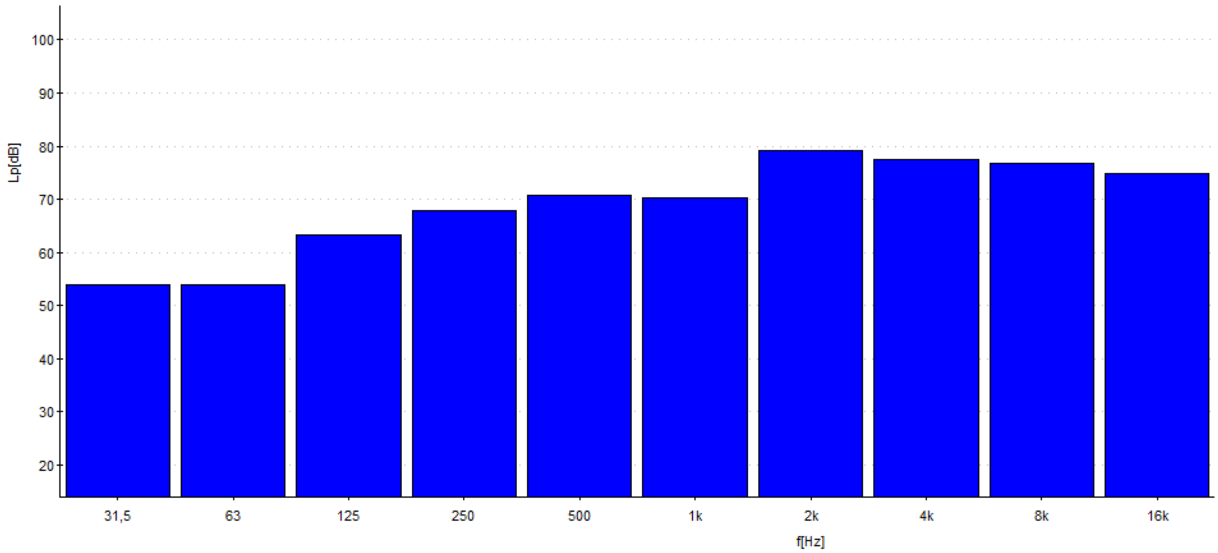


Fig 4.14 Frequency spectrum for Condition 14

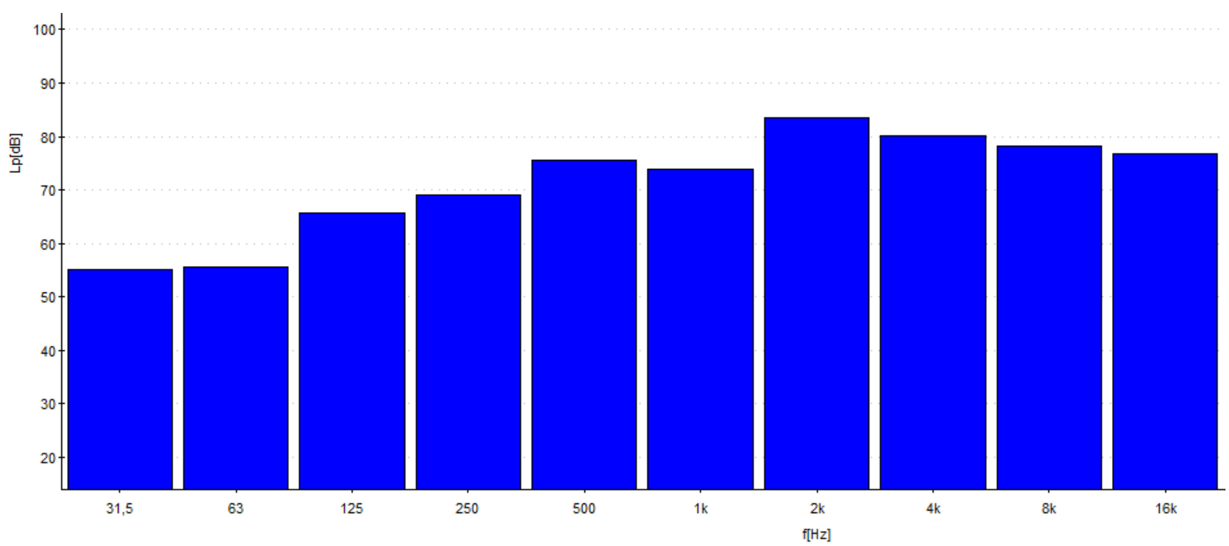


Fig 4.15 Frequency spectrum for Condition 15

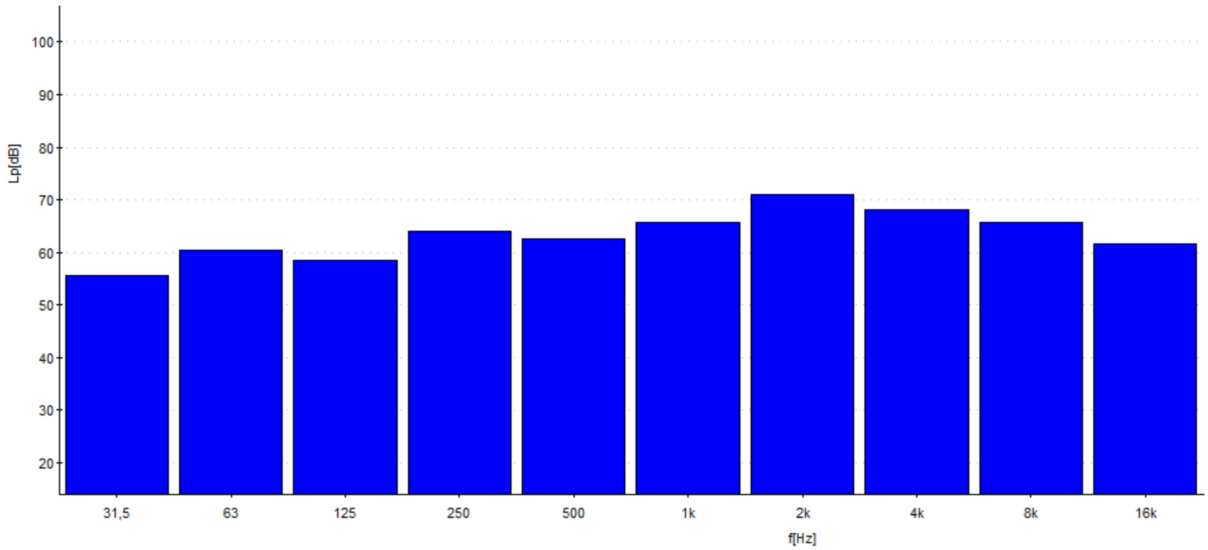


Fig 4.17 Frequency spectrum for Condition 17

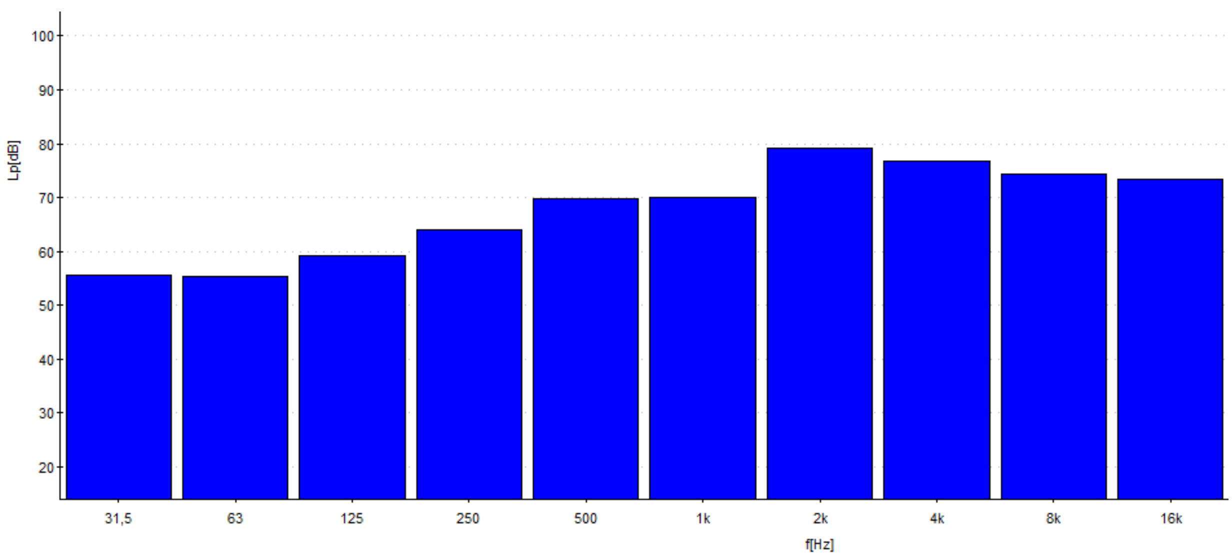


Fig 4.18 Frequency spectrum for Condition 18

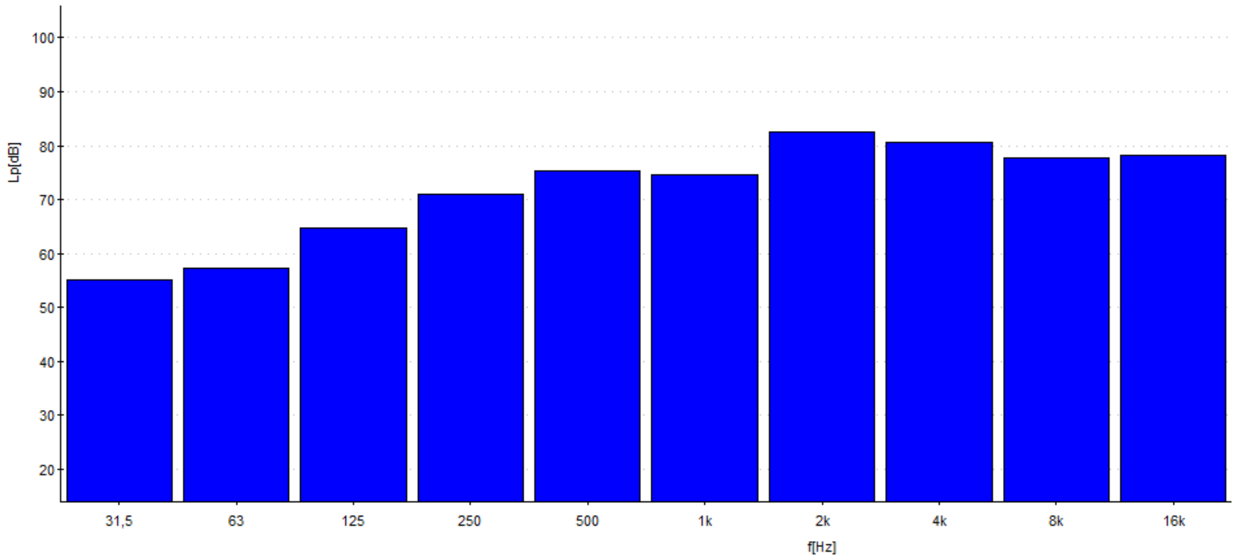


Fig 4.19 Frequency spectrum for Condition 19

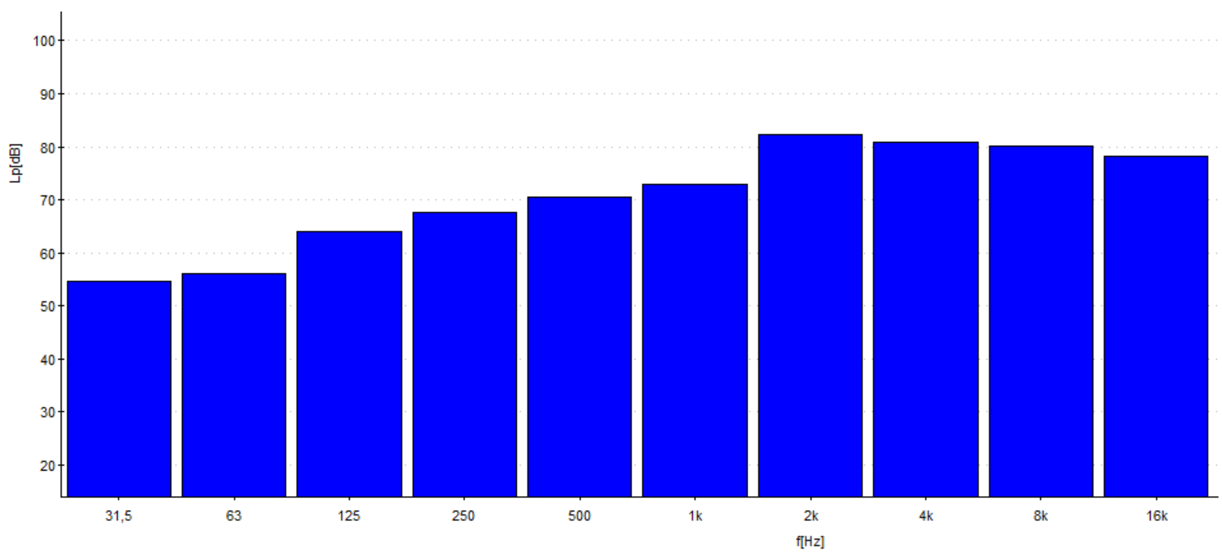


Fig 4.20 Frequency spectrum for Condition 20

4.2 Frequency spectrum interpretation

As the plots obtained contained dB(A) values on Y axis and frequency(Hz) on X axis, values of dominant frequency and their corresponding peak values were taken from the plots.

For different 20 experimental runs major disturbing frequencies and corresponding peak values are tabulated below

Table 4.1 Major disturbing frequencies and corresponding peak values for each experiment run

CONDITION	MAJOR DISTURBING FREQUENCY/ FREQUENCIES	PEAK VALUES dB(A)
1	**2000**	**71**
	4000	**71**
	8000	**72**
2	**2000**	**78**
	8000	**76**
3	**2000**	**81**
	4000	**80**
	8000	**81**
4	**2000**	**82**
	4000	**82**
	8000	**84**

5	**2000**	**85**
	4000	**85**
	8000	**86**
6	**2000**	**70**
	4000	**69**
	8000	**69**
7	**2000**	**75**
	8000	**74**
