Detection of Bearing Faults of Induction Motor Using Park's Vector Approach

Neelam Mehala [#1], Ratna Dahiya [*2]

[1#] *Department of Electronics and Communication Engineering*
YMCA University of Science and Technology,
Faridabad-121006(Haryana) INDIA

[2*] *Department of Electrical Engineering*
National Institute of Technology
Kurukshetra-136119 (Haryana) INDIA

***Abstract*—The reliability of an induction motor is of paramount importance in industrial, commercial, aerospace and military applications. Bearing play an important role in the reliability and performance of all motor systems. Due to close relationship between motor system development and bearing assembly performance, it is difficult to imagine the progress of modern rotating machinery without consideration of the wide application of bearing. Most faults arising in motors are often linked to bearing faults. This paper presents an experimental study to diagnose the bearing fault with help of Park's vector approach. The experiment is conducted on 0.5 hp three phase induction motor. The bearing faults are replicated in the laboratory by drilling the outer and inner race of ball bearing with help of electric discharge machining. The LabVIEW software is used in the experiment to acquire the signal. The acquired signal is analyzed with Park vector approach. The current Park's vector presentation is generated by programming in LabVIEW. The practical results show that Park's Vector approach is an effective technique to diagnose the bearing fault at early stage.**

I. INTRODUCTION

Bearings are common elements of electrical machine. They are employed to permit rotary motion of the shafts. Though modern manufacturing has increased the reliability of bearings, bearings are subject to fail. In fact, bearings are single largest cause of machine failures. According to some statistical data, bearing fault account for over 41% of all motor failures [1]. Bearing consists of two rings called the inner and the outer rings. A set of balls or rolling elements placed in raceways rotate inside these rings. A continued stress on the bearings causes fatigue failures, usually at the inner or outer races of the bearings. Small pieces break loose from the bearing, called flaking or spalling. These failures result in rough running of the bearings that generates detectable vibrations and increased noise levels. This process is helped by other external sources, including contamination, corrosion, improper lubrication, improper installation, and brinelling. The shaft voltages and currents are also sources for bearing failures. These shaft voltages and currents result from flux disturbances such as rotor eccentricities [2]. High bearing temperature is another reason for bearing failure. Bearing temperature should not exceed certain levels at rated condition. For example, in the petroleum and chemical industry, the IEEE 841 standard specifies that the stabilized bearing temperature rise at rated load should not exceed 45 degree. The bearing temperature rise can be caused by degradation of the grease or the bearing. The factors that can cause the bearing temperature rise include winding temperature rise, motor operating speed, temperature distribution within motor, etc. Therefore, the bearing temperature measurement can provide useful information about the machine health and bearing health [3, 4].

Bearing faults can be diagnosed with help of many condition monitoring methods such as vibration monitoring, temperature monitoring, chemical monitoring, acoustic emission monitoring, current monitoring, etc [5]. Except for current monitoring, all these monitoring methods require expensive sensors or specialized tools and are usually intrusive. The Park's vector approach falls under electric monitoring. The proposed method allows continuous real time tracking of bearing fault of induction motors operating under continuous stationary conditions. This method recognizes the fault signatures produced in induction motor and estimate the severity of the faults. In present experimental study, the effects of bearing faults on motor current spectra of an induction motor are investigated using Park's vector approach. This method is based on the visualization of the motor current Park's vector representation. If this is a perfect circle the machine can be considered as healthy. If an elliptical pattern is observed for this representation, the machine is faulty.

II. PARK'S VECTOR APPROACH

In three phase induction motors, the connection to the mains does not usually use the neutral. Therefore, the main current has no homopolar component. A two dimensional representation can then be used for describing three phase induction motor phenomena, a suitable one being based on the current Park's vector [6].

As a function of mains phase variable (i_a, i_b, i_c) the current Park's vector components (i_d, i_q) are [7]-[10]:

$$i_d = \sqrt{\frac{2}{3}} i_a - \frac{1}{\sqrt{6}} i_b - \frac{1}{\sqrt{6}} i_c \quad .....(1)$$

$$i_q = \frac{1}{\sqrt{2}} i_b - \frac{1}{\sqrt{2}} i_c \quad ....(2)$$

Under ideal conditions, three phase currents lead to a Park's vector with the following components:

$$i_d = \frac{\sqrt{6}}{2} I \sin \omega t \quad ....(3)$$

$$i_q = \frac{\sqrt{6}}{2} I \sin\left(\omega t - \frac{\pi}{2}\right) \quad .....(4)$$

where

I = maximum value of the supply phase current

ω_s =supply frequency

t =time variable

Its representation is a circular pattern centered at the origin of the coordinators as illustrated by figure 1. This is very simple reference figure that allows the detection of abnormal conditions by monitoring the deviations of acquired patterns.

