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Experimental Setup for Gear Fault Diagnosis using Machine Learning

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Abstract –There are various types of defects occur in the gear such as scoring, face wear, tooth breakage, pitting, root crack etc. Early detection of such defects is very crucial to prevent the system from sudden breakdown. Fault diagnosis is a process used for preventing breakdown. For such a fault diagnosis. we are analysing vibrations of gears. Scope of this work is to take the vibration signals for various faulty gears along with healthy gears. To classify the defects in spur gear first we need dataset for study. This paper provides the information of experimental setup to generate the dataset of vibration signals of faulty gears and healthy gear. In addition, this paper provides the details of fault generation in spur gear.

Key Words: Spur Gear, Fault Diagnosis, Dataset, Vibration Signal, Tooth Breakage, Face Wear, Machine Learning.

1.INTRODUCTION

Defects in machinery are often reduced productivity and increases the maintenance costs in different industrial applications. Because of this machine condition monitoring is used. Industry needs that their machinery should run continuously, unexpected breakdown due to rotating machinery will generate huge loss in terms of cost. Faults produces in machinery are due to defects in gearboxes due to gear failures. Fault diagnosis is one of the processes in preventive maintenance of gearbox. Early detection is important to prevent the system from breakdown that may damage the whole system. Fault diagnosis improves reliability, economy and safety.

Gears are important components of machines. The fault diagnosis techniques used for gears are as follows:

1. Acoustic emission
2. Wear debris analysis
3. Vibration analysis

1. Acoustic Emission: The phenomenon of elastic wave generation in materials under stress is termed as acoustic emission. Acoustic emission generates due to plastic deformation of cracks. Acoustic emission can detect the growth of subsurface cracks. It requires proper signal processing systems.

2. Wear debris analysis: Wear debris analysis: Component wear particles are studies in the lubricant to determine the condition of the machine parts. It is less costly than other techniques. This doesn't give much information about diagnosis. Abnormal gear is detected by the how much amount of wear is present in the lubricant.

3. Vibration Analysis: Vibration analysis: Every machine generates the vibration while working. By studying this vibration one can diagnose the machine condition. Defects in gears produces an increase in vibrations. These vibrations can be used to detects the type of defect present in the system.

Various types of defects occur in the gear such as scoring, face wear, tooth breakage, pitting, root crack etc. Fault diagnosis is done by studying the vibrations of gears. One can predict the machine failure with vibration analysis. When condition monitoring is applied and the machines are checked regularly, machine faults can be discovered at an early stage and appropriate action can be taken. Focus of this work is on good gear wheel, gear with tooth breakage and gear with pitting failure.

Machine learning is used for analyzing this signal and classify this signal into different types of faults. Machine learning is a subset of artificial intelligence. It focuses on the designing of systems, thereby allowing them to learn and make predictions based on some experience which is data in case of machine learning. Machine learning has three phases feature extraction, feature selection and feature classification.

Feature extraction: Feature extraction are the specific measures which characterizes the signal. Vibration signals will be taken from the spur gear setup at various conditions and various features will be extracted from the signals. These signals will be input to classifier.

Feature selection: Not all of features selected will be useful. It is necessary to eliminate unwanted feature and use the features which help in the process of classification. The process of selecting the good features is called feature selection.

Feature Classification: It is a pattern recognition technique; it is used to categorize a large amount of data into different classes.

Related Work

Saravanan. N [1] in their study they used 4 pinion wheels with various faults. Gear box are considered having various lubrication condition. In their study they considered 18 different conditions of the gearbox so that real life problem can be simulated well. The various faults of pinion wheel, level of lubrication and load on the gear box contribute to the various conditions of the gear box under investigation. They used piezoelectric accelerometer for vibration measurement and it is mounted on the gear and taken signals for various condition of the gear box. They used sampling frequency of 20000 Hz. They have considered sample of length 8192 long enough to ensure data consistency. K.N. Ravikumar et al. [2] in their study they Tested four stroke IC engine gearbox which is fitted with an eddy current dynamometer. To avoid undesirable excitation setup is supported with base frame. Tests were conducted on the driver gear. The different conditions of the gearbox such as healthy, 25% tooth defect, 50% tooth defect, 75% tooth defect and 100% tooth defects were considered for study. First experiments were conducted on healthy gear and then it was replaced with different defective gears. Tri-axial accelerometer is mounted on the casing of gearbox and it was used for getting the vibration signals. DAQ-9234 Data acquisition system is used. Sampling rate of 25.6 kHz was used to store data. LabVIEW software was used for stored the signal in PC system. Experiment is conducted in three different loading condition. Discrete wavelet transform features are extracted from the vibration signals and more contributing features for classification are selected using decision tree algorithm. k-nearest neighbour algorithm, K-star algorithm and locally weighted learning algorithm are used for classification. Anil Kumar et al. [3] discussed how to develop methods to identify defects in gears. They talked about various defects occur in gears. In their study latest and most widely used diagnosis methods for gearbox condition monitoring were discussed. The challenges faced in the area of gear defect diagnosis and different diagnostic methods were provided.

