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Incipient Fault Detection in Spur Gear Box

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Abstract— Gearbox is one of the most widely used transmission systems in the world. However, due to high service load, severe operating situations or fatigue, faults may develop in gears. Vibration health supervising is a non-destructive technique which can be applied to perceive faults proliferating in gear teeth. The main objective of the work is to detect the Incipient faults in the spur gear. The spur gear is induced with the defects using the Electrical Discharge Machine (EDM) and damaged gear is installed in the gearbox and vibrations were captured using the Piezo-electric accelerometer and analyzed using the MATLAB. The experimental tests have shown that the tooth surface roughness changes and contact length variations will generate impulse vibrations and friction force changes with considerable amplitudes. This method of incipient fault detection is very easy to implement and detect the faults which reduces the time required in disassembly of breakdown machines. The results indicate that the Vibration amplitude intensifies with increase in fault percentage which enables us to identify the damage and replace the gears before breakdown.

Key Words— Accelerometer, EDM, Fault detection, gear box, Root crack, Spur gear, Tooth cut.

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1 Introduction

The mechanism which we use for transmission of generated power plays a major role. There are various forms of power transmission techniques e.g.: Gear drive, Belt drives, Rope drives, Chain drives etc. Gear drives are commonly applied in today's industries. People use them to meet various requirements. A Gear is a machine part, which is used to transmit mechanical power from one shaft to the other. Gear is a kind of machine constituent in which teeth are cut around cylindrical or cone shaped surfaces with equivalent spacing. It is convenient for power transmission between two shafts. By meshing a pair of these elements, they are used to transmit rotations and forces from the driving shaft to driven shaft.

Other thing is gears are useful in transmitting power for parallel, non-parallel shafts, while belt or chain drive transmit power only when shafts are parallel. Gears have high life and efficiency than other drives. Due to the meeting of toothed wheel of gears, some part of machine may get permanently damaged in case of disproportionate loading. They are not appropriate for transmitting motion over a large distance. Operating the gear is quite strident. There is a close relationship between gear drives and the harmonic vibration. Even so-called "quiet drives" cannot be free of a definite sum of harmonic vibration.

2 Literature survey

Over more than two-decade, huge emphasis is given to research on vibration-based fault diagnosis methodologies that are applied to vibration signals obtained from gearboxes via transducers mounted on gearbox casing. Even a trivial failure could lead to a catastrophe, therefore condition monitoring and fault diagnosis systems should be planted in a machine to raise alarm thereby escaping accidents and generate cost savings.[1]

In general, gears work under severe conditions consequently they are subject to progressive deterioration of their state, namely at the teeth level. The gear defects induce generally mechanical effects in machines such as sound increased level and vibrations. However, the presence of the tooth crack defect appears at its basis and progress each time when running the machine. It appears especially on fine stainless steels, it became hard by heat treatment, which are very sensitive to stress constrains. The tooth crack appearance is a result of the stress at the tooth basis which exceeds the fatigue limit of the material. This tooth crack does not modify the contact rigidity, but affects the tooth flexion rigidity. This results in a change in the vibration behavior. Hence the need to supervise these gear vibrations continuously to detect at an early stage any emerging defects.[3]

With the advancement of industrial systems, fault monitoring and diagnosis methods based on the data-Driven attract much attention in recent years. This kind of methods are widely used in engineering projects, especially in those big and complicated machines, whose conditions are difficult to obtain from straight view. They can provide the administrator with effective fault information in initial phase and therefore reduce the loss caused by faults. The key point to fault diagnosis is not the faults itself, but the diagnosis method. Because of the complexity of fault diagnosis process, it is necessary to use not a single method but a variety of methods to deal with the problem. [4-5]

In the past few years, a number of investigations were undertaken to predict gear crack path. Several techniques have been proposed and they are mainly based on Linear Elastic Fracture Mechanics (LEFM). Accurate simulation on the tooth root crack propagation path could help capturing the right dynamic vibration features of the geared system. There have been numerous literatures concerning the vibration responses of gear systems with tooth root crack based on the knowledge of crack propagation path shape. Wear of gear pair is challenging to measure directly without disturbing the running contact state and lubrication condition. Indirect methods based on, for example, temperature, acoustic, vibration and oil particle contamination has been used to detect the symptoms of failure caused by wear. Ferrography and spectrometric methods are known to be powerful tools for identifying wear degree and mechanism, but as off-line methods based on analysis of oil samples, they are considered to be too time consuming, laborious and hence providing too delayed information. [6-8]