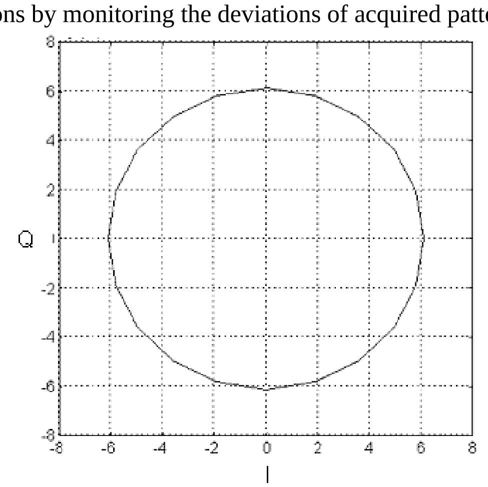

Figure 1: Current Park's vector for ideal condition.

III. EXPERIMENTAL SET UP

In order to diagnose the fault of induction motor with high accuracy, a modern laboratory test bench was set up as shown in figure 2. It consists of an electrical machine coupled with rope brake dynamometer, transformer, NI data acquisition card PCI-6251, data acquisition board ELVIS and Pentium-IV Personnel Computer with software Lab VIEW 8.2. The rated data of the tested three-phase squirrel cage induction machine were: 0.5 hp, 415V, 1.05 A and 1380(FL) r/min. LabVIEW 8.2 software is used to analyse the signals. It is easy to take any measurement with NI LabVIEW. We can automate measurements from several devices and analyze data spontaneously with this software. Data acquisition card PCI-6251 and acquisition board ELVIS are used to acquire the current samples from the motor. NI M Series high-speed multifunction data acquisition (DAQ) device can measure the signal with superior accuracy at fast sampling rates.

Figure 2: Experimental set up

This device has NI-MCal calibration technology for improved measurement accuracy and six DMA channels for high-speed data throughput. It has an onboard NI-PGIA2 amplifier designed for fast settling times at high scanning rates, ensuring 16-bit accuracy even when measuring all channels at maximum speeds. This device has a minimum of 16 analog inputs, 24 digital I/O lines, seven programmable input ranges, analog and digital triggering and two counter/timers. The specifications of this DAQ card are shown in Table I.

TABLE I
SPECIFICATION OF DATA ACQUISITION CARD NI-PCI 6251

Sr. no.	Specification	
1	Analog Inputs	16
2	AI Resolution (bits)	16
3	Analog Outputs	2
4	AO Resolution	16
5	Max Update Rate (MS/s)	2.8
6	AO Range (V)	±10, ±5, ±ext ref
7	Digital I/O	24
8	Correlated (clocked) DIO	8, up to 10 MHz

The NI ELVIS integrates 12 of the most commonly used instruments – including the oscilloscope, DMM, function generator, and Bode analyzer – into a compact form factor ideal for the hardware lab. Based on NI LabVIEW graphical system design software, NI ELVIS offers the flexibility of virtual instrumentation and allows for quick and easy measurement acquisition and display. The speed of the motor is measured by digital tachometer. The virtual instrument (VIs) was built up with programming in LabVIEW 8.2. This VIs was used both for controlling the test measurements and data acquisition, and for the data processing. In order to test the system in practical cases, several measurements were made to read the stator current of a motor.

IV. System Representation Using LabVIEW Programming

The purpose of experimental set up is to measure the induction motor stator current and to analyse these data determining the fault frequencies on the bearing. The currents that flow in the three phases of induction motor are sensed by transformer. Transformer decreased the voltage to 5-10V. This voltage is supplied to National instrument Data acquisition card. Data acquisition card is connected to PCI slot of Pentium IV personnel computer. The digitalized current signal is applied to the low pass current filter to remove the undesirable high frequency components. The 'LabVIEW programme' converts the sampled signal to the Park's vector representation. The current Park's vector representation is generated using advanced signal processing module of LabVIEW 8.2 software. LabVIEW programming for Park Vector Approach is shown in figure 3.