V.Gunasegarana and V.Muralidharana [4] studied pinion gear with 40 tooth and spur gear with 100 tooth. spring loading setup provided to apply the load. Lovelock coupling was used to avoid the initial jerk. An accelerometer was mounted on the pillow block. Other end of sensor cable was connected with NI DAQ. LABVIEW and MATLAB software were used for storing the signals. Digital data was stored in the PC. In their study, normal and broken tooths are run at 1440 rpm. Readings are taken at following different conditions: Good with load (GWL) as simulated normal condition, Good without load (GWOL) as simulated normal condition, Tooth broken with load (BWL) as broken 50% of tooth height, Tooth broken without load (BWOL). This study was conducted for approximately 50% damage because the signal pattern on time domain of each fault condition can describe the characteristics of vibration signature. The vibration signals were acquired from an accelerometer with help of MATLAB program. In this study, National Instruments (NI) DAQ card high resolution device, 24-bit, PXI 4462, was used to acquire vibration signals. 100 kHz of sampling frequency is used for string the data.

P. Cao et al. [5] In their research, experimental data are collected from two-stage gearbox with replaceable gears. The speed of gear was controlled by a motor. Magnetic brake is applied for giving torque. A pinion of 32-tooth and a gear of 80-tooth are installed on the first stage input shaft. 48-tooth pinion and 64-tooth gear installed on the second stage. Tachometer is used to measure the input shaft speed. Accelerometer is used for measure the gear vibration signals. The signals were recorded through a dSPACE system (DS1006 processor board, dSPACE Inc.). 20 KHz of sampling frequency is used for storing the data. nine different gear conditions were used on the input shaft. These conditions are healthy condition, missing tooth, root crack, spalling, and chipping tip with five different levels of severity. Ying Tao et al. [6] In his study, experiments were carried out on the gear box fault diagnosis test bench. The coupling connects the motor the input shaft of the gearbox. The output shaft of the gearbox is connected to electromagnetic torque circuit breaker. Torque is manually control by controller. Accelerometer (Specification: PCB ICP 353C03) is used for collecting the vibration. And by using data acquisition box (Specification: DAQ, NI cDAQ-9234) it was stored in computer. Spur gears of tooth 53 and 80 were installed on the gearbox. Nine different failure modes considered with a healthy gear. 30V of load condition is considered in the experiment. Sampling frequency is 50 kHz. Fault conditions consists of 5000 sample points. 4500 of sample points are considered for study. The sample is split into two datasets. 3000 samples for training purpose for testing 1500 samples.

Akhand Rai and S.H. Upadhyay [7] in their work they discuss the effectiveness of diagnosis and prognosis largely depend upon the quality of features extracted from the bearing signals. They explain some of the condition monitoring tools used for rolling element bearing and discusses the various signal processing methods in diagnosis and prognosis. B. Samanta [8] in their study he used data in which vibration signals measured from seven accelerometers on a pump driven by an electrical motor through a two-stage gear reduction unit were presented. The first two were radially mounted near to driving shaft, third accelerometer was used to measure the axial vibration near the driving shaft. Remaining accelerometers were radially mounted on the machine casing. Readings were taken for two different machines, one with pitting failure in both gears other with no faults. Number of samples collected was 77824 for each channel.

2. DEFECTS GENERATION IN GEAR

There are commonly two defects occur in the industry.

