Fault Detection In compressor Using FFT Algorithm

Vittaya Tipsuwanporn, Mongkol Leawsoong, Arjin Numsomran, and Chanwit Wongratanapornkul

***Abstract*—This paper proposes a study of compressor current signal analysis using Fast Fourier Transform (FFT) algorithm for fault detection of balance weights in the three-phase compressor. The experimentations are implemented in a 5-Hp, 3-phase, 200-Volt rotary compressor with incorrectness of internal balance weights to the specification. The experimental results show the variation of the fault indication signal while the compressor is operated under the incorrect balance weight conditions. Finally the paper shows the relationship between mass of the balance weights, center of mass of internal part of compressor compare with the amplitude of compressor current in frequency domain and simulation result confirm the effectiveness of the purpose methodology.**

***Index Terms*— BLDC, MCSA,FFT,CM,BW**

I. Introduction

Compressor is a mechanical device used to increase gas pressure by reducing its volume. The compressor has two main parts: 1) mechanical parts consist of balance weights for balancing internal forces and moments, crank shaft, cylinders for compressing the gas, and compressor frame. And 2) electrical part consists of motor for driving the mechanical parts [1], [2]. This research considers techniques to detect the balance weights in the compressor as shown in Fig. 1, by mean of Motor Current Signature Analysis (MCSA). Such MCSA is an online analysis to detect the fault of stator current [3]. The result are presents the sideband harmonics as in Fig. 2 .Another, The MCSA can be detected many abnormal that occur in the motor such as bearing fault , rotor eccentricities, fan broken and lubrication loss [1]-[5]. For completeness, the sideband harmonics can be expressed as

$$f_{de} = f_e \pm k\frac{f_e}{p/2} \tag{1}$$

Manuscript received July 20, 2013 .

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f_e = fundamental frequency(Hz), p = pole motor.

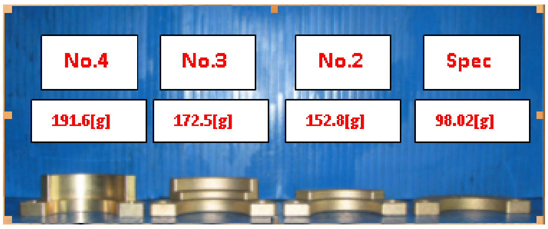

Fig.1 Balance weight of the compressor.

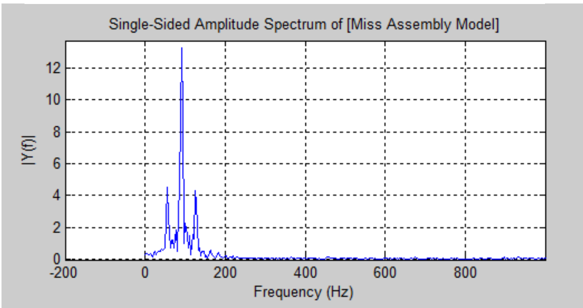

Fig. 2 Current waveform in frequency domain of compressor's malfunction.

Where k is 1^{st}, 2^{nd}, 3^{rd}, … harmonics order. When the amplitude of these harmonics are lower than the amplitude of the fundamental harmonic limits, the compressor is considered to be healthy as shown in Fig. 3, otherwise the fault conditions can be assumed. [7]-[10].

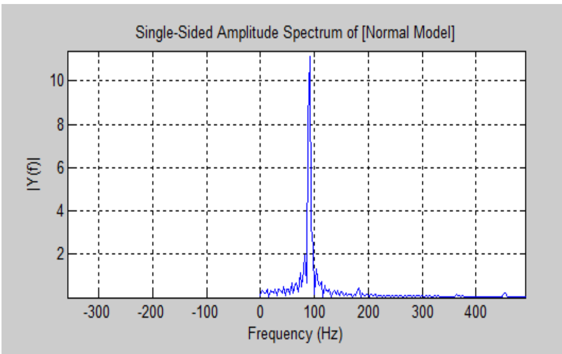

Fig.3 Current waveform in frequency domain of healthy compressor.

II. PRINCIPLE

A. *Motor current signature analysis(MCSA)*

Motor Current signature Analysis (MCSA) has been growing as a preferred predictive tool to detect the motor faults base on the observation of variation in the stator current signature through the air gab resulting to fluctuation

ISBN: 978-988-19252-3-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

of the magnetic flux which affect to the counter electromotive force (CEMF). The current tuning the motor which is modulated according to the change in CEMF is supplied to a data acquisition in order to transform the time domain to the frequency domain by implementing the Fast Fourier Transform (FFT) [11],[12]. Such method is now going to be widely used to diagnose the problems such as broken rotor bars, air gap eccentricity, unbalance weight and other faults. It can be analyzed both in the time domain and the frequency domain using the amplitude of the current signal having information embedded on the operating condition at various driven loads.

