

## Comparison of The Harmonic Content Effect on Induced Current Between Amorphous Ribbon and 3%SiFe (CRGO) Core Material

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**Abstract.** This paper is about to investigate the harmonic content effect on induced current between Amorphous ribbon and 3% Si Fe (CRGO) core material. The experiment method that used is Single sheet tester (SST) in order to measure the harmonic content. The input voltage adjusted at 0.2T, 0.5T and 1.0T. From the result of this investigation find that the 3<sup>rd</sup> order harmonic factor of Amorphous ribbon is lower than 3% SiFe (CRGO) about 9.2% at 0.5T. The 5<sup>th</sup> order harmonic factor of Amorphous material is lower than 3% SiFe (CRGO) about 18.3% at 0.5T. It means that harmonic is affected by ingredient in core material.

**Key words:** Harmonic, Harmonic Factor 3% SiFe, Amorphous ribbon, Single Sheet Tester (SST)

### INTRODUCTION

Early 1885, the first transformer core was made by carbon steel followed by silicon steel. Nowadays, it has been changed to Cold Rolled Grain Oriented (CRGO) laminations (Themistoklis, D., et al., 2010). Other than that, Amorphous steel also used as transformer core. They have been selected because of their several characteristic that can give an advantage to the performance of transformer itself. However, there is a problem need to be considered in order to make sure the core material will give a better performance to transformer. The problems is harmonic occurred in those two core material (Syafudin Masri, et al., 2011). Harmonic will disturb voltage and current output at transformer and will bring to some losses to the power system (Syafudin Masri, et al., 2011). Many researchers have trying to find what cause of harmonic (Themistoklis, D., et al., 2010).. Harmonic will give an effect to distribution transformer no-load loss (Themistoklis, D., et al., 2010).. Cold Rolled Grain Oriented (CRGO) is widely used as core material in transformer design and stator or rotor part in electrical motor. It is chosen because of the magnetic characteristic that satisfies the requirement of electrical demand. It contains silicon level of 3% Si Fe (wikipedia.org/wiki/Electrical). Cold-Rolled Grain Oriented (CRGO) is usually supplied by producing mills in coil form and it has to be cut into "lamination" which are then will be used as transformer core (Nada Kosutic hulita, 2011). Grain Oriented steels is also decarbonised and has not more than 0.06% of carbon in their chemical composition, which will prevents ageing of the steel [5]. As refer to Fig. 1, the core is magnetized by magnetic field (H) is called magnetizing force. The magnetic flux density (B) of the core will increase and saturates at the knee point and then it will starts decreasing as magnetizing force (H) decreases. At point b, called Magnetic Retentivity where it means no magnetic field force is applied to the material but still magnetic flux density is not zero in the material. At point C, called Coercive Force where by applying magnetic field in opposite direction will make the magnetic flux (B) is zero.

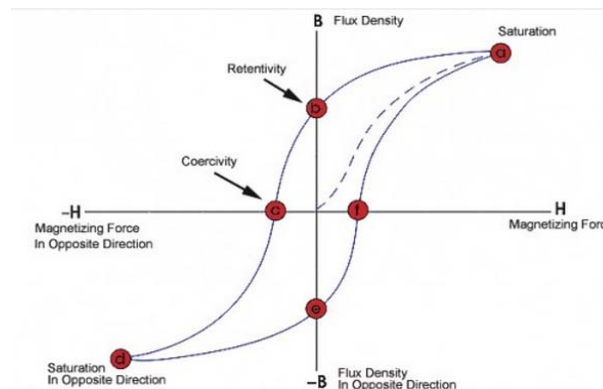
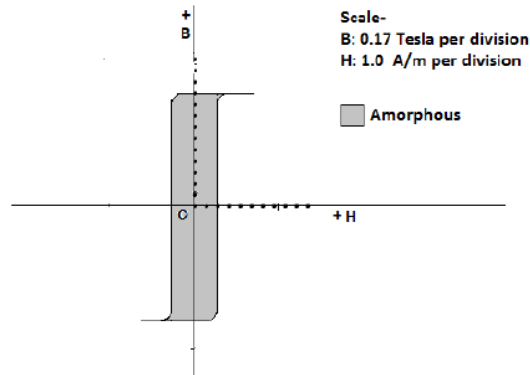