8	**2000**	**80**
	4000	**78**
	8000	**79**
9	**2000**	**82**
	4000	**81**
	8000	**81**
10	**2000**	**85**
	4000	**84**
	8000	**85**
11	**250**	**68**
	2000	**69**

12	**2000**	**76**
13	**2000**	**79**
	4000	**78**
	8000	**77**
14	**2000**	**79**
	4000	**78**
	8000	**77**
15	**2000**	**83**
	4000	**81**
17	**2000**	**70**
18	**2000**	**80**
	4000	**78**
19	**2000**	**81**
	4000	**80**
20	**2000**	**82**
	4000	**81**
	8000	**81**

4.3 Trend analysis for RPM

Compiling the observations from the plots obtained line graphs showing trends were plotted showing the variation of noise level values with increasing RPM at different conditions of chain wear and lubrication. These graphs showing trends are shown below.

4.3.1 Old chain without lubrication

Noise level in dB(A) shows a positive trend of increasing dB(A) with increasing the RPM

As rpm is increased for old chain without lubrication there is continuous increase in noise level values from 72dB(A) to 86dB(A)

Whereas major disturbing frequencies remaining constant i.e. 2000 Hz , 4000 Hz and 800Hz

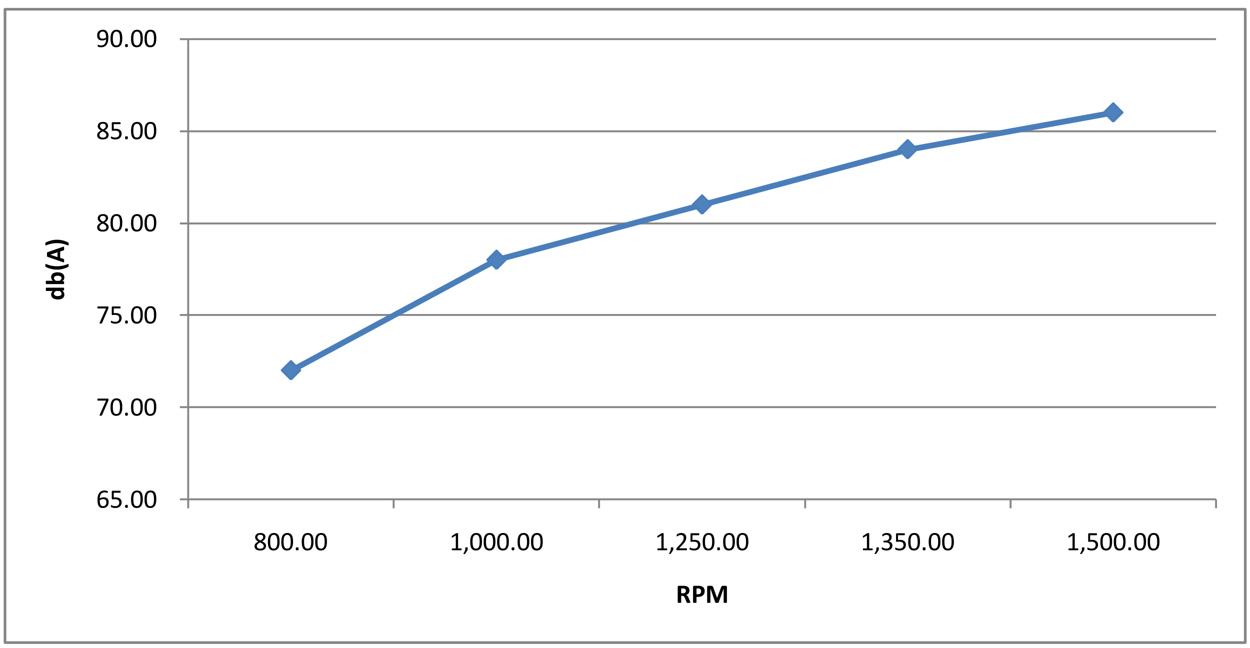


Fig 4.21 Trend in peak values with increasing RPM of old chain without lubrication

4.3.2 Old chain with lubrication

Noise level in dB(A) shows a positive trend of increasing dB(A) with increasing the RPM .