B. *Fast Fourier Transform (FFT)*

Fast Fourier Transform (FFT) is an algorithm to compute the discrete current signal which are derived randomly from the motor through the data acquisition in term of

$$X_k = \sum_{n=0}^{N-1} X_n e^{-i2\pi\frac{n}{N}} \tag{2}$$

X_k = transform values.
X_n = Sample values.
N = number of sample.

There are total N outputs and the value of X_k is derived from summation of such N outputs. FFT algorithm is a method to compute the summation of the results in term of N log N composes of four main processes as demonstrated in Fig. 4 [4].

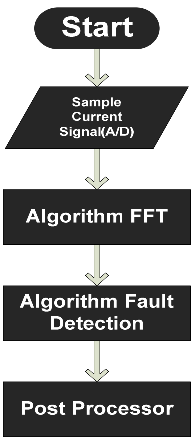

Fig. 4 Monitoring Scheme.

Sampler: Sample signal of the stator current signature is sent through a low pass filter in order to remove undesired high frequency components that produced an aliasing, and then, an analog to digital converter A/D is employed to converting the input signal.

Processor: The sample signal is converted into the frequency domain by using Fast Fourier Transform (FFT) algorithm.

Fault Detection Algorithm: In order to reduce a number of spectrum information into a usable level, an algorithm employs a frequency filter to eliminate those components that provides non-useful failure information. The algorithm keeps only the components that are particularly interested which inform specified characteristic frequencies of the current spectrum that are coupled to the particular motor faults.

Post Processor: Since the fault is not spurious event but degrading the motor continuously. The post processor diagnoses the frequency component and then classifies them.

C. *Center of Mass*

Center of mass is a point which locates the resultant weight of a system. For example, considering *n* particles located to the various compressor regions as shown in Fig. 5, it is evident that system of parallel forces can be replaced by a single equivalent resultant force and its application of the total weight can be located at the defined point G. It is possible to obtain an equivalent force of a system by adding the vector representing each of the individual force. And also, the application point of the equivalent force can be determined by summation of the moment about the reference point. Similarly, in a system of n particles whose weight W_i (I = 1,2,3…n), the total weight is found by adding the individual weight of the particles and the location where this weight acts can be determined by doing summation of the moment about point of reference. Thus, the resultant of the weight is equal to the total weight of n particles as

$$W_R = \sum_{i=1}^{n} W_i \tag{3}$$

W_i = weight of each particles.

The summation of the moments of the weights of all the particles about the x, y, z axes are equal to the moment of the resultant weight about such axis, Thus, the *x*-coordinate of G can be determined from the summation of moments about the y-axis as follows

$$\bar{x}W_R = x_1W_1 + x_2W_2 + \dots + x_nW_n \tag{4}$$

Similarity, the y-coordinate of G can be determined from the summation of the moments about the x-axis as follows

$$\bar{y}W_R = x_1W_1 + x_2W_2 + \dots + x_nW_n \tag{5}$$

Since the weights do not produce the moments about the z-axis, therefore, the z-coordinate of G is calculated by rotating the coordinate system with the particles attached to it by 90 degree about either the x- or y- axis, and then proceeds in a similar manner as

$$\bar{z}W_R = z_1W_1 + z_2W_2 + \dots + z_nW_n \tag{6}$$

Finally, by following these procedures it is possible to determine the coordinate of the center of mass G of the system which compose of n particles as

$$\bar{x} = \frac{\sum_{i=1}^{n} x_iW_i}{\sum_{i=1}^{n} W_i}; \bar{y} = \frac{\sum_{i=1}^{n} y_iW_i}{\sum_{i=1}^{n} W_i}; \bar{z} = \frac{\sum_{i=1}^{n} z_iW_i}{\sum_{i=1}^{n} W_i} \tag{7}$$

ISBN: 978-988-19252-3-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

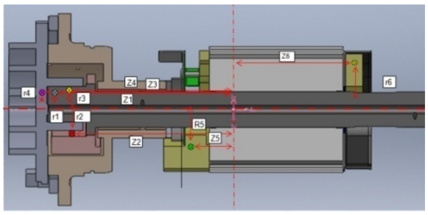

Fig. 5 Demonstration of the internal particles in the compressor.