1. Pitting failure – This is common tooth surface damage. Pitting occurs due to repeated loading. When contact stress exceeds the surface fatigue strength of the material such a failure occurs. This pitting failure gradually increases and spreads over the surface. This failure depends on the surface contact stress and number of stress cycle. Initially this occurs on localized stressed areas. Load is redistributed by removing the material from high contact stress. This type of failure occurs because of not having good contact. Imperfect contact occurs due to local surface irregularities or because of minor involute errors. This type of failure can be avoided by giving smooth gear tooth surfaces.

This defect is generated by using file and center punch. File is used for removing the material from face of the gear. Indentation is made on the gear using center punch as shown in the figure 1. This indentation will behave like pitting failure defect.

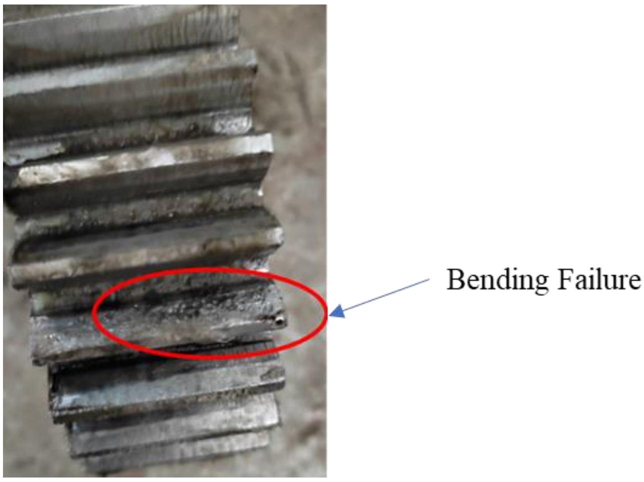

Fig-1: Pitting failure defect

2. Bending failure – This failure caused by breakage of whole teeth or partial portion of a tooth. This type of failure may occur at mobile gearbox such as rotation of boogie of a poclain because of heavy weight taken in poclain hand and due to rotating on inclined portion. In this type of failure crack originates in the root section of the gear. This type failure occurs due to overloading. To avoid such a failure gear should be designed properly so that stresses generated will not be more than endurance limit of the material. Also root fillets should be well polished.

This defect is generated by using milling machine by cutting the half of tooth as shown in figure 2.

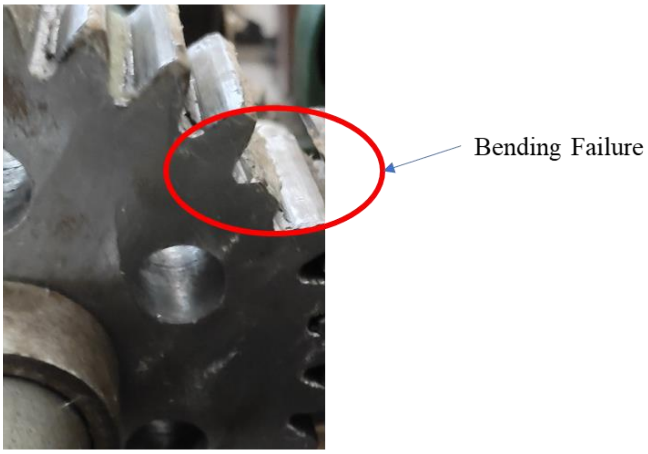

Fig-2: Bending failure defect

3. MOUNTING

In many condition monitoring setup, mounting location of accelerometer is very important. There are different methods for mounting such as glue mounting, bolt mounting, magnetic mounting etc. In this study magnetic mounting is used as shown in figure 3. This accelerometer has inbuilt magnetic mounting provision. Accelerometer in horizontal plane detects better vibration signals than vertical plane, hence sensor is mounted in horizontal plane. There is more stiffness of the system in vertical direction as compared to horizontal direction because of vertical bolts.

Fig-3: Mounting of accelerometer

4. DATA ACQUISION SYSTEM

Data acquisition system (DAS) is the process of storing signals which measure physical thing and converting it into a digital form which can be stored into computer. A data acquisition system is a collection of hardware and software. It measures or control the physical characteristics in the real world. Complete data acquisition system consists of DAQ hardware, signal conditioning hardware, sensors and actuators, and computer which can run DAQ software. Data acquisition systems consist of four essential components. These are as follows:

1. Sensors

Fig-4: Accelerometer

Sensor Specification
Sensitivity of the sensor = 100 mV/g

Sensors are used to measure physical phenomenon such as vibration, temperature etc. A sensor can also be called as transducer. Sensor converts a physical input into electrical signal. In this paper the sensor used is accelerometer. Sensor as shown in figure 4 is used to measure the vibration signals.