Fig. 1: B-H curve for CRGO (<http://kiran111.hubpages.com>)

The same phenomenon will happen if the flux applied in the opposite direction in another cycle. These called hysteresis loop. Lower Magnetic Retentivity in magnetic material is the loss of magnetic field applied to

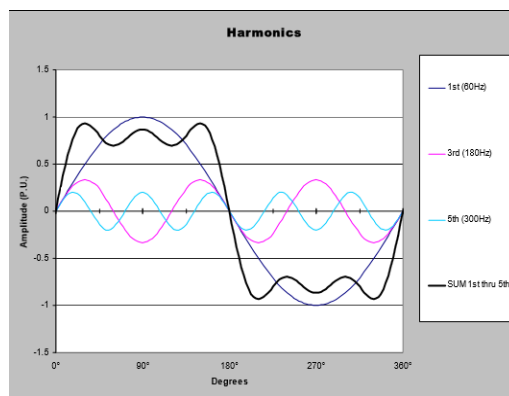
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make magnetic flux zero. So, CRGO has a small hysteresis loss compared to other material (<http://kiran111.hubpages.com>). Amorphous steel is also known as metallic glass or glassy metal. Most of the metals are crystalline in their solid state ([wikipedia.org/wiki/Electrical](http://wikipedia.org/wiki/Electrical)). These will bring them to have a highly ordered arrangement of atoms. It is a non-crystalline and has a glass structure. Unlike common glasses which are typically insulator, amorphous metal has a good electrical conductivity ([wikipedia.org/wiki/Electrical](http://wikipedia.org/wiki/Electrical)). The viscosity prevents the atoms moving enough to form an ordered pattern. The energy loss (hysteresis loss) is small when flux of magnetic induction passes the iron core (Hitachi Amorphous Transformer). Eddy current loss reduced because thickness is approximately 0.33mm which is 1/10 comparing with silicon steel (Hitachi Amorphous Transformer). It contains iron-boron-silicon ( $Fe_{78} B_{13} Si_9$ ).



**Fig. 2:** B-H curve for Amorphous ribbon (<http://kiran111.hubpages.com>)

As refer to Fig. 2, area under the graph is small compared to area under the graph for B-H curve CRGO in Fig. 1. It shows that Amorphous ribbon has low core loss, low magnetising current, low zero sequence current, less noise, higher inrush current and longer life. However Amorphous ribbon will give third harmonic effect to transformer because input voltage is increase and flux density also increase. Harmonic in simple word means a wave whose frequency is an integer multiple of the fundamental frequency (Dr. Mohamed Fuad Faisal, 2012). When the higher frequency value added to fundamental frequency waveform, it will become distortion to the fundamental (Dr. Mohamed Fuad Faisal, 2012). As refer to Fig. 1, fundamental frequency is 60Hz, when the frequency is added by multiple of three, the order of harmonic will become third order. Same if frequency added by multiple of five, the order of harmonic will become fifth order. It clearly stated that sum of first harmonic until fifth harmonic will become a complex waveform. Positive sequence of harmonic will have same phase rotation as fundamental voltage frequency, 50 Hz. First, seventh, thirteenth, nineteenth order of harmonic are the example of positive sequence harmonics (Dr. Mohamed Fuad Faisal, 2012).



**Fig. 3:** Harmonic definition (Michael Leporace – Specification Engineer)

Graphical method is used to calculate harmonic content from the graph. The equation for harmonic content shows by the Fourier Series such as:

$$Y = F_0 + F_1 \sin(\omega t + \phi_1) + F_2 \sin(\omega t + \phi_2) + \dots + F_n \sin(\omega t + \phi_n) \tag{1}$$

The objective of this investigation is to compare the harmonic content in 3% Si Fe and Amorphous ribbon core material.