D. *Clark and Park's vector approach*

A space vector transformation of time domain signal from neutral three-phase coordinate system into stationary two phase reference frame system as illustrated in Fig. 6, is called "Crake Vector" and can be written as

$$I_\alpha = \frac{2}{3} I_a - \frac{1}{3}\left(I_b - I_c\right) \tag{8}$$

$$I_\beta = \frac{2}{3}\left(I_b - I_c\right) \tag{9}$$

I_α *and* I_β component are orthogonal reference frame.

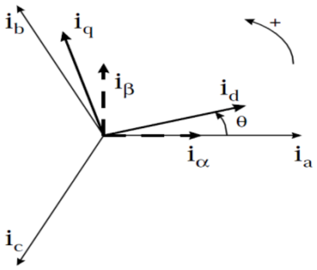

Fig. 6 Two–phase reference frame system of Clark transformation vector.

Park's transformation is the two phase $\alpha\beta$ for calculated the frame representation with the Clarke transformation then fed to a vector rotation block where it rotates over an angle θ to following the frame d, q attached to a rotor flux. The rotation over an angle θ is done according to formulas.

$$I_d = I_\alpha \cos\theta + I_\beta \sin\theta \tag{10}$$

$$I_q = -I_\alpha \sin\theta + I_\beta \cos\theta \tag{11}$$

Under abnormal conditions, for example broken bar and unbalance weight in the compressor, the brushless dc motor supply current will contain side band components. This additional components are calculated by using (2), and are presented in both the motor current Park's vector components (I_d *and* I_q). The implementation of the Park's vector approach intends to eliminate some of the technical limitations of the conventional MCSA. Moreover, the results employing the Park's vector approach are more discriminative than those results obtained by the traditional FFT- base MCSA.

III. PROPOSED METHOD

The objective of this research is implementation of MCSA technique in order to detect the fault of the compressor in term of the unspecified balance weights (as shown in Fig. 1) which affects to the location of the center of mass and the current signature. As a result, the current distortion is occurred in the stator that generates new frequency sideband in fault harmonics [4]. In ideality, the current of brushless dc motor is sinusoidal shape, but the effect of misspecification balance weights results to non-sinusoidal shape and detects of unusual conditions in the current signal. However, it is necessary to study the relationship that has effect to the center of mass in the internal part of the compressor, and the relationship of center of mass and the current amplitude either in time domain or frequency domain. Practically, it is possible to apply MCSA techniques for fault detection in the compressor whose scheme can be demonstrated as Fig. 7.

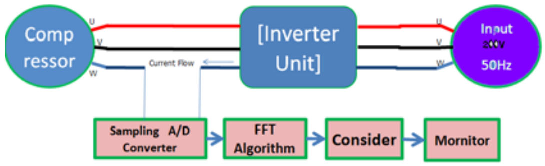

Fig. 7. MCSA fault Detection schemes.

For different size of motor, there is difference of current flow density in the motor stator too. So it is possible to make a relationship between current flow and the rotor speed by considering the rotor frequency as

$$n = f_1 s \tag{12}$$

f_1 = frequency.
s = motor slip.

And the synchronic speed can be derived from

$$n_s = \frac{f}{p/2} \tag{13}$$

n_s = synchronous speed.
p = pole motor.

Immediately, it appears a relationship between frequency test and rotor's frequency. Electrical speed can be obtained as a function of the pair of poles and the harmonic number i.

$$n = \frac{\frac{p}{2}(n_s - n)}{i} \tag{14}$$

n= rotor speed
n_s= synchronous speed.

In the motor stator, it is necessary to add rotor's speed (relative speed between stator and rotor) as

$$\frac{p(n_s - n)}{i} + n = \frac{p(n_s)}{i} + n(1 - \frac{p}{i}) \tag{15}$$

Which can be expressed as electrical speed

$$pn_s + n(i - p/2) \tag{16}$$

$$f + n(1-s)(i - p/2) \tag{17}$$

According to first harmonics, it is possible to fine the equation due to the fault mark under the spectrum frequency.

$$f_{fault} = f + f_1((1-s) \pm ps/2) \tag{18}$$

ISBN: 978-988-19252-3-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

In case of interior, the permanent magnet synchronous motor slip = 0,

$$f_{fault} = f_e + k\frac{f}{p/2} \tag{19}$$

Difference masses of the balance weight produce difference effects on the motor. It is possible to simulate the current flow density in the stator and the rotor by use of simulation software. Fig. 8 shows the current flow density according to the specified balance weight. Fig. 9 and Fig. 10 show the current flow density due to incorrectness of the balance weight at the same testing value of voltage, amplitude and rotor speed.