3 DESIGN AND ANALYSIS

3.1 Spur Gear Box

The design of the Spur gear box is done using Solid works (2016). The design is well balanced and it doesn't have any deformation which can result in unbalance of mass and create vibration. Analysis of the same is done using ANSYS (2016), only the parts bearing load are subjected to Structural analysis and they all were in safe design condition.

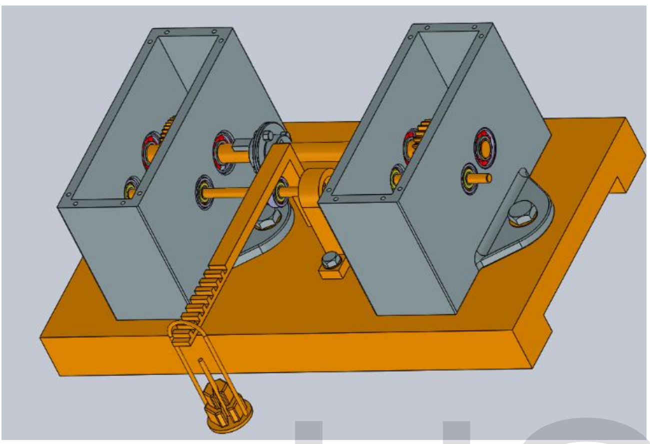

Fig.1 Final Assembled Image of Spur Gear Box

3.2 Spur Gear and other load bearing parts

The design of Spur gear is also done using Solid works (2016). Analysis is done with the help of ANSYS (2016). After analysis of the design, the gear is manufactured with 20MnCr5 material since it is the commonly used gear material in many machines. It has great mechanical properties which is why that material was chosen for our investigation purpose. The gear meshing stiffness analysis was done by considering its maximum speed which was 1500 rpm.

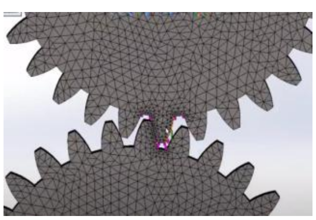

Fig.3 Meshed image of the gear

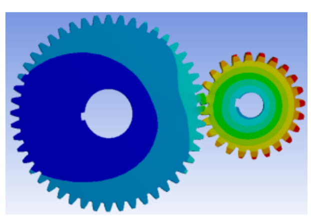

Fig.2 Von-mises stress distribution

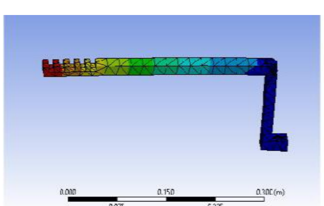

Fig.4 Stress distribution in Hinged beam

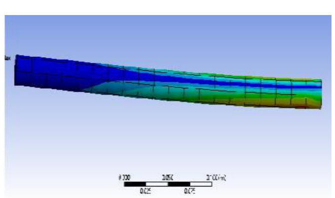

Fig.5 Stress Distribution on the Shaft

4 EXPERIMENTAL SETUP

The aim of the experiment was to initiate and propagate wear under accelerated test conditions. Lubricant temperature, lubricant film thickness, vibration acceleration and tooth stiffness analyses were used in the detection and quantification of advancement of wear incurred by spur gear teeth. The experimental setup used for this study was designed in standard back- to-back arrangement.

The arrangement consists of two parallel steel shafts and four gears (two pinions with 12 and 24 teeth and the other two gears with 24 and 48 teeth) and a pair of pinions; gears have been assembled on either side of the shafts. The gear sets used in this experiment are made of 20MnCr5 steel which heat treated for 1mm depth, 40HRC. The gears with 12 and 24 teeth had a module of 3mm and pressure angle of 20° FDI. The gears with 24 and 48 teeth had a module of 2mm and pressure angle of 20° FDI.