2. Signal Conditioning

Main purpose of signal conditioning is to conditioning signals so that they can be converted into the digital signal by the Analog to Digital subsystem and it can be stored and analyzed. Signal conditioning includes range matching, amplification, filtering, converting, isolation. It includes other processes which can make the data suitable after conditioning.

3. Analog to Digital Converter

Output of the most of physical phenomenon after signal condition is in analog form. It is converted to digital form by Analog to Digital converter system.

DEWE 43 V as shown in figure 5 consists of both signal conditioning and A/D converter. The specifications of DEWE 43 V are given in table 1

Fig-5: DEWE 43 V

No of channels	8
Inputs	Voltage
Power Supply	9-36 V DC
IP rating	IP50
Sensor supply	+5 V, +12 V
Sampling rate	Simultaneous 200 kS/sec
ADC type	24-bit sigma-delta with anti-aliasing filter
Input type	Differential

Table-1: Specification of DEWE 43 V

4. Computer with DAS software

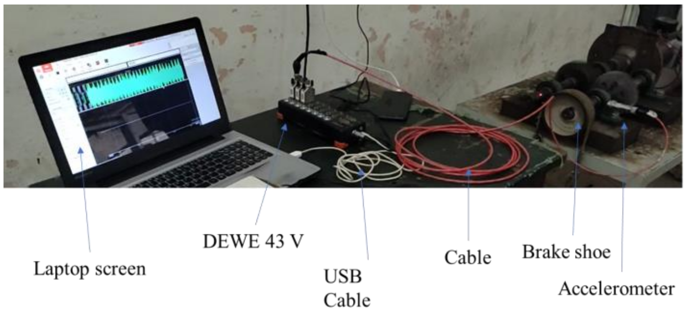

Fig-6: Experimental setup

Accelerometer is used for detecting the vibration signals. accelerometer is connected to DEWESOFT system using cable as shown in figure 7. Signal from accelerometer is processed using signal conditioning unit and then it is acquired using computer. DewesoftX software is used for viewing and storing the signals as shown in figure 6. These signals are then exported to excel sheet using DewesoftX software.

Fig-7: Cable

In data acquisition system power is supply to DEWE 43 V system. Accelerometer is connected to DEWE 43 V using cable. This DEWE 43 V is then connected to computer using USB cable. Block diagram of the setup is as shown in figure 8.

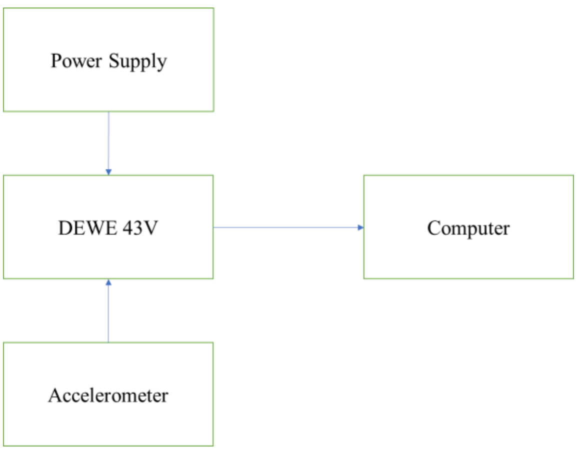

Fig-8: Block diagram of data acquisition system

5. EXPERIMENTAL STUDY

3 gear wheels are used for experimental study. Lubrication is provided with grease. Piezoelectric accelerometer is mounted on the bearing in horizontal plane. There is low signal to noise ratio on bearing hence bearing is considered for mounting the sensor. Vibration signals are taken for various loads like 0.5 kg, 1 kg, 1.5 kg, 2 kg, 2.5 kg. Load is given by brake shoe as shown in figure 10.

