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STUDY FOR 2F NOISE REDUCTION OF AIR-CONDITIONER USING SINGLE PHASE INDUCTION MOTOR

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Abstract

In this paper twice line frequency noise including harmonics (2f noise) has been investigated in an air conditioner using capacitor running single phase induction motor. The 2f noise is very annoying sound due to the low frequency characteristics. Especially, if it occurs in small closed room, it even should make standing wave inside the room. To reduce this 2f noise, we studied the causes of 2f vibration of single phase induction motor from an analytical approach about electrical motor driving mechanism. As result we found unbalance MMF is the main causes of motor 2f vibration. And following experimental study shows a linear correlation between this unbalanced MMF of motor and the 2f noise of air conditioner.

INTRODUCTION

Many home electronics, as well as many industrial machines, use a single phase induction motor because the single phase induction motor allows direct connection with commercial electricity without any driver or converter system. And also the relatively low price and easiness of manufacturing are other reasons of using single phase induction motor for home electronics.[1]

The most of the home electronics, using single phase induction motor, generate low frequency tonal noise corresponds with twice of the electrical frequency of AC input power (2f noise). Although this 2f noise has been very well known for home electronics developers for a long time, but it is still very stubborn problem to be solved. This is due to the absence or insufficient understanding of the motor electro-magnetic mechanism in a view point of noise and vibration. So that many developers focus their efforts on mechanical approaches (avoid resonance, isolation of motor vibration, reinforcement of the main body and accurate fabrication of motor etc). As a necessity, these approaches can not lead essential solution.

To solve the main cause of 2f noise problem, we focus on the reduction of motor vibration. From a long time experience of manufacturing and application of single phase induction motor, mechanical causes are well known. So we investigate electro-magnetic force of motor rather than mechanical causes.

SOURCES OF 2F VIBRATION IN MOTOR

Types of excitation force in motor

Motor vibration consists of two types of main components on frequency domain. The fist one is rotor rotating frequency component and the second is electrical AC power frequency component. And these components make the frequency spectrum very complicate due to the harmonics and side bands. 2f vibration is one of the electrical AC power frequency component and the causes of the 2f vibration are known as eccentricity of air gap and rotor, loose stator core, thermal bow of rotor shaft, unbalanced line voltages, ground or inter phase faults etc. [1], [2], [3]

These causes from the previous works are based on a three phase induction motor for industrial use. If we use a three phase induction motor, problems can be fixed when above mentioned causes are removed. But in case of single phase induction motor for home electronics application, we can’t easily solve vibration problems as in case of three phase induction motor. Especially some of single phase induction motor has very strong 2f vibration despite of very accurate mechanical manufacturing process. This means that a single phase induction motor has another critical source of 2f vibration.

Magneto Motive Force (MMF) unbalance of single phase induction motor

The single phase induction motor has several types according to make starting torque. In the range of consumption power of home electronics, from dozens of W to a few kW, a capacitor running single phase induction motor is most widely used. Fig. 1 shows an electrical circuit diagram of stator winding of typical capacitor running single phase induction motor. As shown in Fig. 1 starting winding with a capacitor is connected parallel to main winding. Due to this capacitor, the current phase of starting winding would have gap with the phase of main winding so that motor act like a two phase induction motor. In this way the stator can make rotating magnetic field which enables the motor start and run.

The capacitance of capacitor, as well as the winding specification, determines the basic motor performances like rated RPM and mechanical shaft power. So these motor design factors are determined in terms of motor performances first. [4] While main design factors are focusing on the performances, the magnetic force balance between main and starting winding should be broken. And the magnetic force unbalance could be one of the main causes of the motor 2f noise.

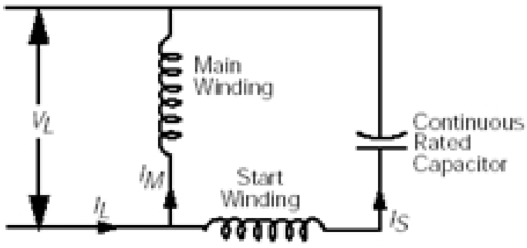

Figure 1. Diagram of stator windings of a capacitor running single phase induction motor

Magnetic force unbalance in capacitor running single phase induction motor can be simply derived by the rotating field theory. When the phase difference of each winding is Φ in figure 1, the current of each winding can be expressed like below.