The setup consists of a 1 HP two stage spur gearbox. The gear box is driven by a 1 HP, 3-phase induction motor with a rated speed of 1500 rpm. The speed is controlled by sleeve gearbox and for the present study the motor is operated at 1500 rpm. In other words, the speed of gear shaft in the first stage of the gearbox is 750 rpm. With a step-up ratio of 1:2, the speed of the pinion shaft in the second stage of the gear box is 1500 rpm.

Fig.6 Spur Gear Test Rig

Five types of gear faults were expected to be investigated such as:

i. Depth wise tooth removal i.e. 0%, 25%, 50%, 75% and 100% tooth removal conditions across the tooth width.

ii. Root crack with 0.5 mm of starting crack and increasing till it breaks and taking accelerometer reading every 0.5mm increase

iii. Removing surface finish on every tooth.

iv. Drilled holes in gear tooth.

v. Multiple faults including all these above faults.

For all operating conditions vibration signals were expected to be acquired and recorded after proper signal conditioning. The acquired signals would be decomposed using program developed in MATLAB.

TABLE ： Sleeve gear box specifications:

Gear 1	Pinion 1
Module m= 2mm	Module m= 2mm
Face width b= 28.27mm	Face width b= 28.27mm
Pressure angle = 20°	Pressure angle = 20°
Outer dia = 78mm	Outer dia = 42mm
No. of teeth = 24	No. of teeth = 12
Bore dia = 25mm	Bore dia = 12mm
Pitch circle dia = 72mm	Pitch circle dia = 36mm
Addendum = 3mm	Addendum = 3mm
Tooth depth = 6.75mm	Tooth depth = 6.75mm
Dedendum = 3.75mm	Dedendum = 3.75mm
Root dia = 64.5mm	Root dia = 28.5mm
Tooth thickness = 4.709mm	Tooth thickness = 4.6989mm

TABLE ： Test gear box specifications:

GEAR 2	PINION 2
Module m= 2mm	Module m= 2mm
Face width b= 18.8495mm	Face width b= 18.8495mm
Pressure angle = 20°	Pressure angle = 20°
Outer dia = 100mm	Outer dia = 52mm
No. of teeth = 48	No. of teeth = 24
Bore dia = 25mm	Bore dia = 12mm
Pitch circle dia = 96mm	Pitch circle dia = 48mm
Addendum = 2mm	Addendum = 2mm
Tooth depth = 4.5mm	Tooth depth = 4.5mm
Dedendum = 2.5mm	Dedendum = 2.5mm
Root dia = 91mm	Root dia = 43mm
Tooth thickness = 3.1410mm	Tooth thickness = 2.1393mm