As rpm are increased for old chain without lubrication there is continuous increase in noise level values from 70 dB(A) to 85 dB(A)

Whereas major disturbing frequencies remaining constant i.e. 2000 Hz , 4000 Hz and 8000Hz being same as in old chain without lubrication

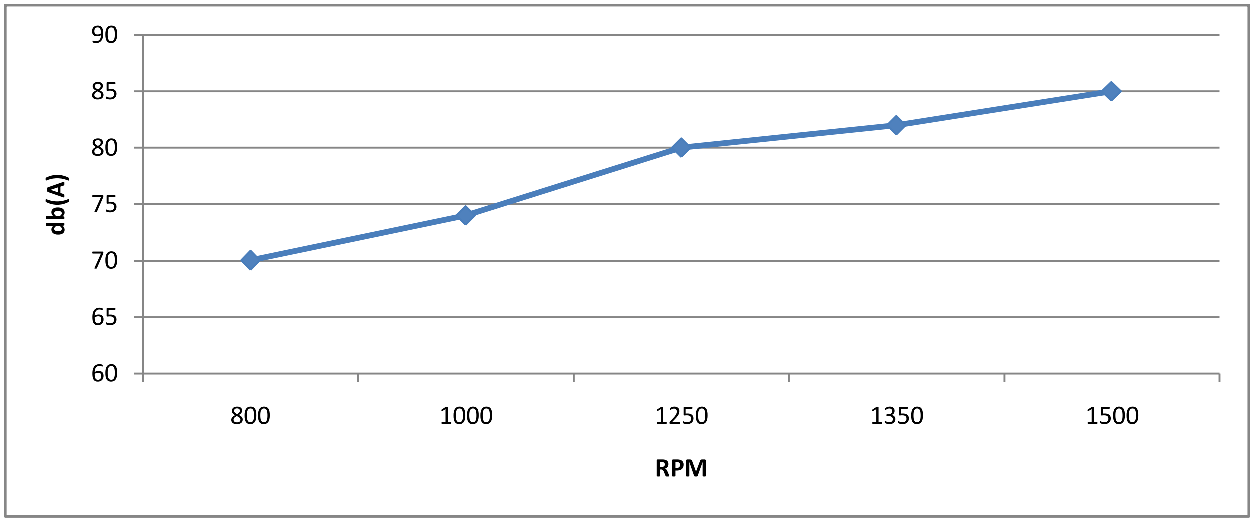


Fig 4.22 Trend in peak values with increasing RPM of old chain with lubrication

4.3.3 New chain without lubrication

Noise level in dB(A) shows a positive trend of increasing dB(A) with increasing the RPM

As rpm are increased for old chain without lubrication there is continuous increase in noise level values from 69 dB(A) to 83 dB(A)

Whereas major disturbing frequencies remaining constant i.e. 2000 Hz , 4000 Hz and 8000Hz being same as in old chain without lubrication , including 250 Hz at 800 rpm also

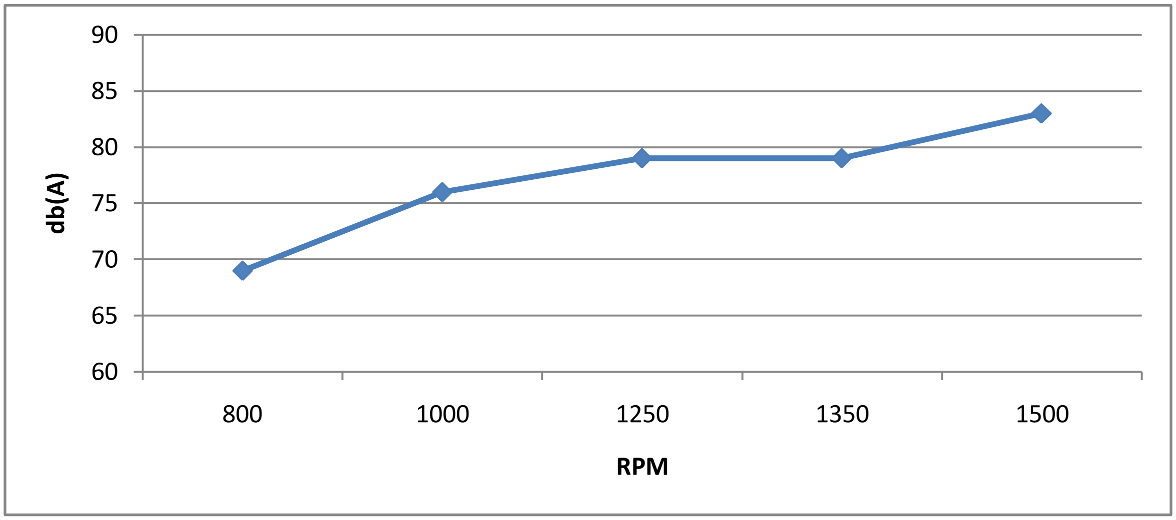


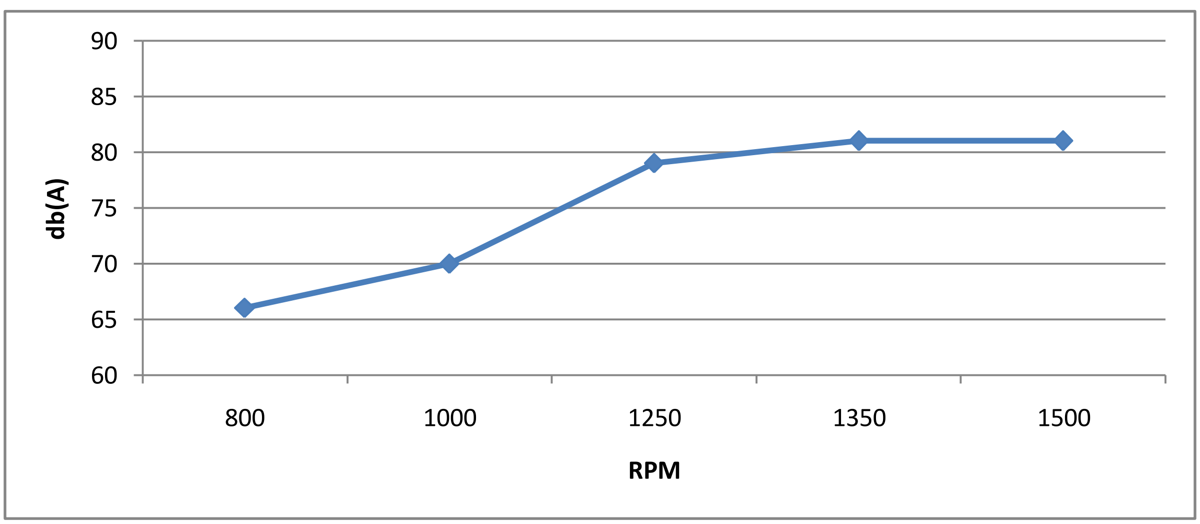
Fig 4.23 Trend in peak values with increasing RPM of new chain without lubrication

4.3.4 New chain with lubrication

Noise level in dB(A) shows a positive trend of increasing dB(A) with increasing the RPM

As rpm are increased for old chain without lubrication there is continuous increase in noise level values from 66 dB(A) to 81 dB(A)

Whereas major disturbing frequencies remaining constant i.e. 2000 Hz , 4000 Hz and 8000Hz



4.24 Trend in peak values with increasing RPM of new chain with lubrication

4.4 Trend analysis for chain wear

Further the line graphs were plotted showing the variation of noise level values with chain wear at different RPM. Graph depicts the variation of noise level values between new and old chain at different RPM

4.4.1 New and old chain at different rpm without lubrication

Chain wear increases the noise levelswhereas major disturbing frequencies being constant . Noise level dB(A) increases as the chain wears with time.