**Experimental Setup:**

The methodology that used to investigate this material is shown in the flow chart in Fig. 6. The method used to measure the harmonic content by using the Single Sheet Tester which is SST having closed magnetic path (a closed type of SST) has a problem that measurement accuracy of magnetostriction is considerably affected by electromagnetic force between specimen and yoke. Flux closure yoke are used can be single sided or double sided. If single sided yoke, eddy current pools can form in the strip where flux leaves or enters its normal to its surface. Fig. 5 shows the single sheet tester with single yoke. With double sided yokes these eddy current effects largely cancel. The equation used to get input voltage and this voltage need to supply at windings coil with Tesla of flux density.

$$V = 4.44 \times B \times N \times f \times A \tag{2}$$

where

V = Voltage

4.44 = Constant

B = Tesla

N = Number of winding turn = 125 turns

f = Frequency = 50 Hz

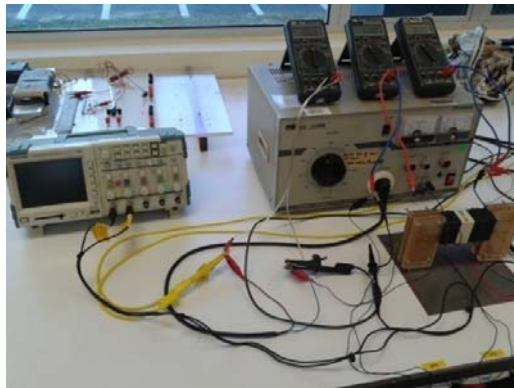
The experiment setup is shown in Fig. 7 .Oscilloscope is important in order to get the waveform for harmonic current. Then, we should know all this value below:

A = Cross sectional on the surface of yoke = n x t x w [m]

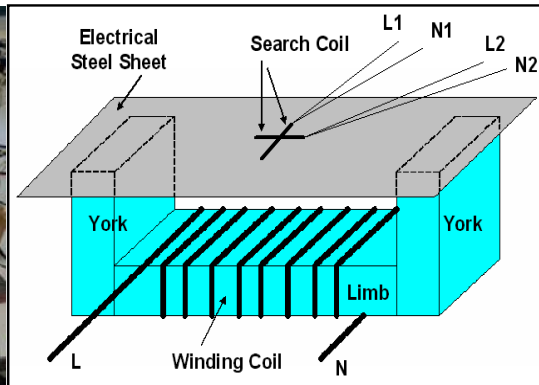
N = number of layer of yoke lamination = 40 layers

t = thickness of yoke lamination [m] = 0.3 mm for M5 grade material

w = width of yoke lamination [m] = 3cm



**Fig. 4:** Setting of experiment for SST



**Fig. 5:** The single sheet tester with single yoke

**RESULT AND DISCUSSION**

Input voltage is getting by calculating using Eq. 1. Three condition need to be considered are under excited, operation and saturation.

**Table 1:** Calculation result for input voltage

Condition	Flux (T)	Input Voltage (V)
Excited	0.2	2.0
Operation	0.5	5.0
Saturation	1.0	10.0