5 RESULT AND DISCUSSION

5.1 Table: Signals captured for healthy gear using Accelerometer

Time	AI 1	Time	AI 1	Time	AI 1	Time	AI 1	Time	AI 1	Time	AI 1	Time	AI 1	Time	AI 1	Time	AI 1	Time	AI 1
s	m/s2	s	m/s2	s	m/s2	s	m/s2	s	m/s2	s	m/s2	s	m/s2	s	m/s2	s	m/s2	s	m/s2
52.4287	0.640408	52.4302	0.101302	52.4317	-0.1898	52.4332	-0.05292	52.4347	0.173079	52.43625	0.151716	52.4378	-0.16214	52.43935	-0.27259	52.4407	-0.26589	52.44225	0.3
52.42875	1.124522	52.43025	0.282352	52.43175	0.023689	52.43325	0.031423	52.43475	0.138928	52.4363	0.095122	52.43785	-0.31911	52.4394	-0.41075	52.44075	-0.34145	52.4423	0.31
52.4288	0.559924	52.4303	0.506094	52.4318	0.146579	52.4333	0.110875	52.4348	0.228214	52.43635	-0.10369	52.4379	-0.08235	52.43945	-0.20033	52.4408	-0.31474	52.44235	0.06
52.42885	-0.23398	52.43035	0.150268	52.43185	0.010866	52.43335	-0.08034	52.43485	0.222496	52.4364	0.135512	52.43795	0.142356	52.4395	0.128739	52.44085	-0.32905	52.4424	-0.1
52.4289	-0.57373	52.4304	-0.01126	52.4319	0.282874	52.4334	-0.19418	52.4349	-0.04472	52.43645	0.240527	52.438	0.117956	52.43935	-0.27259	52.4409	-0.19588	52.44245	-0.0
52.42895	-0.83081	52.43045	-0.25254	52.43195	0.311189	52.43345	0.016571	52.43495	-0.3537	52.4365	-0.28215	52.43805	-0.21346	52.4394	-0.41075	52.44095	-0.03226	52.4425	-0.2
52.429	-0.70294	52.4305	-0.50244	52.432	-0.15126	52.4335	-0.03097	52.435	-0.28996	52.43655	-0.31106	52.4381	-0.48932	52.43945	-0.20033	52.441	0.083794	52.44255	-0.7
52.42905	-0.50275	52.43055	-0.39534	52.43205	-0.10394	52.43355	-0.04331	52.43505	-0.42814	52.4366	-0.2164	52.43815	-0.39439	52.4395	0.128739	52.44105	0.133104	52.4426	-0.7
52.4291	-0.47248	52.4306	-0.56383	52.4321	-0.27888	52.4336	-0.0614	52.4351	-0.63462	52.43665	-0.24449	52.4382	-0.12679	52.43955	0.091907	52.4411	0.195095	52.44265	-0.6
52.42915	-0.31954	52.43065	-0.4864	52.43215	-0.50233	52.43365	-0.14368	52.43515	-0.46289	52.4367	0.028659	52.43825	-0.10685	52.4396	-0.02391	52.44115	0.277145	52.4427	-0.5
52.4292	0.200303	52.4307	-0.37177	52.4322	-0.19106	52.4337	-0.03148	52.4352	-0.12153	52.43675	0.026773	52.4383	-0.33577	52.43965	-0.00285	52.4412	0.191821	52.44275	-0.3
52.42925	0.381638	52.43075	-0.18786	52.43225	-0.23119	52.43375	0.228166	52.43525	0.04784	52.4368	-0.03913	52.43835	-0.43417	52.4397	0.034922	52.44125	-0.06798	52.4428	-0.5
52.4293	0.633184	52.4308	0.181525	52.4323	-0.2682	52.4338	0.227123	52.4353	0.472525	52.43685	0.199211	52.4384	-0.2861	52.43975	-0.00368	52.4413	-0.30483	52.44285	-0.
52.42935	0.325115	52.43085	0.223137	52.43235	0.063331	52.43385	0.098657	52.43535	0.500151	52.4369	0.512784	52.43845	0.145358	52.4398	-0.07932	52.44135	-0.43158	52.4429	0.30
52.4294	0.06797	52.4309	-0.02331	52.4324	0.125904	52.4339	0.092299	52.4354	0.045005	52.43695	0.447401	52.4385	0.326598	52.43985	-0.07392	52.4414	-0.39218	52.44295	0.19
52.42945	-0.03379	52.43095	-0.02359	52.43245	0.168453	52.43395	0.125429	52.43545	0.101741	52.437	0.206162	52.43855	-0.14421	52.4399	-0.07586	52.44145	-0.3037	52.443	0.15
52.4295	-0.14979	52.431	-0.22902	52.4325	0.123128	52.434	0.038647	52.4355	0.113389	52.43705	-0.03904	52.4386	-0.4692	52.43995	0.03854	52.4415	-0.27897	52.44305	0.23
52.42955	0.008837	52.43105	-0.45599	52.43255	-0.19346	52.43405	0.015255	52.43555	-0.20131	52.4371	-0.13096	52.43865	-0.53772	52.44	0.250609	52.44155	-0.13035	52.4431	0.13
52.4296	-0.20278	52.4311	-0.36218	52.4326	-0.34978	52.4341	-0.06958	52.4356	0.034519	52.43715	-0.21003	52.4387	-0.46939	52.44005	0.3856	52.4416	0.127185	52.44315	0.20
52.42965	-0.40498	52.43115	-0.52473	52.43265	-0.1506	52.43415	-0.19524	52.43565	0.066938	52.4372	-0.28947	52.43875	-0.47722	52.4401	0.359112	52.44165	0.230954	52.4432	0.03
52.4297	-0.1783	52.4312	-0.5781	52.4327	0.014745	52.4342	-0.07274	52.4357	-0.22418	52.43725	-0.44095	52.4388	-0.57431	52.44015	0.19016	52.4417	0.097874	52.44325	-0.3
52.42975	-0.00337	52.43125	-0.26242	52.43275	0.144065	52.43425	-0.04121	52.43575	-0.21883	52.4373	-0.57536	52.43885	-0.49721	52.4402	-0.06294	52.44175	-0.14917	52.4433	-0.
52.4298	0.146271	52.4313	-0.1372	52.4328	-0.07987	52.4343	-0.33152	52.4358	0.12964	52.43735	-0.23638	52.4389	-0.16279	52.44025	-0.20641	52.4418	-0.40945	52.44335	-0.7
52.42985	0.340144	52.43135	-0.08862	52.43285	-0.2713	52.43435	-0.41318	52.43585	0.20245	52.4374	0.146959	52.43895	-0.12996	52.4403	-0.14121	52.44185	-0.54421	52.44565	-0.4
52.4299	-0.11116	52.4314	-0.06193	52.4329	-0.1464	52.4344	-0.37775	52.4359	0.263587	52.43745	0.175879	52.439	-0.10835	52.44035	-0.06912	52.4419	-0.60959	52.4457	-0.3
52.42995	-0.43251	52.43145	-0.08344	52.43295	0.045788	52.43445	-0.28818	52.43595	0.258889	52.4375	-0.04034	52.43905	0.008232	52.4404	-0.11971	52.44195	-0.7538	52.44575	-0.1
52.43	-0.24904	52.4315	-0.05135	52.433	0.15665	52.4345	-0.06398	52.436	0.022882	52.43755	-0.29386	52.4391	-0.17514	52.44045	-0.18332	52.442	-0.85957	52.4458	-0.0
52.43005	-0.43705	52.43155	-0.19063	52.43305	-0.12264	52.43455	0.004567	52.43605	-0.1686	52.4376	-0.32956	52.43915	-0.26648	52.4405	-0.10192	52.44205	-0.63665	52.44585	0.06
52.4301	-0.38253	52.4316	-0.28871	52.4331	-0.30693	52.4346	-0.18475	52.4361	0.213612	52.43765	0.174325	52.4392	-0.15008	52.44055	-0.04831	52.4421	-0.32956	52.4459	-0.0
52.43015	-0.11644	52.43165	-0.09203	52.43315	-0.15919	52.43465	-0.0884	52.43615	0.433178	52.4377	0.420794	52.43925	-0.0277	52.4406	-0.02537	52.44215	-0.02786	52.44595	-0.2