For RPM 800 , dB(A) peak value increases from 69dB(A) to 72dB(A) and similar trend is obtained for RPM of 1000 , 1250 , 1350 , 1500

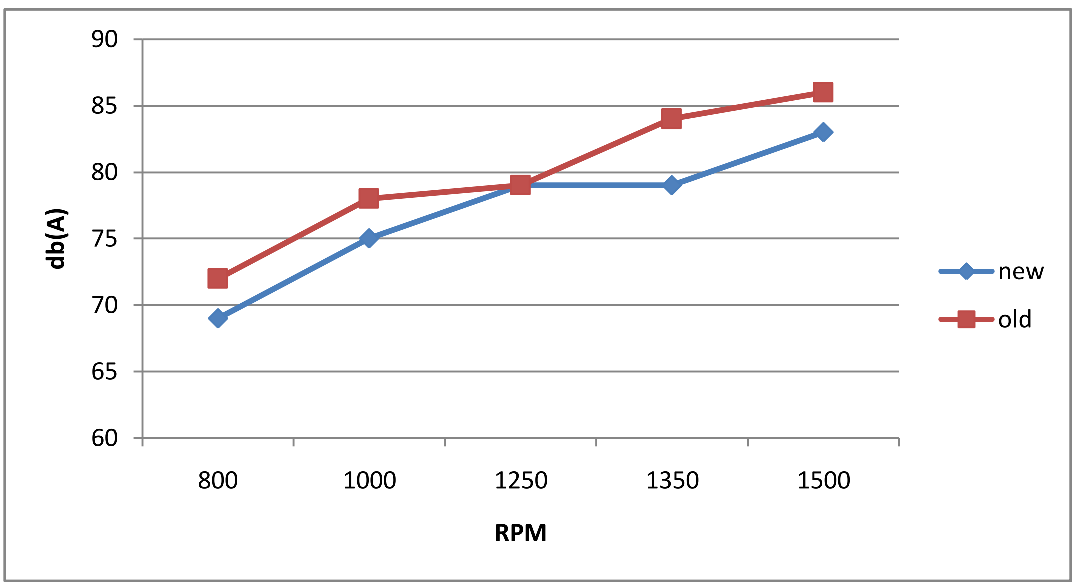


Fig 4.25 Trend in peak values with chain wear without lubrication at diff RPM

4.4.2 New and old chain at different RPM with lubrication

Chain wear increases the noise level whereas major disturbing frequencies being constant . Noise level dB(A) increases as the chain wears with time.

For RPM 800 , noise level value increases from 66dB(A) to 70dB(A) and similar trend is obtained for RPM of 1000 , 1250 , 1350 , 1500

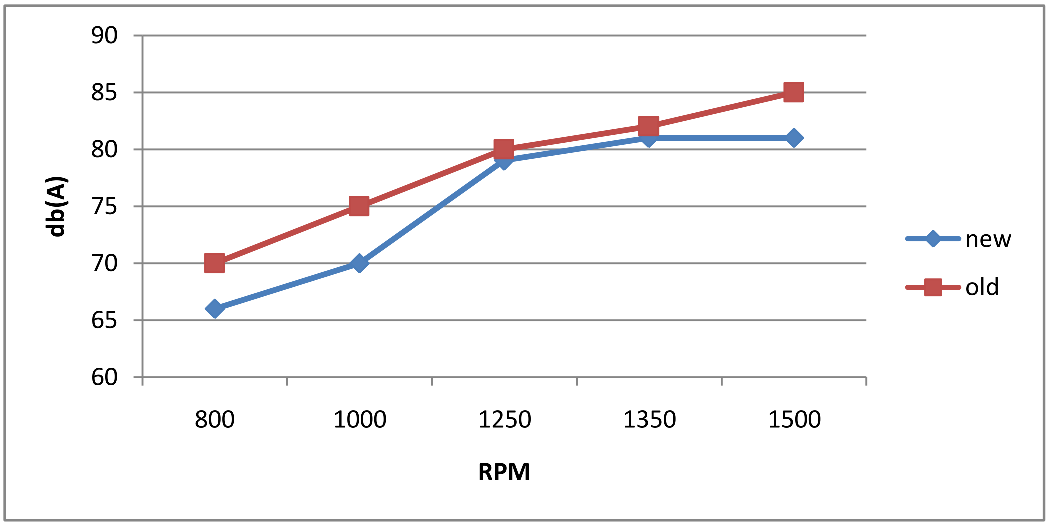


Fig 4.26 Trend in peak values with chain wear with lubrication at diff RPM

4.5 Trend analysis for lubrication

Further the graph was obtained for variation in noise level with lubrication at different RPM. Graph depicts the variation of dB(A) values for conditions of with and without lubrication at different RPM

4.5.1 Old chain with and without lubrication at different RPM

With lubrication noise level values decreases, major disturbing frequencies being constant. Noise level dB(A) decreases with lubrication. Decrease in values of noise level for different RPM is shown below

For RPM 800, noise level value decreases from 72dB(A) to 70dB(A) and similar trend is obtained for RPM of 1000 , 1250 , 1350 , 1500

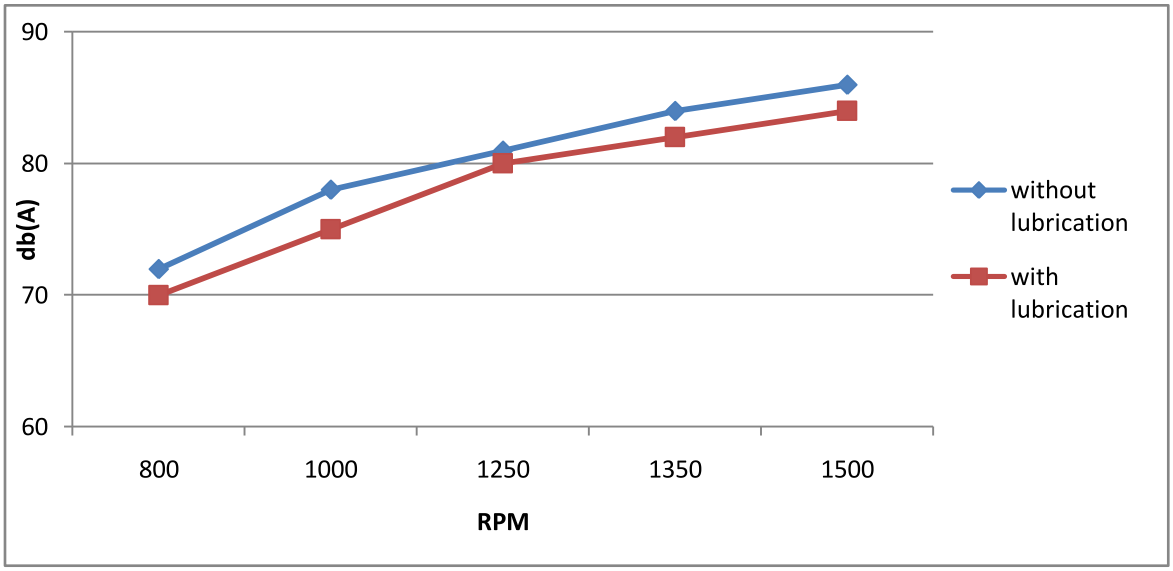


Fig 4.27 Trend in peak values with lubrication old chain

4.5.2 New chain with and without lubrication at different RPM

With lubrication peak noise level decreases , major disturbing frequencies being constant. Noise level dB(A) decreases with lubrication. Decrease in peak values of dB(A) for different RPM is shown below

For RPM 800 , dB(A) peak value decreases from 69dB(A) to 66dB(A) and similar trend is obtained for RPM of 1000 , 1250 , 1350 , 1500

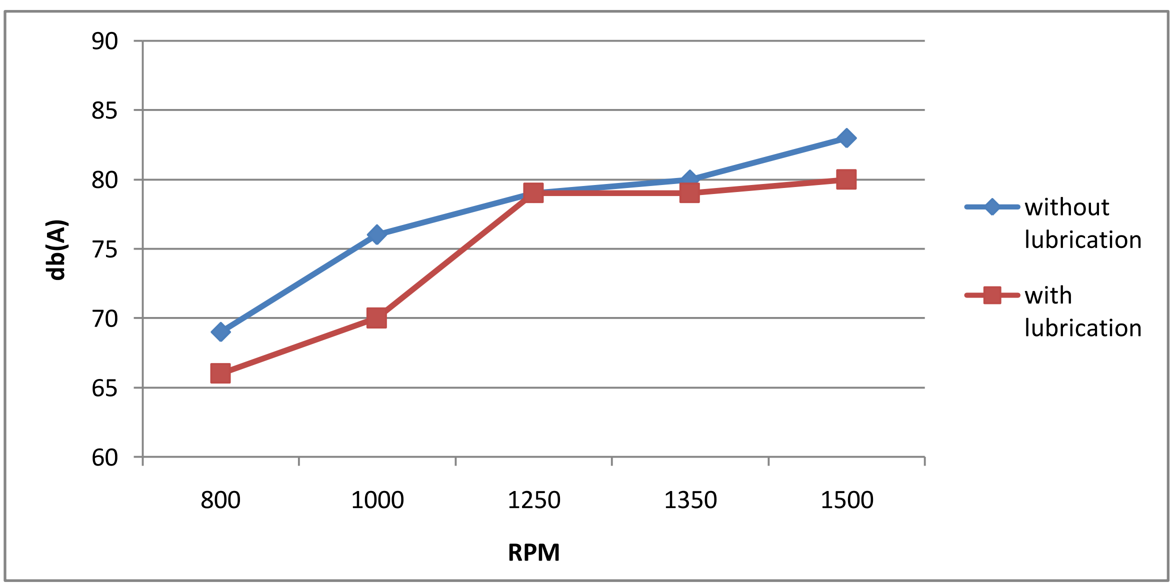


Fig 4.28 Trend in peak values with lubrication for new chain

4.6 Analysis using ANOVA

The experimental results for noise were analyzed using ANOVA and is given in the table below. The P values given in the last column of ANOVA table suggests the significance of the factors or process parameters on response parameters. The principle behind significance value is that the P value should be lesser than 0.05, considering confidence level of 95%. The principle of F test is that, F value should be large as compared to e-pooled, larger the F value more significance is the factor. Table shows that p value for RPM, lubrication and chain wear which indicates that all the three factors are significant factors for noise of cam chain. Ranks has been given to each of three factors, higher the rank higher is the significance.