Main winding : $I_m \cos \omega t$
Staring winding : $I_s \cos(\omega t - \Phi)$

And let the number of winding turns as N_m, N_s for main and starting winding, then the MMF(Magneto Motive Force, Ampere-Turn) for each winding is,

Main winding : $N_m I_m \cos \omega t$
Staring winding : $N_s I_s \cos(\omega t - \Phi)$

Both MMF in main and starting winding make the rotating magnetic field which is essential for induction motor running. From the rotating field theory [5], [6], [7] the rotating MMF can derived as equation (1), (2). And the MMF unbalance in figure 1 is identical with the backward rotating magnetic field.

$$F_{fw}(t,\theta) = \frac{1}{\sqrt{2}}\{(N_m I_m + N_s I_s \sin\Phi)\cos(\omega t - \theta) - N_s I_s \cos\Phi \sin(\omega t - \theta)\} \quad (1)$$

$$F_{bw}(t,\theta) = \frac{1}{\sqrt{2}}\{(N_m I_m - N_s I_s \sin\Phi)\cos(\omega t + \theta) - N_s I_s \cos\Phi \sin(\omega t + \theta)\} \quad (2)$$

According to equation (2), the mechanism of 2f vibration from this unbalanced magnetic force can be explained by figure 2. Figure 2 shows time domain MMF generated in one revolution of rotor in 2 pole capacitor running single phase induction motor. First, shown in figure 2-1, is balanced case. Balance means the MMF from main and starting windings are in balanced condition which the backward rotating magnetic field is zero. The equation (1) is zero when,

1) $N_m I_m = N_s I_s$
2) $\Phi = 90 \deg$

This means that MMFs of main and starting winding are same in magnitude and the phase difference is 90deg. At this condition motor can generate constant torque because the resultant MMF from main and starting winding is just rotating around the stator without changing the magnitude. And the rotating frequency of MMF is 2f/poles so that, in shown case 2 poles motor, the MMF rotating frequency is f(line frequency).

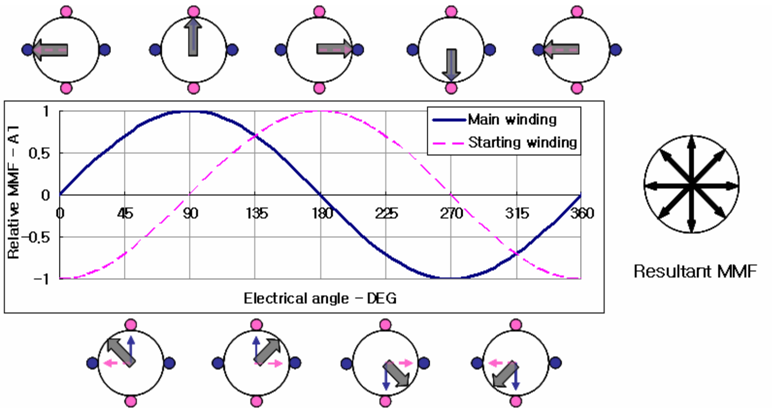

Figure 2-1 – MMF formation in stator windings : case1 balanced condition

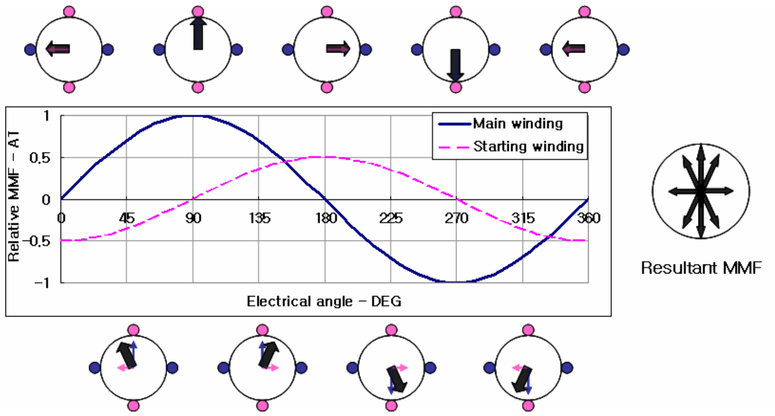

Figure 2-2 – MMF formation in stator windings : case2 MMF magnitudes are different