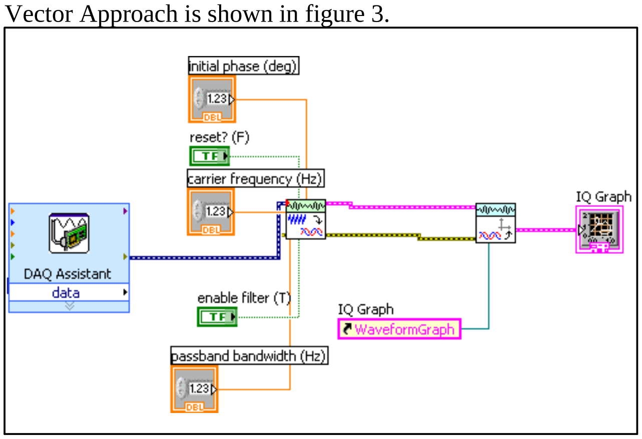

Figure 3: LabVIEW programming for Park Vector Approach

TABLE III
PARAMETERS OF EXPERIMENTAL INDUCTION MOTOR

Parameters	**Data**
Power	0.5 hp
Frequency	50 Hz
Number of phases	3
Speed	1380 r.p.m
Volt	415 V
Current	1.05 Amp
No. of pole pairs	2
Air gap length	2 mm
Number of rotor slots	36
Efficiency(FL)	86%

In this study, 0.5 hp four pole induction motor was used whose parameters are given in Table II. The motor is attached with a rope brake dynamometer. The nominal current is 1.05 A when star connected to 415 V. The bearing of the induction motor are single row, deep groove ball bearing, type 6202.2Z. Each bearing has eight balls. Experiments were conducted on four bearings: two of these are undamaged while two bearing were damaged. One bearing was made fail by drilling the hole in its outer race while another bearing was made fail by drilling the hole in its inner race. Electric Discharge Machine is used to drill the hole in inner and outer race. The damaged bearings were installed on motor one by one. Figure 4 show the inner race and outer race faults which were replicated in laboratory.

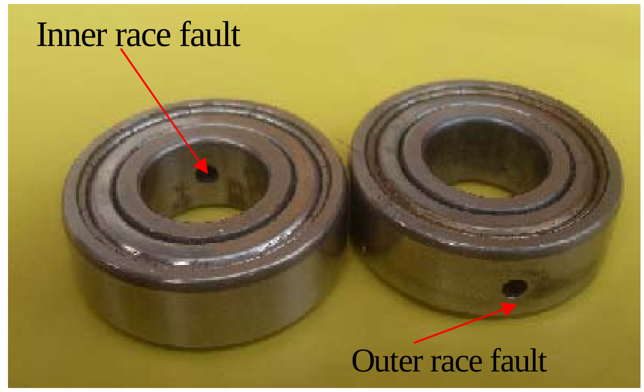

Figure 4: Inner race fault and outer race faults of bearing

V. Experimental Observation and Discussion

The park's vector approach is a relatively effective technique which has been successfully applied in the steady state diagnosis of bearing faults. The analysis of the three-phase induction motor can be simplified using the Park transformation. The method is based on the visualization of the motor current Park's vector representation. If this is a perfect circle the machine can be considered as healthy. If an elliptical pattern is observed for this representation, the machine is faulty. From the characteristics of the ellipse the fault's type can be established. The induction motor was initially tested with undamaged bearings in order to plot Park pattern. Afterwards, it was tested with the two different artificial deteriorated bearings. One bearing is made to fail in experiments by drilling the hole in outer race while other is to made fail by drilling the hole of same size in inner race. The test rig shown in figure 2 is used for this experiment. A time window of 175ms was used for all data acquisition in order to get simple and sufficient detailed pattern. The sample rate was 2000 sample/second. The number of samples was taken 350. The figure 3 shows the LabVIEW programming for Park's Vector approach. Figure 5 show the current pattern for motor with healthy bearing. Like wise, figures 6 and 7 show current pattern for inner race fault and outer race fault respectively. It could be seen that current pattern for faulty motor is clearly different from current pattern of the healthy motor. The shape of the current's phasor in figure 6 and figure 7 is not of perfect circular shape, which indicates bearing fault in the squirrel cage induction machine. This clearly shows the diagnosis capability of the Park's Vector approach.