Piezo-electric Accelerometer is one of the best devices to capture vibration signals, since it can capture 20000 sample readings per second which makes it easy for critical analysis of vibration of the device.

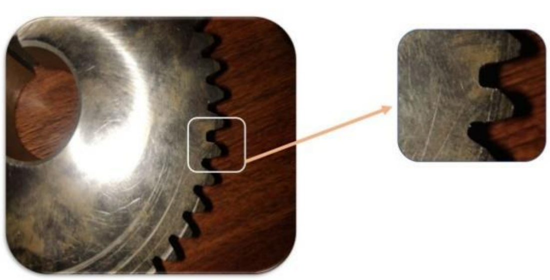

Fig.7 Root Crack Induced through EDM

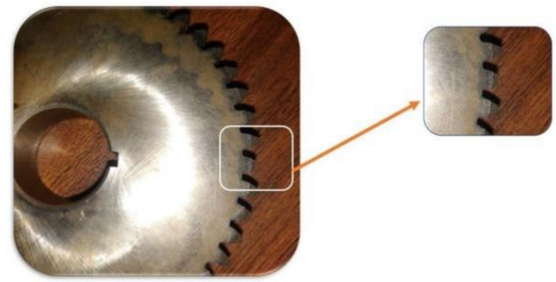

Fig.8 Tooth cut using EDM

After referring to previous year reports and journal papers on vibration analysis the expected results are as follows for tooth cut fault and Similarly analysis can be done for remaining faults and the results can be compared.