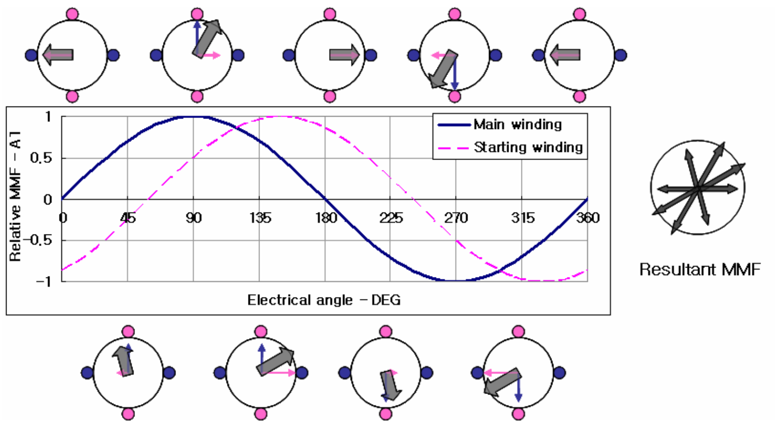

Figure 2-3 – MMF formation in stator windings : case3 Phase is differences are60deg

Case 2 shown in figure 2-2, is the condition that the MMF of starting winding is half of main windings MMF with the phase difference is 90deg. In this case the resultant MMF is rotating around the stator with the magnitude is changing. Furthermore the magnitude changes twice in one revolution of MMF rotating. This means that the torque generate at this condition should be fluctuating twice of line frequency(2f). And the torque fluctuation is the causing the motor 2f vibration.

Case 3 shown in figure 2-3, is the condition that the phase differences are 60deg with same magnitude of MMF. Also the resultant MMF is rotating around the stator with the magnitude is changing. Figure 2-3 shows the phase mismatch could make same result with case 2.

CORRELATION OF UNBALNCED MMF WITH 2F NOISE

In above section, we found the unbalanced MMF is the source of 2f vibration in capacitor running single phase induction motor. Then in this section we will investigate the correlation between unbalance force and 2f noise using two types of home air conditioning units.

Window type air conditioner

In this section we will study the evidence of correlation between unbalanced MMF with 2f noise using single window type air conditioning unit(WAC). To verify the effect of unbalanced MMF on 2f noise, we selected one WAC set shown in figure 3 which make strong 2f noise in normal operating condition.

Figure 3 – Window type air conditioner

Unbalanced MMF and 2f noise have been measured with varying capacitance in figure 1, because the easiest way of changing the magnitude of unbalanced MMF is to control the capacitance of capacitor. For unbalanced MMF measurement we define the magnitude of unbalanced MMF from equation (2) as below to make quantitative analysis.

$$\text{Magnitude of unbalanced } MMF = \frac{1}{2}\sqrt{(N_m I_m - N_s I_s \sin\Phi)^2 + (N_s I_s \cos\Phi)^2} \quad (2)$$

The result shows, in figure 4, that the 2f noise and vibration has very strong correlation with the magnitude of unbalanced MMF calculated from equation (3). In accordance with this result we redesigned the stator windings so that the MMF should be balanced. This could be done by changing the coil thickness and the turns of winding, while other factors are remain the same. As result, shown in table 1, the 2f noise has been reduced by more then10dB.