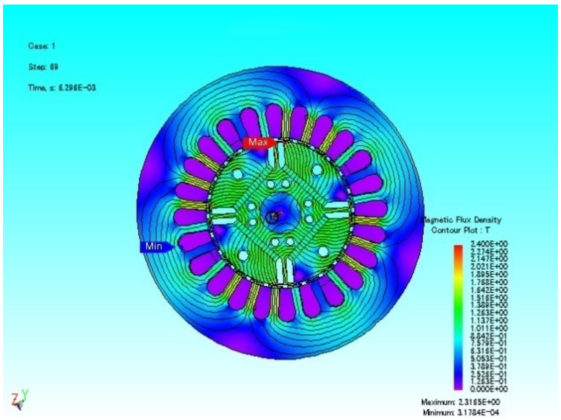

Fig. 8 Current flow density of healthy compressor (Balance weight 98.02 gram according to the specification).

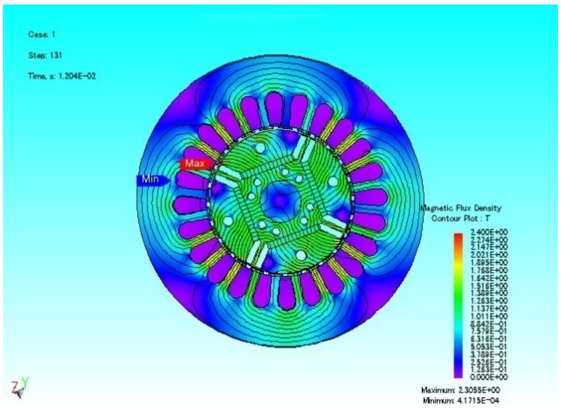

Fig. 9 Current flow density of faulty compressor (Balance weight 152.02 gram, over the specification to 55%).

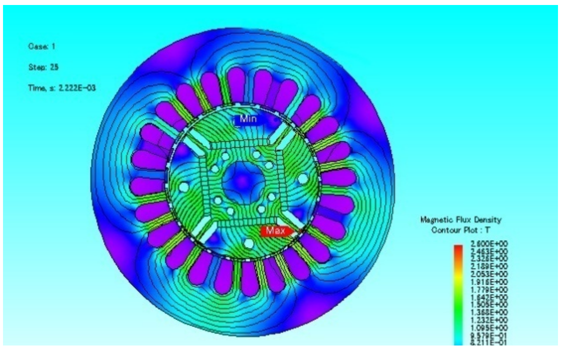

Fig. 10 Current flow density of faulty compressor (Balance weight of 191.06 gram, over the specification to 94%).

The stator current signatures based on the time domain of the healthy and faulty compressors are shown in Fig. 11 and Fig. 12, respectively.

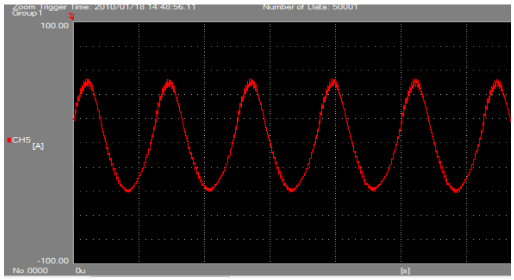

Fig. 11 Stator current waveform based on time domain of healthy compressor.

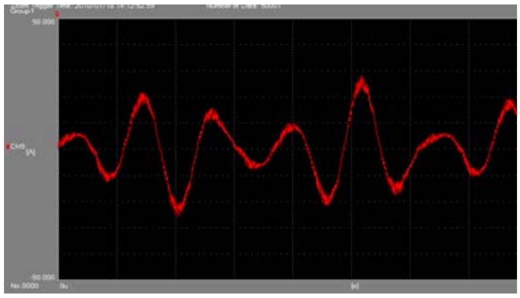

Fig. 12 Stator current waveform based on time domain of faulty compressor.

The stator current based on the frequency domain of healthy and faulty compressor are shown in Fig.13 and Fig. 14, respectively.