Main effect plot shown in the fig shows the variation in noise from cam chain with the change in process parameters i.e. RPM, lubrication and chain wear.

Analysis of Variance

Table 4.2 Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
RPM	4	551.20	137.800	81.24	0.000
Lubrication	1	11.25	11.250	6.63	0.023
Chain	1	36.45	36.450	21.49	0.000
Error	13	22.05	1.696		
Total	19	620.95			

Table 4.3 Response table for means

Level	RPM	Lubrication	Chain wear
1	69.25	78.70	76.50
2	74.75	77.10	79.30
3	80.00		
4	81.50		
5	84.00		
Delta	14.75	1.60	2.80
Rank	1	3	2

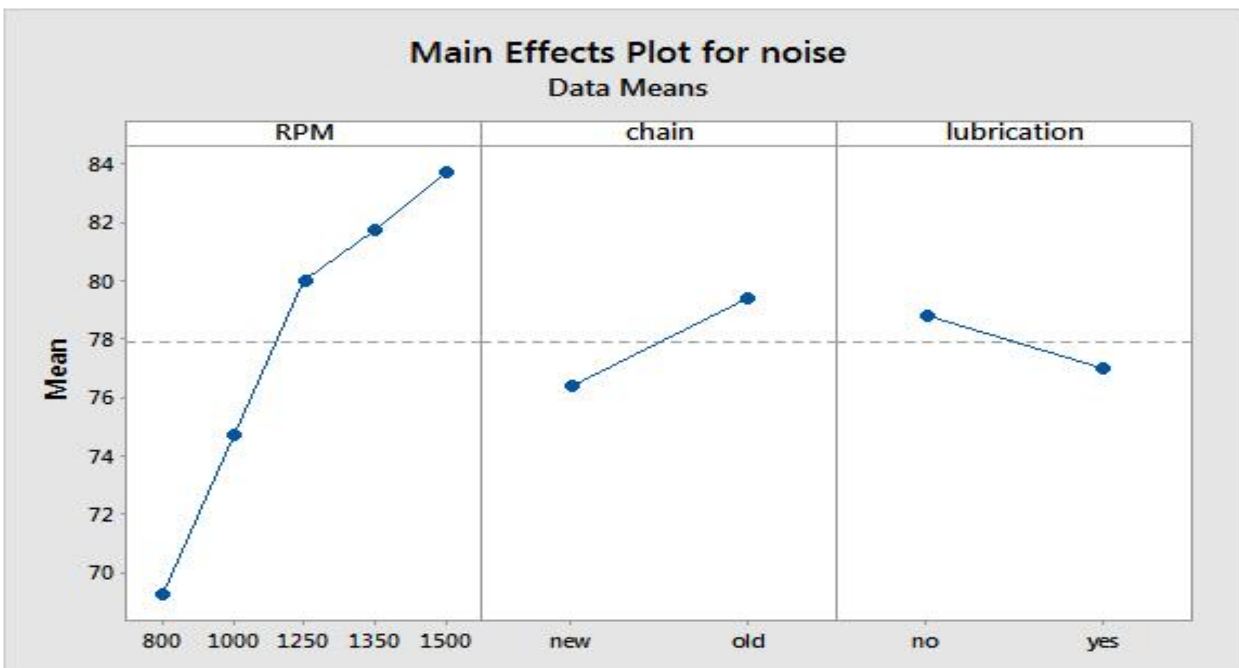


Fig 4.28 Main effect plots for noise

4.7 Discussion

The effect of process parameters i.e. RPM, chain wear and chain lubrication on noise perceived from cam chain were investigated. Maximum value of db was 86 dB(A) and at condition of 1500 RPM , old chain and without lubrication.Minimum value of dB was 66 dB(A) obtained for conditions of new chain at 800 RPM and with lubrication.

In almost all cases dominant frequencies remained same i.e. 2000, 4000 and 8000 Hz with corresponding dB(A)peak values ranging from 66 dB(A) to 86 dB(A) . Noise is more annoying as major frequencies lies in higher range only

The experimental results for noise were analyzed using ANOVA and it was found that all the three factors are significant factors for noise of cam chain. Ranks have been given to each of three factors, higher the rank higher is the significance.RPM of the chain was found to be most significant factor for perceived chain noise followed by chain wear and lubrication.

A typical behavior was observed at a speed of 1250 RPM, where effect of wear of chain and effect of lubrication was very insignificant on noise generation. This RPM corresponds to frequency of nearly 130 Hz and needs further investigation.

CHAPTER 5

Results and discussion of vibration measurement

In order to study the vibration produced due to cam chain in the engine the system was used to measure the vibration at a point below the cylinder head due to rotating cam chain of timing system of automobile engine. CESVA SC310 sound level meter was used in vibration mode to measure the system vibration. An accelerometer was attached to the system below the engine head to measure the vibration of the system.

Frequency spectrum between L_T(dB) and frequency were plotted that shows the major frequencies and corresponding peak values of vibration to these dominant frequencies.

Measurements were taken at different RPMs of 800, 1000, 1200, 1250, 1350, 1500.