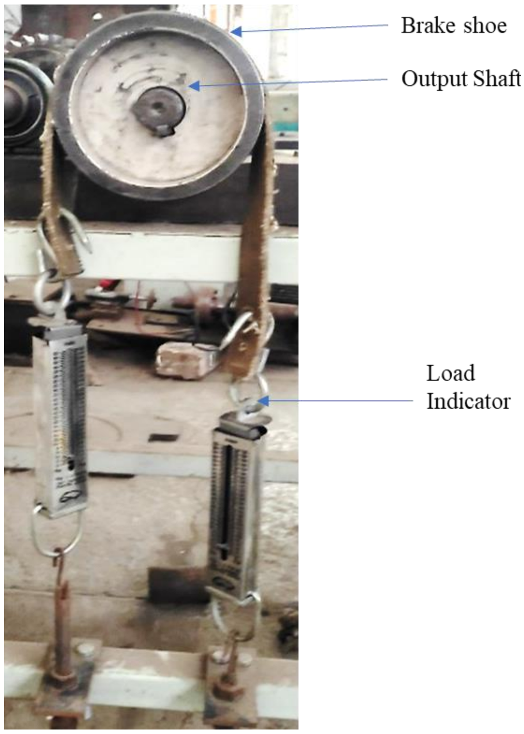

Fig-10: Brake shoe

A sampling frequency of 20000 Hz is taken for all condition. All reading were taken for at least 10 sec so that sufficiently large data will be acquired for study. Two external spur gears of following specification were in contact. Tachometer is used to measure the speed. Three conditions were studied in the experiment and they are healthy condition, bending failure, pitting failure. Firstly, two healthy gears were in mesh and vibration signals taken for different loads as shown figure 9.

Specification	**Dimensions**
No of tooth on pinion	30
No of tooth on gear	30
Module	4 mm
Face width	40 mm
Shaft diameter	30 mm
Center Distance between two shafts	12 mm
Material	EN8 Steel

Table-2: Dimensions of the setup

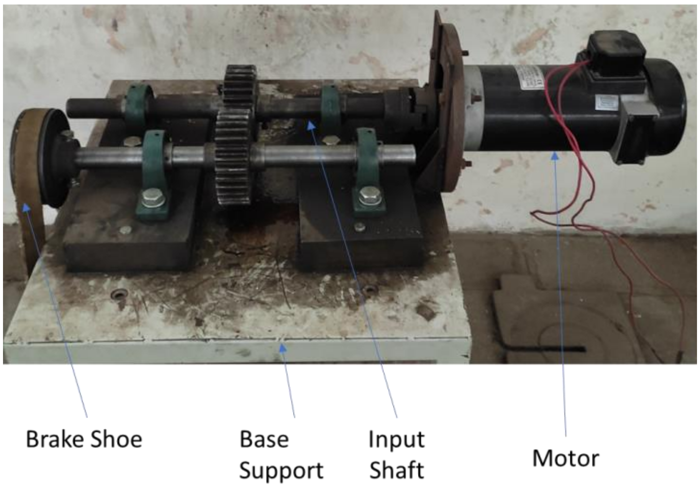

Fig-9: Gear assembly setup

Dimensions of the assembly are given in table 2. Dataset for healthy gear is stored. Then one healthy gear is replaced by one faulty gear. Such readings are taken for all three conditions. Motor is used to give drive to input shaft. Brake shoe is mounted on output shaft. Graphs of obtained dataset for healthy, gear with bending failure and gear with pitting failure are shown in figure 11, figure 12 and figure 13 respectively.