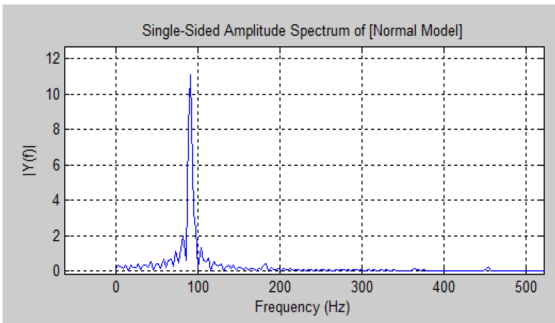

Fig. 13 Current waveform based on the frequency domain of healthy compressor.

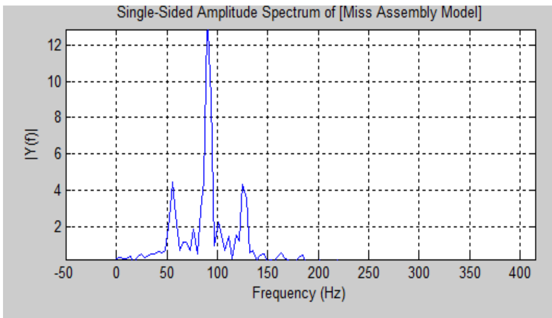

Fig. 14 Current waveform based on the frequency domain of faulty compressor.

ISBN: 978-988-19252-3-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Test condition:

- The difference balance weight Compressor with brushless dc motor inside 4 set.
- Inverter drives 200V 3 phase
- Air-conditioning unit 1800 Btu.
- Compressor Speed 2700 rpm.

IV. EXPERIMENTAL RESULT

The test is divided in following four cases as shown the details in Table I, while the testing results are performed by replacing the corrected mass of the balance weight with difference masses as shown details in Table II, and the relationship between the center of mass and faulty amplitude based on the frequency domain show in Fig. 19 and Fig. 20, respectively.

TABLE I
FAULT CONDITION

Case	Description
1	Assembly the balance weight according to specification
2	Incorrect balance weight No.2 (Fig. 1)
3	Incorrect balance weight No.3 (Fig. 1)
4	Incorrect balance weight No.4 (Fig. 1)

TABLE II
TESTING RESULT

No	Mass(g)	center of Mass[%]	I(FFT)[A]
1	98.2	0.8	0.868
2	152.8	5	2.77
3	172.5	7	3.54
4	191.6	9	4.09

Case 1: The balance weight is according to Spec.

TABLE III

Performance Data	Value
The absolute of Static Center of mass (%)	0.8
The absolute of Dynamics Center of mass (%)	0
FFT Amplitude (A)	0.868
Amplitude of Fundamental (A)	18
The Frequency Side Band f_e (Hz)	± 20

f_e= fundamental frequency

By using Eq. (1), we will obtain

$$f_{de} = f_e \pm k\frac{f_e}{p/2}$$

$f_{fundamental}$ = 90Hz [2700 rpm]
Motor Pole = 6 Pole

$$f_{de^+} = 60 + 1\frac{60}{6/2} = 80Hz$$

$$f_{de^-} = 60 - 1\frac{60}{6/2} = 40Hz$$

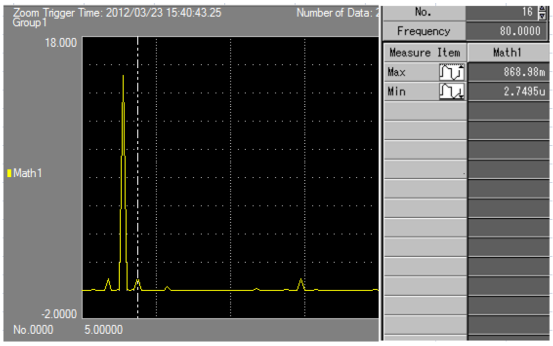

Fig. 15 The side band frequency of healthy compressor.

Case 2: Incorrect balance weight No. 2.

TABLE IV

Performance Data	Value
The absolute of Static Center of mass (%)	5
The absolute of Dynamics Center of mass (%)	12
FFT Amplitude (A)	2.77
Amplitude of Fundamental (A)	18.8
The Frequency Side Band f_e (Hz)	± 20

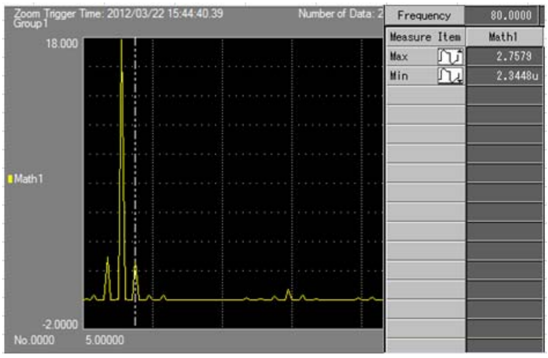

Fig. 16 The side band frequency of fault compressor due to the incorrect balance weight No.2.