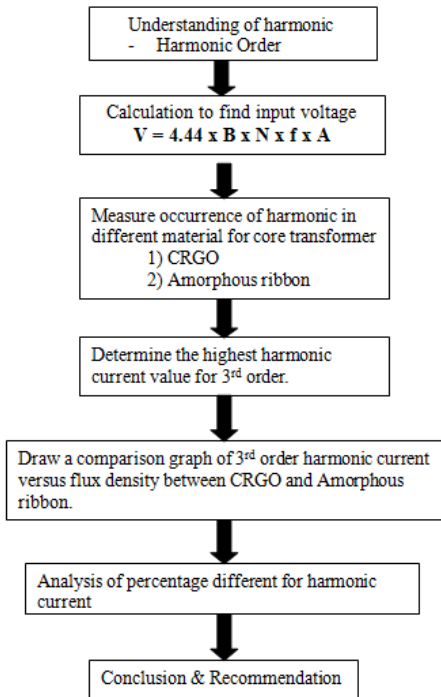


Fig. 6: Flow chart for methodology

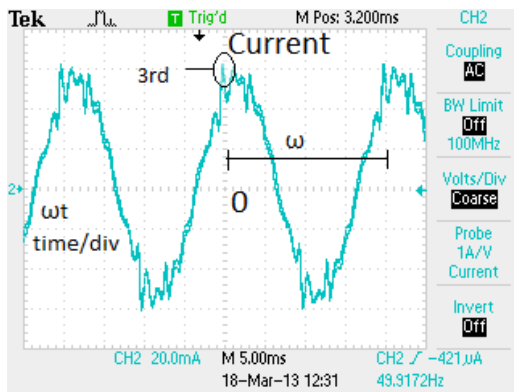


Fig. 7: Induced current for flux density of 0.2T, 50Hz

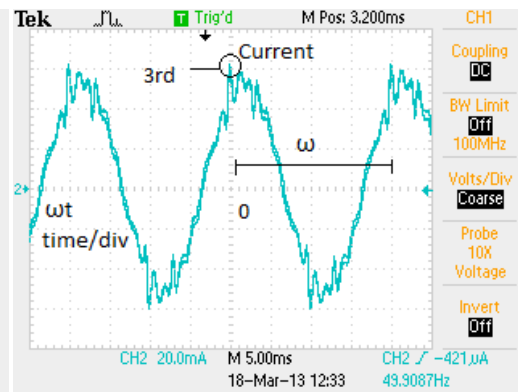


Fig. 8: Induced current for flux density of 0.5T, 50Hz

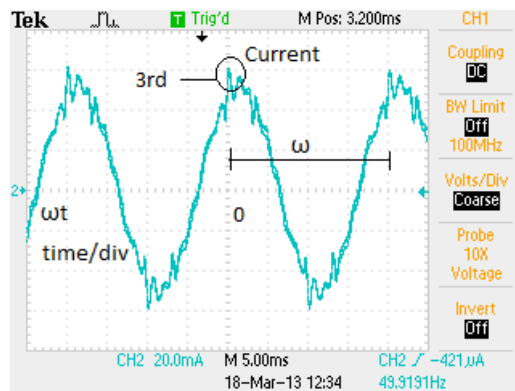
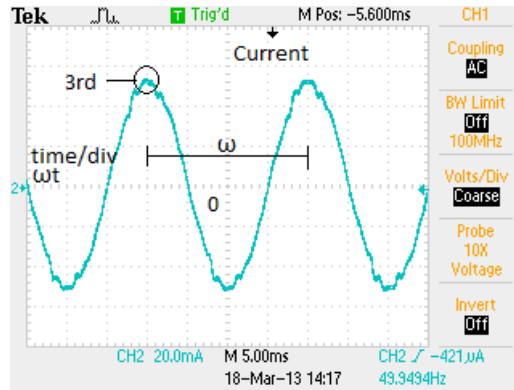


Fig. 9: Induced current for flux density of 1.0T, 50Hz

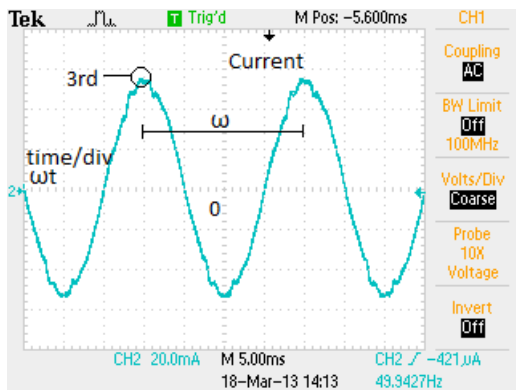
For under excited mode, 3% SiFe core material shows 0.2T given for input voltage can refer to Fig. 7, which is the highest induced current value is 0.064A. While in operation mode, 0.5T, given for input voltage, can refer to Fig. 8, which is the highest induced current value, 0.064A and for saturation mode, 1.0T given for input voltage can refer to Fig. 9, which is the highest current value is 0.060A. Fig. 7, Fig. 8. and Fig.9 shows the x-axis is referred to time/div which in these case the time is 20 ms. Continue with under excited mode, for