5.1 Frequency spectrum obtained at different RPM are shown below

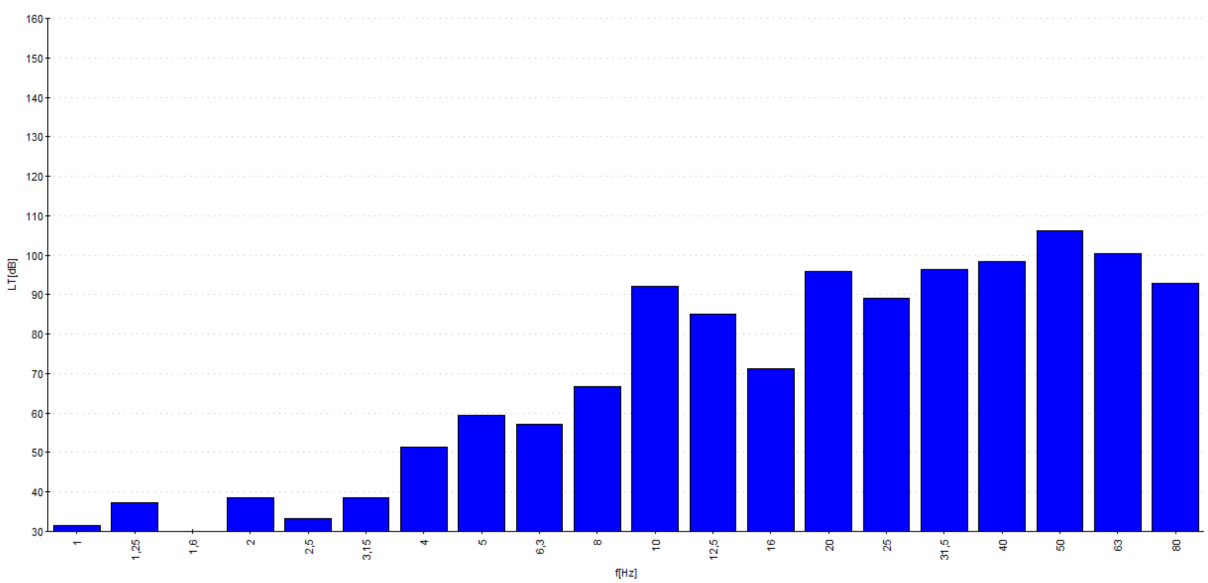


Fig 5.1 Frequency spectrum at 800 RPM

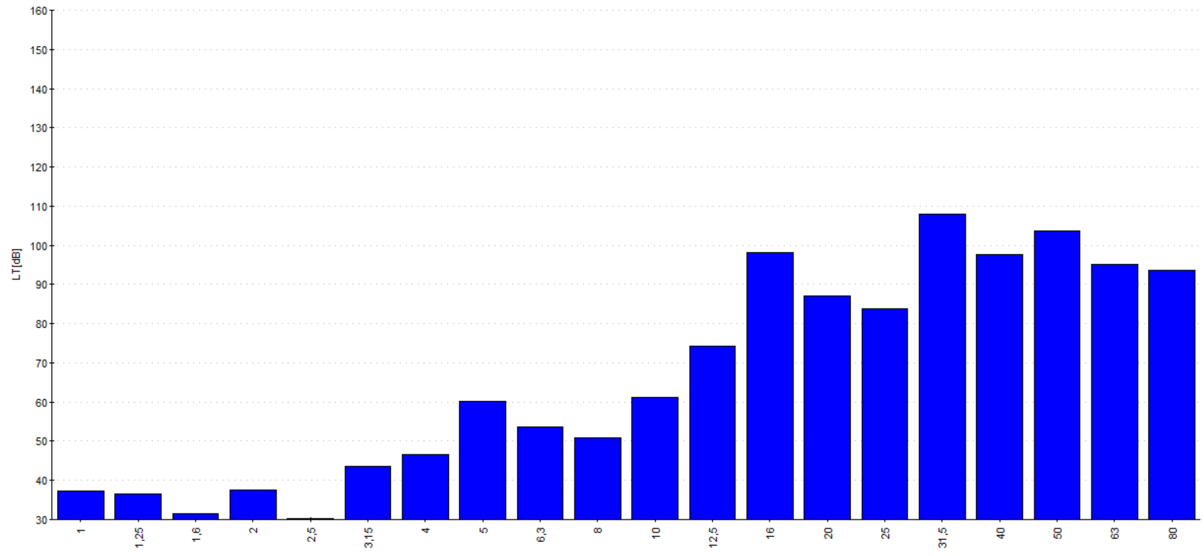


Fig 5.2 Frequency spectrum at 1000 RPM

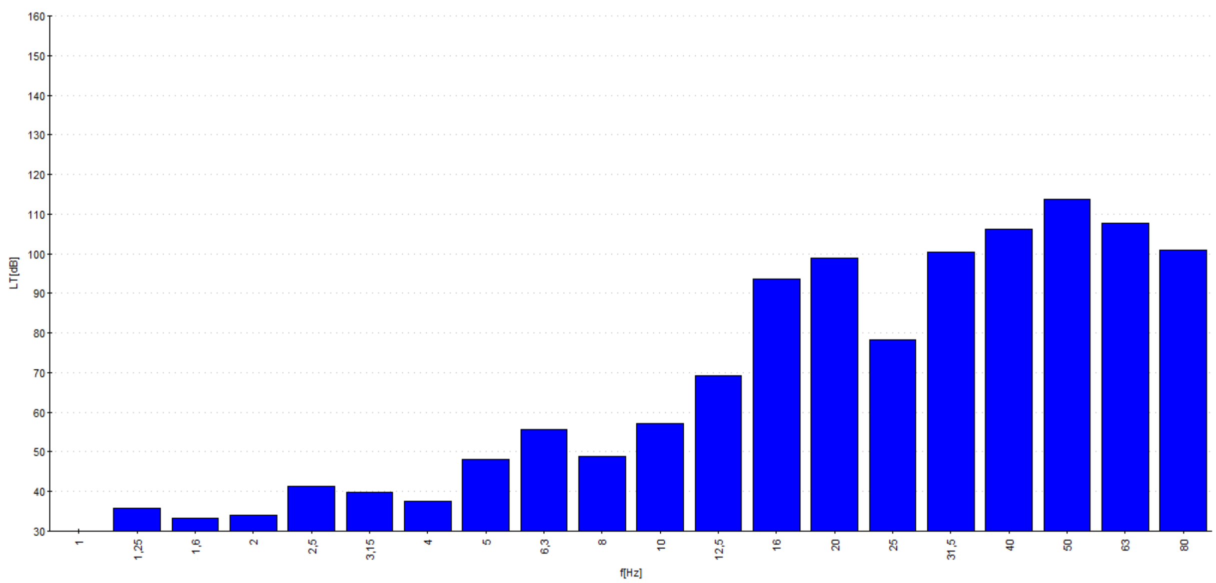


Fig 5.3 Frequency spectrum at 1200 RPM

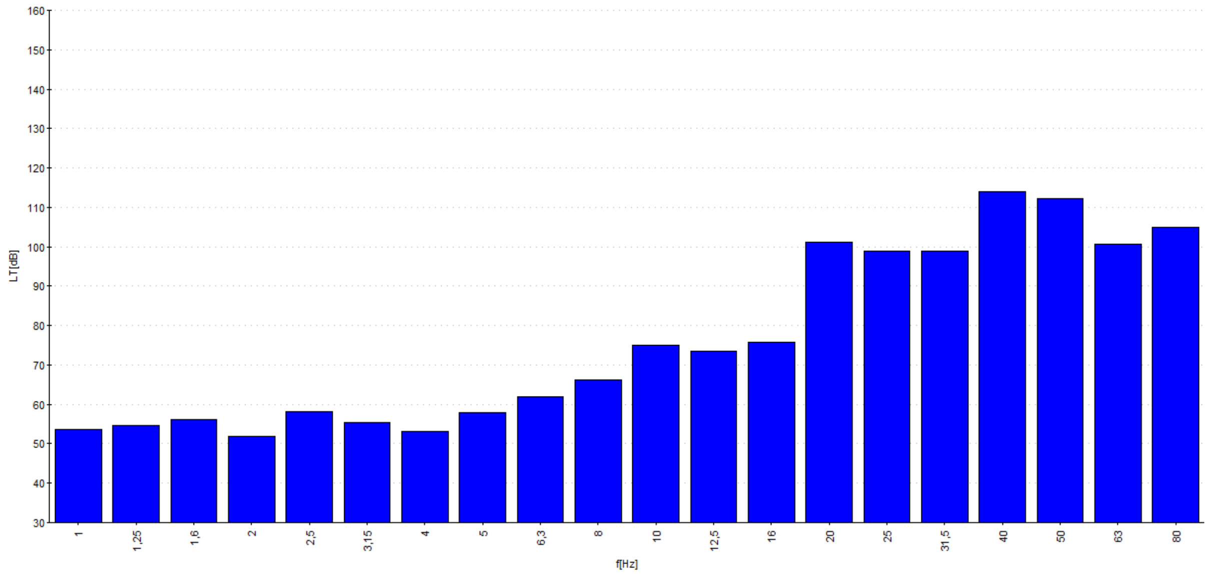


Fig 5.4 Frequency spectrum at 1250 RPM

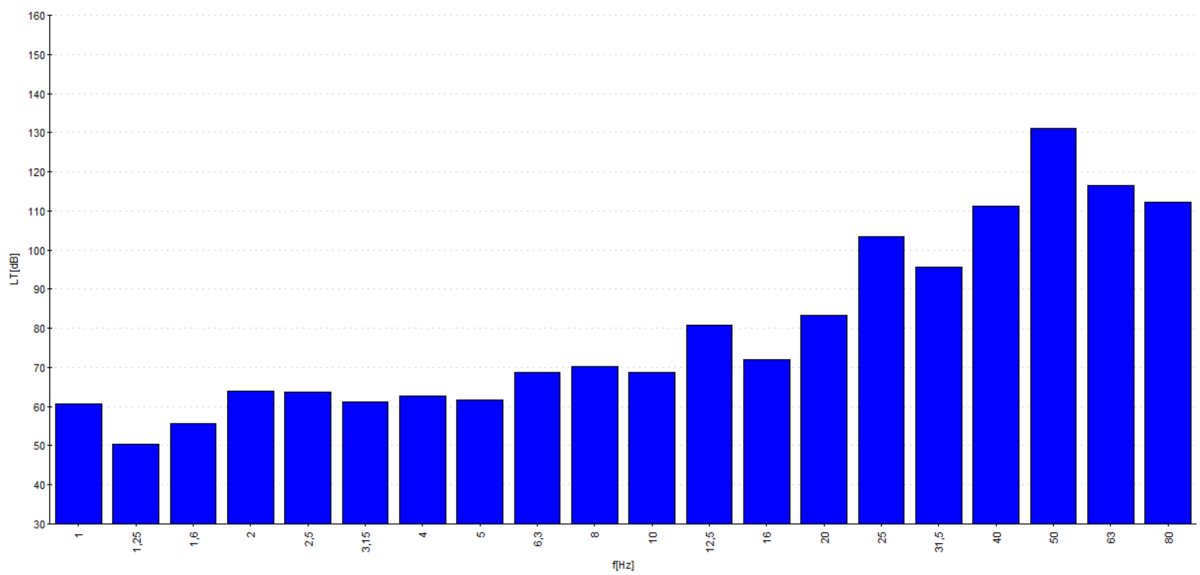


Fig 5.5 Frequency plot at 1350 RPM

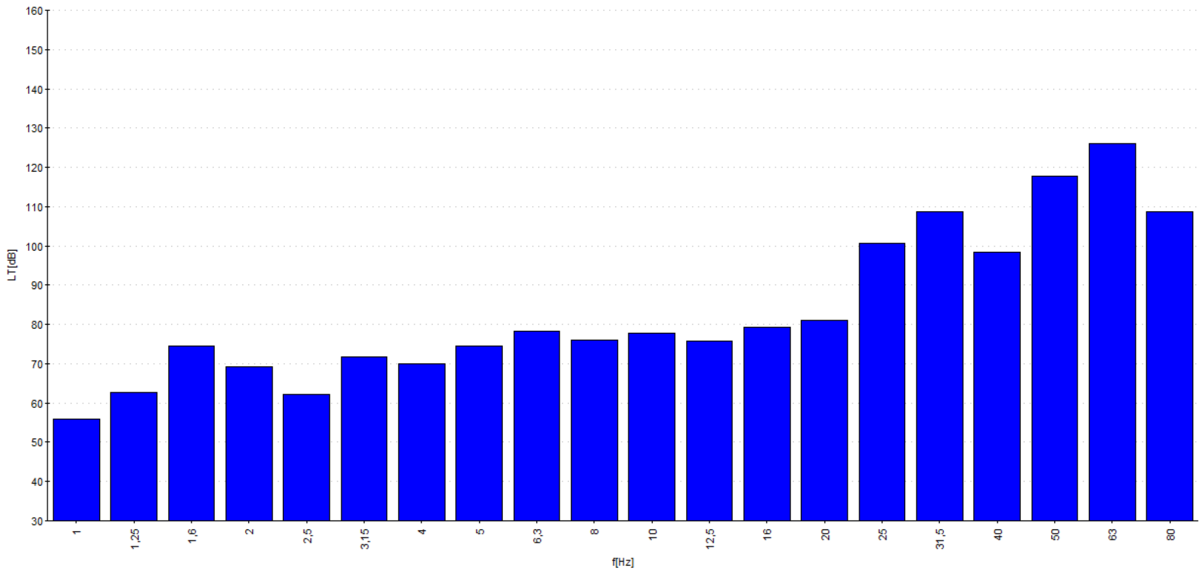


Fig 5.6 Frequency spectrum at 1500 RPM

5.2 TREND IN PEAK VALUES OF FREQUENCIES WITH RPM

Table 5.1 Peak values corresponding to different RPM

RPM	**PEAK VALUES , Lt (dB)**
800	**105**
1000	**110**
1200	**115**
1250	**115**
1350	**130**
1500	**130**

With increase in RPM from 800 to 1500, peak values of the vibration increases from 105 to 130 Lt(dB)

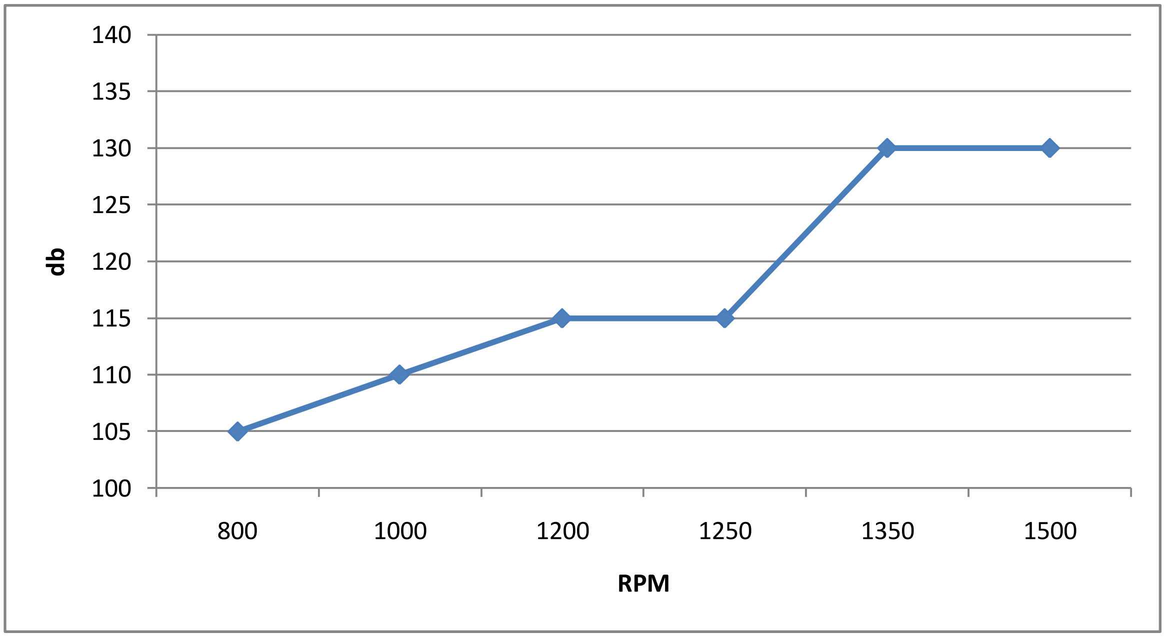


Fig 5.7 Trend in peak values of frequency with RPM

5.3 Spectrum interpretation and fault diagnosis

It was desirable to detect all types of factors that could be responsible for vibration induced in rotating cam chain. In order to relate the major dominant frequencies to their corresponding causes condition monitoring of the system was done by interpreting the frequency spectrum obtained and hence use s for fault diagnosis.

Table 5.1 classifies different types of faults and helps in indicating that at which frequency the faults are displayed in vibration spectrum. This is powerful tool for spectrum interpretation

- ❖ Column 2 includes nature of fault that is probably the cause of vibration in machinery. In case of cam chain there are 7 factors those can be stated responsible for vibration in timing system of the automobile engine. Column two includes those 7 factors
- ❖ Column 3 in the table includes the frequency of dominant vibration that will be accounting for the corresponding vibration factor. e.g. if dominant frequency in the

vibration spectrum obtained is (1*RPM)/60 , then main cause of the vibration will include the factor corresponding to that value i.e. rotating members out of balance.

- ❖ Column 4 includes the direction of vibration that is induced due to rotating elements or other causes of vibration discussed in the table. Vibration induced due to different factors could be both radial and axial to rotating part.

Table 5.1 A vibration troubleshooting chart [20]

Sr number	**Nature of fault**	**Frequency of dominant vibration in hertz**	**Direction of vibration induced**