Case 3: Incorrect balance weight No.3.

TABLE V

Performance Data	Value
The absolute of Static Center of mass (%)	7
The absolute of Dynamics Center of mass (%)	19
FFT Amplitude (A)	3.54
Amplitude of Fundamental (A)	17.9
The Frequency Side Band f_e (Hz)	± 20

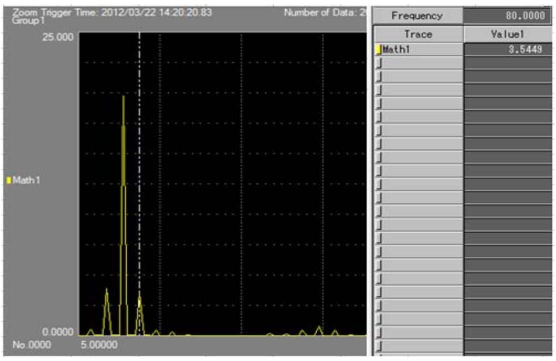

Fig. 17 The side band frequency of fault compressor due to the incorrect balance weight No.3.

ISBN: 978-988-19252-3-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Case 4 : Incorrect balance weight No.4.

TABLE VI

Performance Data	Value
The absolute of Static Center of mass (%)	9
The absolute of Dynamics Center of mass (%)	24
FFT Amplitude (A)	4.09
Amplitude of Fundamental (A)	18.5
The Frequency Side Band f_e (Hz)	± 20

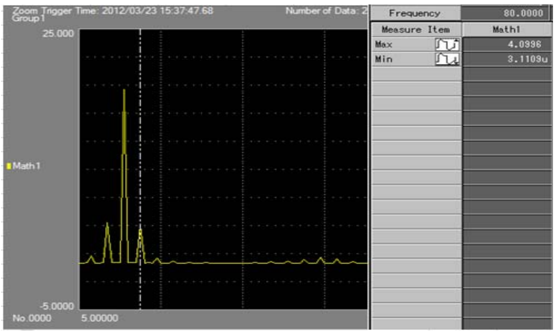

Fig. 18 The side band frequency of fault compressor due to the incorrect balance weight No.4.

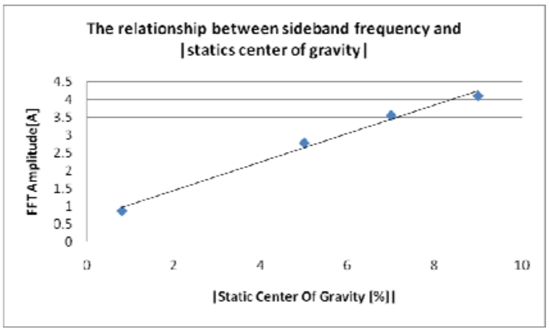

Fig. 19 Relationship between static center of mass and amplitude of faulty current in frequency domain.

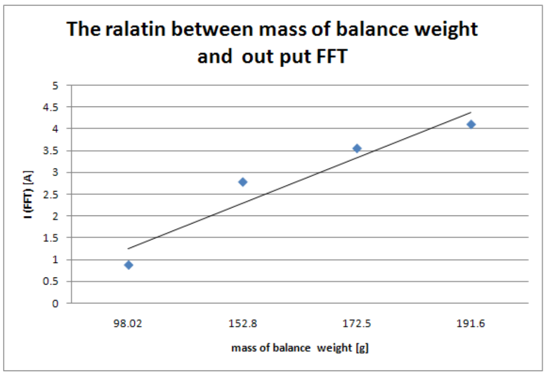

Fig. 20 Relationship between mass of balance weight and the amplitude of faulty current in frequency domain.

V. Conclusion

The motor current signature analysis (MCSA) provides a high sensitive and low cost which suitable to apply in the production process for inspect the compressor. Moreover, it can be used to cooperation with other technology such as motor circuit analysis and protection system in motor control. And also, it is possible to eliminate those fault frequencies by analysis on α *and* β reference frame. This paper discusses the fundamental of MCSA and demonstrates through manufacture case studies. In addition, the proposed method is possible to implementing for the inspection and production systems which are required to be considered and provided good reliability.

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