5.2 ANALYSED SIGNALS:

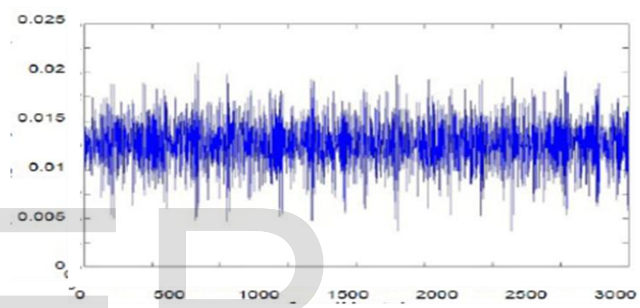

Fig.9 Healthy Gear (0%) tooth removal

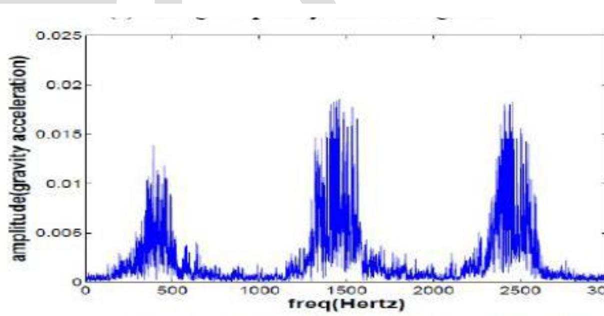

Fig.10 Faulty Gear (25%) tooth removal

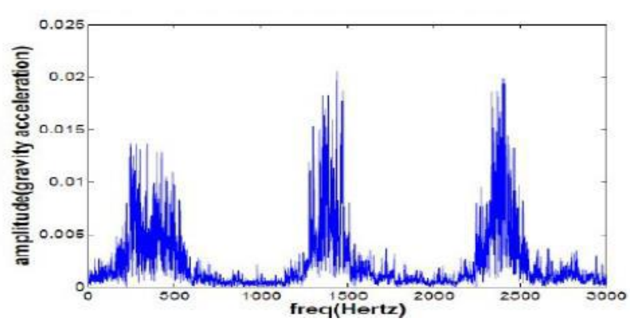

Fig.11 Faulty Gear (50%) tooth removal

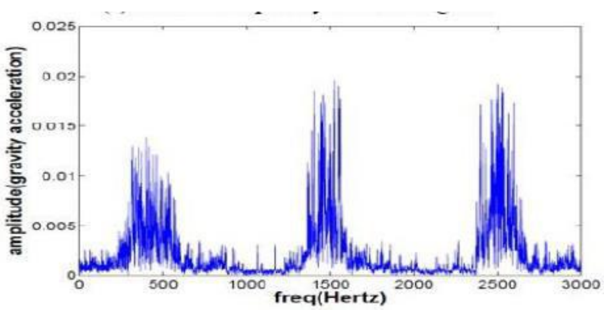

Fig.12 Faulty Gear (75%) tooth removal

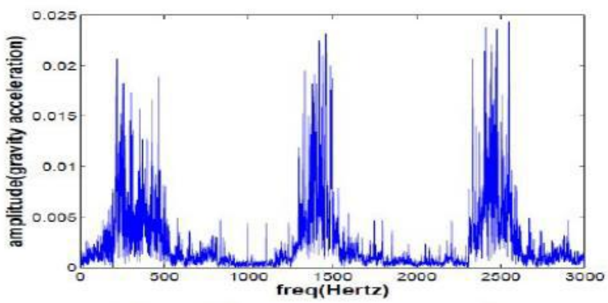

Fig.13 Faulty Gear (100%) tooth removal

After completion of the investigation of tooth cut fault, we can know that with the increase of tooth cut depth, the vibration amplitude of acceleration increases sharply, the value of statistical indictors increases gradually. Especially, for the vibration signal under tooth cut fault, according to the vibration signal of the tooth fault, the cut tooth will result in the large impulse amplitude, and the sideband amplitudes of meshing frequency and its harmonic will be larger than that of healthy gear. Based on the instantaneous energy, the tooth damage will bring about significant energy impacts, which can be regard as the obvious difference between healthy gear and tooth cut gear.

6 CONCLUSIONS

i. The design of the Spur gear box is well balanced so that it doesn't add any additional load on the gears or on any other moving element which isn't required.

ii. The Structural analysis of load bearing parts shows that there won't be any deformation under normal loading condition of the machine.

iii. Considered expected results show that the vibration pattern increases its variation with increase in the damage percentage, which enables us to correctly identify the problem in unknown gear.

iv. This method of incipient fault detection is very easy to implement and detect the faults which reduces the time required in disassembly of breakdown machines.