1	Rotating members out of balance	1 * RPM	Radial
2	Misalignment and bent shaft	2 * RPM	Radial and axial
3	Oil film whirl	42% to 48% RPM	Primarily radial
4	Hysteresis whirl	Shaft critical speed	Primarily radial
5	Damaged or worn sprockets	RPM * number of teeth	Radial and axial
6	Mechanical looseness	2 * RPM	
7	Electrically induced vib.	1 * RPM	Radial and axial

5.3.1 Condition monitoring at 800 RPM

Condition monitoring was performed for relating the major dominant frequencies with factors responsible. Table includes factors that could be responsible for the induced vibration, frequencies according to table that will be responsible for impact of these parameters and relation of dominant frequencies with the frequencies by the table 5.1. If dominant frequencies from the frequency spectrum are same or close to those given by table 5.1 for the particular cause, the factor will be considered as major source of induced vibration [20].

Frequency spectrum obtained for system vibration at 800 RPM shows that the dominant frequencies lies between 20 Hz to 80 Hz.

Table 5.2 Fault diagnosis at 800 RPM

Factors	**Frequencies attributing at 800 RPM acc to table 5.1**	**Frequency lies in dominant range (yes/no)**
Rotating members out of balance	**13.33**	**No**
Misalignment and bent shaft	**26.66**	**Yes**
Oil film whirl	**6**	**No**
Hysteresis whirl	**13.33**	**No**
Damaged or worn sprockets	**373.33**	**No**
Mechanical looseness	**26.66**	**Yes**
Electrically induced vib.	**13.33**	**No**

Hence the major factors were

- Misalignment and bent shaft
- Mechanical looseness

5.3.2 Condition monitoring at 1000 RPM

Frequency spectrum obtained for system vibration at 1000 RPM shows that the dominant frequencies lies between 16 Hz to 80 Hz.

Table 5.3 Fault diagnosis at 1000 RPM

Factors	**Frequencies attributing at 1000 RPM acc to table 5.1**	**Frequency lies in dominant range (yes/no)**
Rotating members out of balance	**16.66**	**Yes**
Misalignment and bent shaft	**33.33**	**Yes**
Oil film whirl	**7.5**	**No**
Hysteresis whirl	**16.66**	**Yes**
Damaged or worn sprockets	**466**	**No**
Mechanical looseness	**33.33**	**Yes**
Electrically induced vib.	**16.66**	**Yes**

Hence the major factors were

- Rotating members out of balance
- Misalignment and bent shaft
- Hysteresis whirl
- Mechanical looseness
- Electrically induced vibration

5.3.3 Condition monitoring at 1200 RPM

Frequency spectrum obtained for system vibration at 1200 RPM shows that the dominant frequencies lies between 20 Hz to 80 Hz.