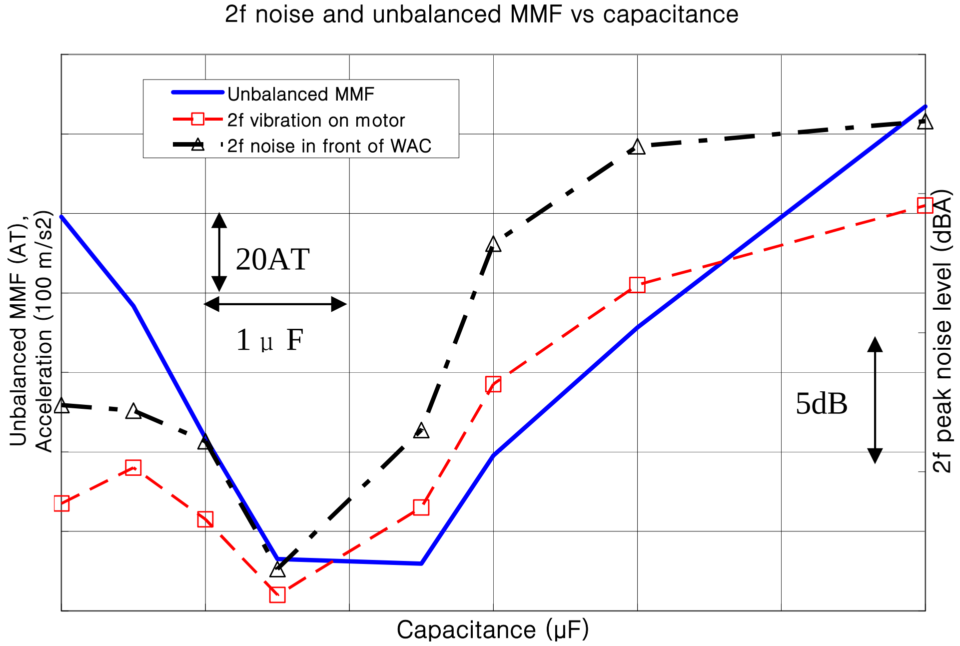

Figure 4 . Effect of unbalanced MMF on 2f noise and vibration of WAC

	Before redesign	After redesign
Unbalance MMF(Ampere turn)	305.8	57.2
2f noise level(dBA)	43.5	28.1

Table 1. Comparison of MMF unbalance and 2f noise for WAC by redesigning motor

4 way cassette type air conditioner

Figure 5 shows a 4 way cassette type air conditioner which is an indoor unit of separated type air conditioning system. Inside 4 way cassette, a motor is mounted on the flat and thin plate of box type frame so that motor vibration can be easily radiate from the flat plate. 4 way cassettes are usually installed on the ceiling of meeting room or office.

Figure 5. 4 way cassette air conditioner

As a further quantitative research on the correlation between 2f noise and unbalanced MMF, 13 models of 4 way cassettes are tested. Each model has different motor and one model has 4 steps of running RPM. The correlation of unbalanced MMF and 2f noise from 4 way cassette has been plotted in figure 6. For measuring 2f noise, “Total-2f” has introduced to exclude the effect of different motor RPM and flow rate. Total-2f is a difference of overall sound pressure level with the 2f peak noise level. Total-2f level is also known as direct relation with human perception rate of a particular peak noise.

The result shows 2f noise has linear correlation with unbalanced MMF. This means that if we have target of 2f noise level for certain human perception rate, it can be attained by designing motor stator windings.

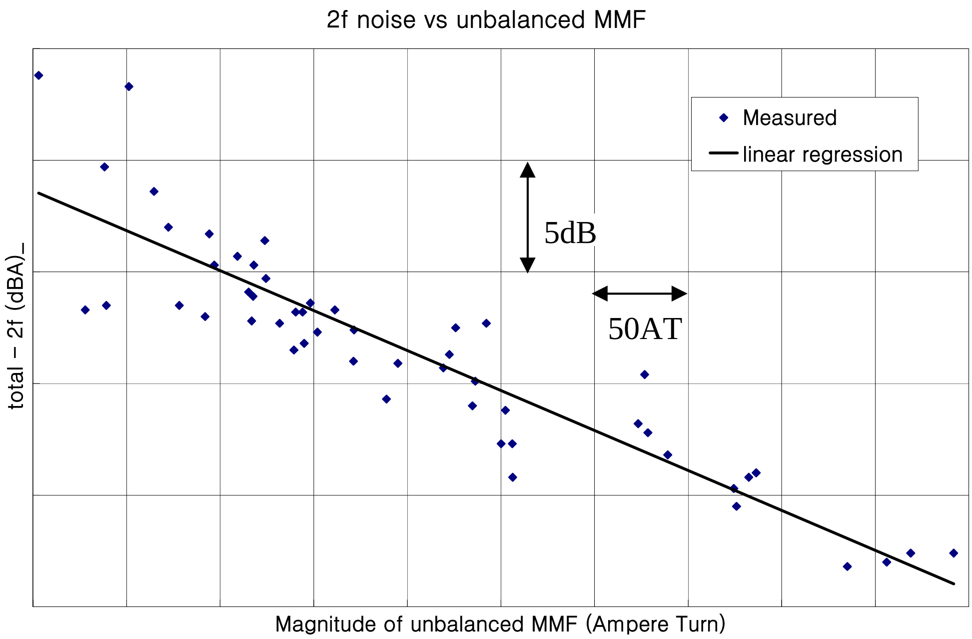

Figure 6. Correlation between unbalanced MMF vs 2f noise from 4way cassette

CONCLUSIONS

From an analytical approach, we found unbalanced MMF in single phase induction motor is one of the main causes of 2f vibration and it is approved experimentally. From a quantitative research we found the magnitude of unbalanced MMF has linear correlation with 2f noise in terms with Total-2f level. With this result home electronics developer can have a guide line for single phase induction motor design to reduce 2f noise and vibration.

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