7 SCOPE FOR FUTURE WORK

i. The experiment can be continued for different faults and different combinations of fault which are mentioned in the above report.

ii. The experiment can be conducted with different viscosities of oil and report them for easy analysis in different machines.

iii. Different type of gear box can be made to analyze all types of gear in the same machine.

8 REFERENCE

1. Vikas Sharma, Anand Parey, "A review of gear fault diagnosis using various condition indicators". Procedia Engineering 144 (2016) 253 – 263
2. M. Er-raoudi, M. Diany, H. Aissaoui and M. Mabrouki, "Gear fault detection using artificial neural networks with discrete wavelet transform and principal component analysis". Journal of Mechanical Engineering and Sciences (JMES), Volume 10, Issue 2, September 2016
3. Azeddine Ratni, Chemseddine Rahmoune, Djamel Benazzouz, "A new method to enhance of fault detection and diagnosis in gearbox systems". Solid Mechanics and Systems Laboratory, September 2016
4. 4) Zuyu Yin, JianHou, "Recent advances on SVM based fault diagnosis and process monitoring in complicated industrial processes". Elsevier, September 2015
5. 5) Birahima Gueye, Yimin Shao, and Zaigang Chen, "Prediction of Gear tooth crack propagation path based on pseudo evolutionary structural optimization". International journal of COMADEM Vol 20 No 1 (January 2017) 29-34
6. 6) J. Kattelus, J. Miettinen, A. Lehtovaara, "Detection of gear pitting failure progression with on-line particle monitoring". Tribology International (Elsevier) 2016
7. 7) Yang Luo, Natalie Baddour, Ming Liang, "performance assessment of gear condition indicators in detecting progressive gear tooth crack". Computers and Information in Engineering Conference, IDETC/CIE 2017 August 6-9
8. 8) S. Kushwah & R. B. Sharma, "the wear condition of spur gearbox under variable loads using wear debris analysis technique – an investigation". International Journal of Automobile Engineering Research and Development (IJAuERD), Vol. 7, Issue 2, Aug 2017, 1-8
9. 9) Ruiliang Zhang, Xi Gu, Fengshou Gu, Tie Wang and Andrew D. Ball. "Gear Wear Process Monitoring Using a Sideband Estimator Based on Modulation Signal Bispectrum". 10 March 2017
10. 10) René-Vinicio Sánchez, Pablo Lucero, Rafael E. Vásquez, Mariela Cerrada, Diego Cabrera, "A comparative feature analysis for gear pitting level classification by using acoustic emission, vibration and current signals". ScienceDirect, 51-24 (2018) 346-352
11. 11) Sanjay Kumar, Deepam Goyal, Rajeev K. Dang, Sukhdeep S. Dhami, B.S. Pabla, "Condition based maintenance of bearings and gears for fault detection". ScienceDirect, Materials Today: Proceedings 5 (2018) 6128–6137
12. 12) S. M. Hutt, A. Clarke, R. Pullin, and H. P. Evans, "Characterising the Acoustic Emission from a Simulated Gear Contact in Mixed Lubrication Conditions". Springer Nature Switzerland AG 2019, ACM 15, pp. 400–408
13. 13) Yuan Chen · Rupeng Zhu · Guanghu Jin · Yeping Xiong, "Influence of Crack Depth on Dynamic Characteristics of Spur Gear System". Journal of Vibration Engineering & Technologies (2019) 7:227–233
14. 14) Xu Li, Kangkang Chen, Yifan Huangfu, Hui Ma, Baishun Zhao and Kun Yu, "Vibration characteristic analysis of spur gear systems under tooth crack or fracture". Journal of Low Frequency Noise, Vibration and Active Control 0(0) 1 –19 (2019)
15. 15) Yang Luo, Natalie Baddour, Ming Liang, "dynamical modelling and experimental validation for tooth pitting and spalling in spur gears". mechanical systems and signal processing, (Elsevier), Mechanical Systems and Signal Processing 119 (2019) 155–18