Table 5.4 Fault diagnosis at 1200 RPM

Factors	**Frequencies attributing at 1200 RPM acc to table 5.1**	**Frequency lies in dominant range (yes/no)**
Rotating members out of balance	**20**	**Yes**
Misalignment and bent shaft	**40**	**Yes**
Oil film whirl	**9**	**No**
Hysteresis whirl	**20**	**Yes**
Damaged or worn sprockets	**560**	**No**
Mechanical looseness	**20**	**Yes**
Electrically induced vib.	**40**	**Yes**

Hence the major factors were

- Rotating members out of balance
- Misalignment and bent shaft
- Hysteresis whirl
- Mechanical looseness
- Electrically induced vibration

5.3.4 Condition monitoring at 1250 RPM

Frequency spectrum obtained for system vibration at 1250 RPM shows that the dominant frequencies lies between 20 Hz to 80 Hz.

Table 5.5 Fault diagnosis at 1250 RPM

Factors	**Frequencies attributing at 1250 RPM acc to table 5.1**	**Frequency lies in dominant range (yes/no)**
Rotating members out of balance	**20.83**	**Yes**
Misalignment and bent shaft	**41.66**	**Yes**
Oil film whirl	**9.375**	**No**
Hysteresis whirl	**20.83**	**Yes**
Damaged or worn sprockets	**583.33**	**No**
Mechanical looseness	**20.83**	**Yes**
Electrically induced vib.	**41.66**	**Yes**

Hence the major factors were

- Rotating members out of balance
- Misalignment and bent shaft
- Hysteresis whirl
- Mechanical looseness
- Electrically induced vibration

5.3.5 Condition monitoring at 1350 RPM

Frequency spectrum obtained for system vibration at 1350 RPM shows that the dominant frequencies lies between 20 Hz to 80 Hz.

Table 5.6 Fault diagnosis at 1350 RPM

Factors	**Frequencies attributing at 1350 RPM acc to table 5.1**	**Frequency lies in dominant range (yes/no)**
Rotating members out of balance	**22.5**	**Yes**
Misalignment and bent shaft	**45**	**Yes**
Oil film whirl	**10.125**	**No**
Hysteresis whirl	**22.5**	**Yes**
Damaged or worn sprockets	**630**	**No**
Mechanical looseness	**22.5**	**Yes**
Electrically induced vib.	**45**	**Yes**

Hence the major factors were

- Rotating members out of balance
- Misalignment and bent shaft
- Hysteresis whirl
- Mechanical looseness
- Electrically induced vibration

5.3.6 Condition monitoring at 1500 RPM

Frequency spectrum obtained for system vibration at 1500 RPM shows that the dominant frequencies lies between 16 Hz to 80 Hz.

Table 5.7 Fault diagnosis at 1500 RPM

Factors	**Frequencies attributing at 1500 RPM acc to table 5.1**	**Frequency lies in dominant range (yes/no)**
Rotating members out of balance	**25**	**Yes**
Misalignment and bent shaft	**50**	**Yes**
Oil film whirl	**11.25**	**No**
Hysteresis whirl	**25**	**Yes**
Damaged or worn sprockets	**700**	**No**
Mechanical looseness	**25**	**Yes**
Electrically induced vib.	**50**	**Yes**

Hence the major factors were

- Rotating members out of balance
- Misalignment and bent shaft
- Hysteresis whirl
- Mechanical looseness
- Electrically induced vibration

5.4 DISCUSSION

Frequency spectrum for vibration was obtained using sound level meter in vibration mode. System was operated at 6 different RPMs (800, 1000, 1200, 1250, 1350, 1500). Further major dominant frequencies were identified at each operating condition of RPM that lies between 20Hz to60Hz in almost all cases with peak values ranging from 90dB to 110dB.

Further condition monitoring of the system was done based on spectrum interpretation and fault diagnosis. Based on standard data for fault diagnosis it was found that following are major factors for vibration induced in the system

- Rotating members out of balance i.e. rotating larger and smaller sprocket
- Misalignment and bent shaft i.e. due to misalignment of cam shaft
- Hysteresis whirl
- Mechanical looseness i.e. sprockets were not adequate tight with RPM and looseness due to chain wear
- Electrically induced vibration i.e. vibration induced due to motor when switched on

Damaged or worn sprocket was not the cause of vibration in the system studied as new set of sprockets and chain was used in experiment. Also the lubricating oil whirl between the chain and sprocket during meshing was not the major cause as frequencies attributing to this factor was not dominant frequency in the spectrum.

CHAPTER 6

Summary and conclusion

6.1 Conclusion

The present study was carried out to measure and evaluate the noise of cam chain of motorcycle engine. A set was prepared to rotate the cam chain of motorcycle engine with the help of motor in order to measure the noise of cam chain only. Further the effect of various parameters on the noise perceived from cam chain was studied. Trend analysis of the data was performed. Also measurement was analyzed using ANOVA and significance of the various factors was obtained. Ranking of various parameters was done on the basis of Taguchi analysis. The process parameters that has been considered for changing are RPM of chain (800, 1000, 1250, 1350, 1500), lubrication of chain (with and without lubrication) and chain wear (new and old chain)

Further the vibration of the timing system of engine was studied and causes for the induced vibration was studied using condition monitoring and fault diagnosis technique.

The following conclusion have been drawn from experimental study

- Minimum value of noise level was obtained for new chain , with lubrication and at 800 RPM
- Maximum value of noise level was obtained for old chain, without lubrication and at 1500 RPM.
- Noise level increases with increase in RPM of the engine, increases with chain wear and decreases with lubrication.
- All three factors were found significant for the noise level in timing system of engine. RPM of the system was found most significant with chain wear on second position and lubrication on third according to the ranking.
- Vibration of the timing system increases with increase in RPM of the chain
- Fault diagnosis provided the probable causes of the vibration in the system as rotating members out of balance, misalignment and bent shaft, hysteresis whirl, mechanical looseness, electrically induced vibration.

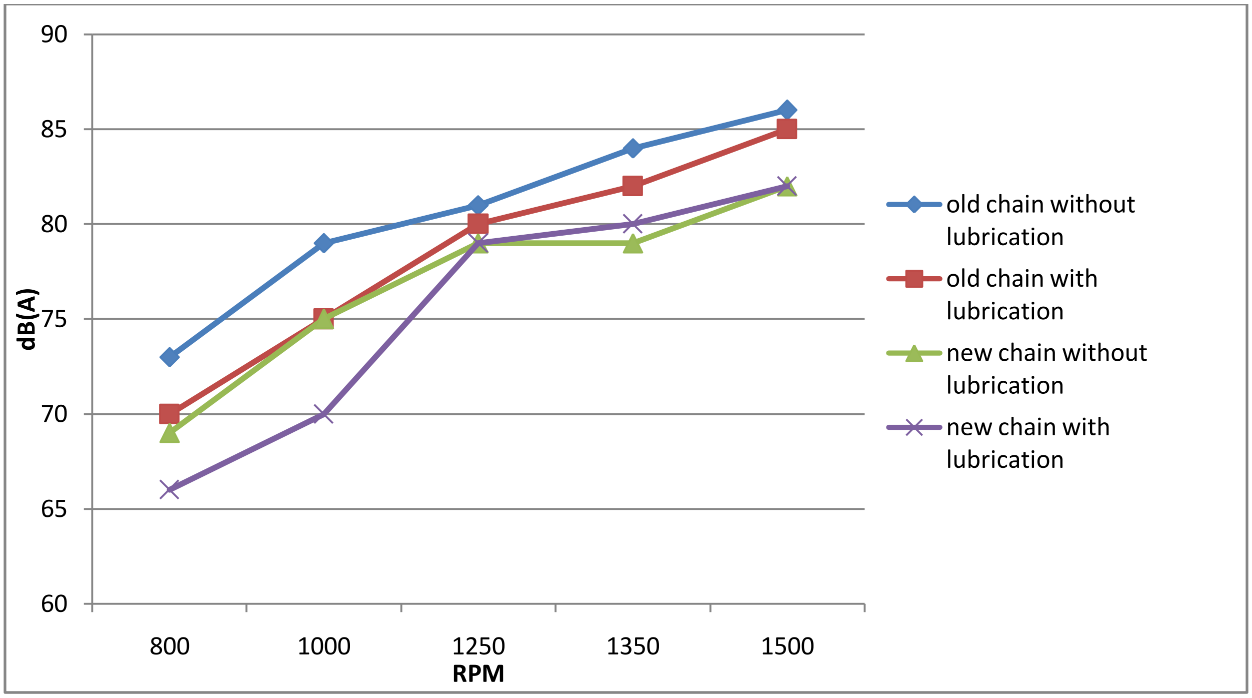


Fig 6.1 Concluded trends

6.2 Future scope

Following are some of the future recommendations on the basis of present study

- As the set up prepared for the experimentation was not closed, grease was used as the lubricating material instead of oil. System could be prepared that will be close and crankshaft sprocket will rotate in oil tub.
- Major disturbing frequencies obtained from the experiment can be compared with modal analysis of the same chain sprocket system using Hypermesh software.
- A typical behavior was observed at a speed of 1250 RPM, where effect of wear of chain and effect of lubrication was very insignificant on noise generation. This RPM correspons to frequency of nearly 130 Hz and needs further investigation.

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