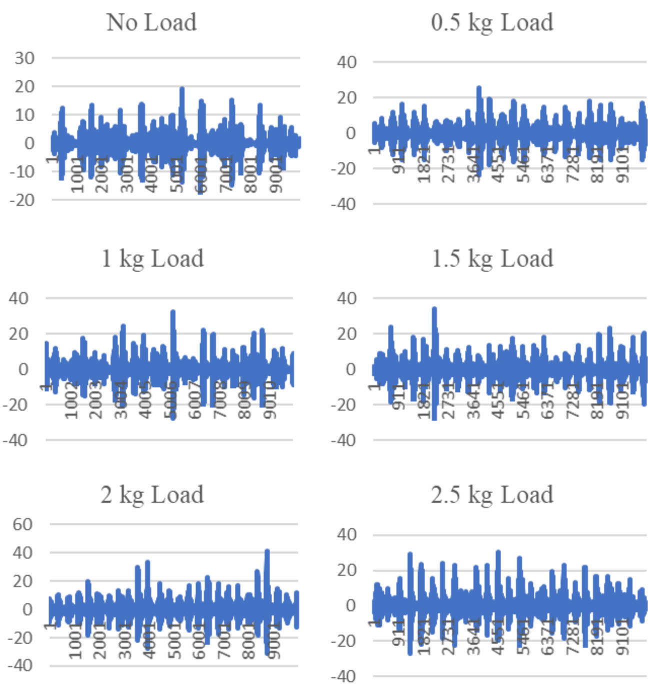

Fig-11: Vibration Signal for Healthy Gear under different loading conditions

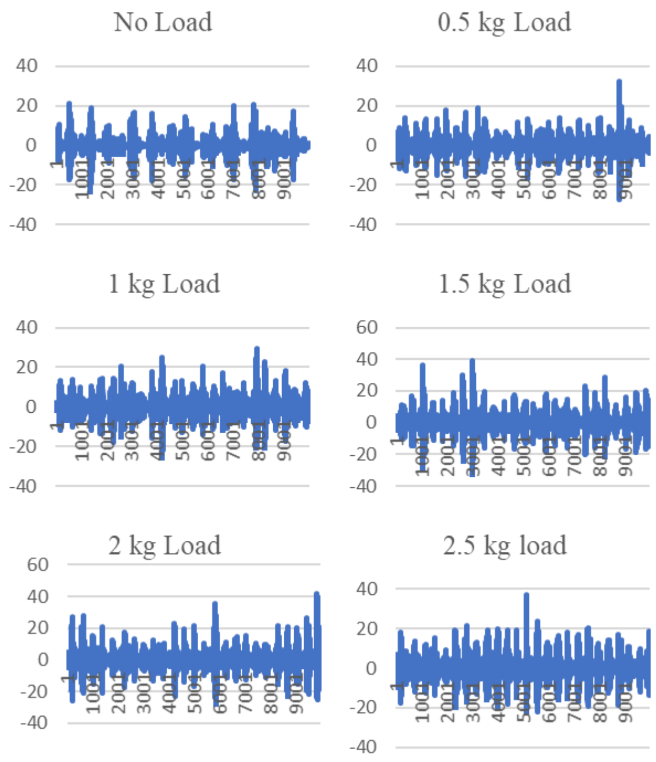

Fig-12: Vibration Signal for Gear with Bending Failure under different loading conditions

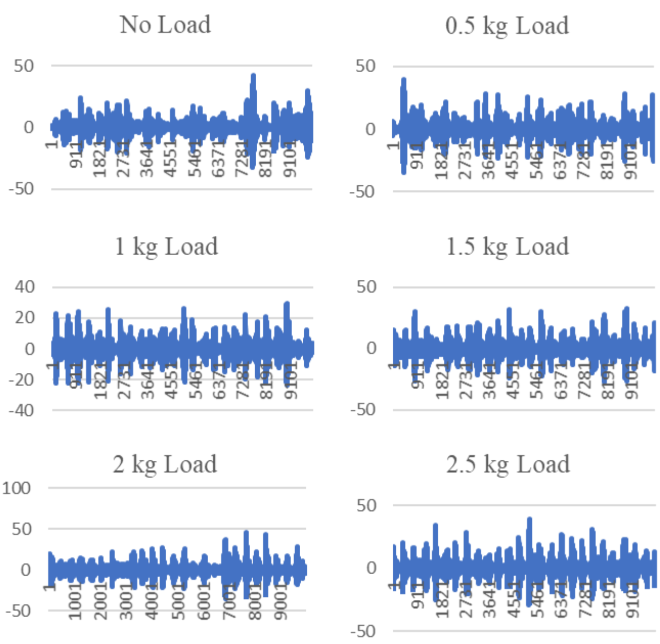

Fig-13: Vibration Signal for Gear with Pitting Failure under different loading conditions

6. CONCLUSIONS

The experiment was conducted to understand the various conditions of the gear such as healthy gear, failure due to bending that is tooth breakage and failure due to pitting. The gear assembly setup was run at different loads and the vibration signals for different conditions of gears were acquired using the

DEWESOFT data acquisition setup. Using this experiment dataset for healthy gear, gear with bending failure and gear with pitting is successfully stored in computer.

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