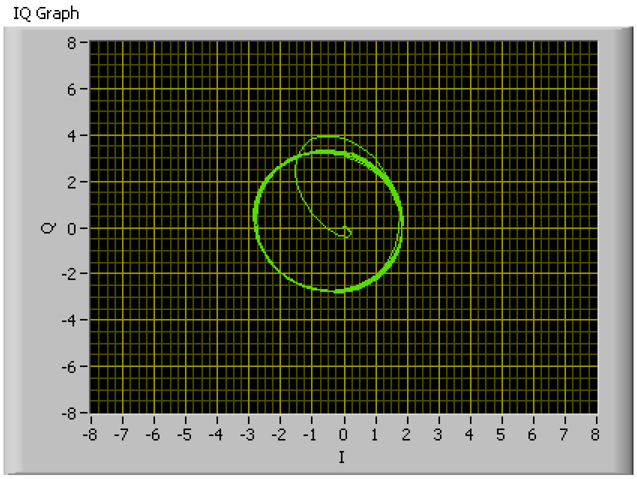

Figure 5: Current park' vector pattern for a healthy motor

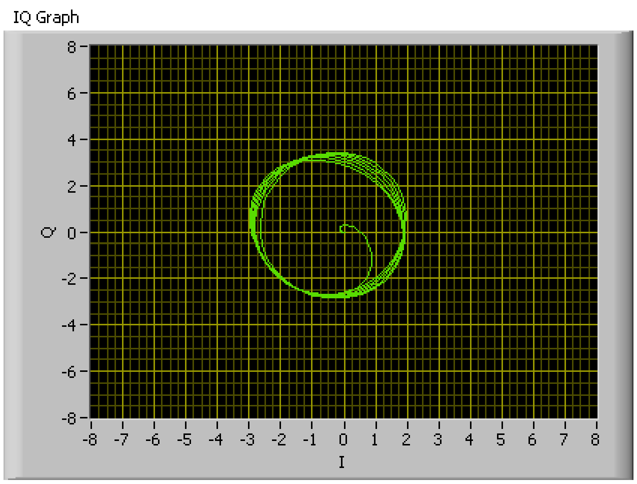

Figure 6: Current Park vector's pattern for faulty bearing with inner race fault

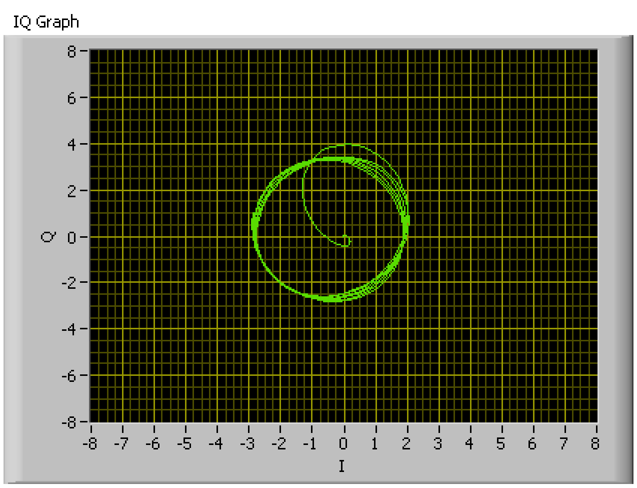

Figure 7: Current Park vector's pattern for faulty bearing with outer race fault

VI. Conclusion

Condition monitoring and diagnosis are very important issues in electrical machine protection, because they can greatly improve the reliability, availability and maintainability in a wide range of applications. This paper presented Park's vector approach for detection of bearing faults of induction motor. The results of experiment show that Park's vector approach can be successfully used for diagnosis of bearing failure. The bearing fault can be clearly observed by comparing the shape of current pattern of faulty and healthy motor. Based on this approach, different patterns may be obtained for different faults. In further works the above-described method may be extended also to diagnose the other faults of induction motor.

Acknowledgment

The authors wish to acknowledge Mr. Satpal, Sr. Instructor, General Electric Workshop and Mr. Suresh Kumar, Instructors, RAC Workshop, YMCA University of Science and Technology, Faridabad (Haryana) who were always available and helped us to perform laboratory experiments.

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