Amorphous at 0.2T given for input voltage in Fig. 10, shows that the highest induced current is 0.056A. Next, for operation mode at 0.5T, given for input voltage in Fig. 11, shows that the highest induced current is 0.054A. For saturation mode at 1.0T, given for input voltage in Fig. 12 shows that the highest induced current is 0.052A. Fig. 10, Fig. 11. and Fig.12, x-axis is referred to time/div which in these case the time is 20 ms. The method that used to find the harmonic factor (HF) and Total Harmonic Distortion (THD) are using graphical method found from the Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, and

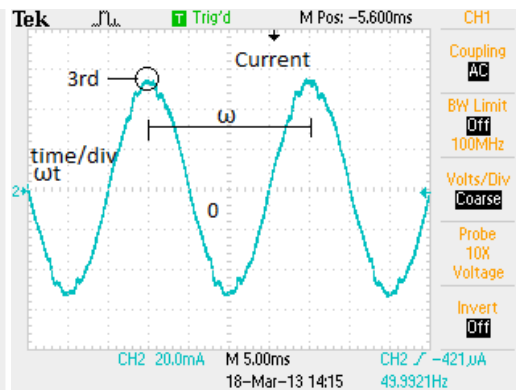


**Fig. 10:** Induced current for flux density of 1.0T, 50Hz

Fig. 12. From Fig. 13 shows the 3<sup>rd</sup> order harmonic factor of Amorphous material is higher than 3% SiFe (CRGO) at 0.2T is 10%. The 3<sup>rd</sup> order harmonic factor of Amorphous material is lower than 3% SiFe (CRGO) at 0.5T is 9.2%. The 3<sup>rd</sup> order harmonic factor of Amorphous material is higher than 3% SiFe (CRGO) at 1T is 6.8%. Comparison of 3<sup>rd</sup> order harmonic factor effect is highest on both materials occurs at 0.2T. Effect of harmonic current is highest at 0.5T for Amorphous material and similarly for 3% SiFe (CRGO).



**Fig. 11:** Induced current for flux density of 0.2T, 50Hz



**Fig. 12:** Induced current for flux density of 0.5T, 50Hz

From Fig. 14 shows a 5<sup>th</sup> order harmonic factor of Amorphous material is higher than 3% SiFe (CRGO) at 0.2T is 54.7%. The 5<sup>th</sup> order harmonic factor of Amorphous material is lower than 3% SiFe (CRGO) at 0.5T is 18.3%. The 5<sup>th</sup> order harmonic factor of Amorphous material is lower than 3% SiFe (CRGO) at 1T is 74%. Comparison of 5<sup>th</sup> order harmonic factor effect is highest on both materials occurs at 1T. Effect of harmonic current is highest at 1T for Amorphous material and similarly for 3% SiFe (CRGO).

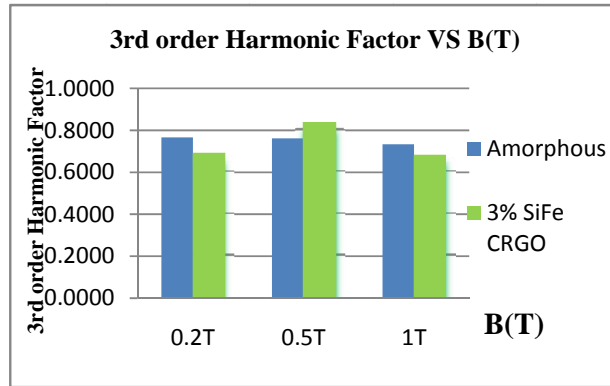


Fig. 13: Comparison of 3<sup>rd</sup> order Harmonic Factor between Amorphous and 3% SiFe CRGO

From Fig. 15 shows a THD of Amorphous material is higher than 3% SiFe (CRGO) at 0.2T is 2.693%. The THD of Amorphous material is lower than 3% SiFe (CRGO) at 0.5T is 6%. THD of Amorphous material is higher than 3% SiFe (CRGO) at 1T is 13.51%. This thing happened because if refer to B-H curve for both material that in 0.2T the domain material of 3% SiFe shows not excited yet. While in 0.5T shows the domain material of Amorphous ribbon is in under operation and domain material of 3% SiFe is not operate yet. At 1T, the domain material of Amorphous ribbon is near to saturation but for domain material of 3% SiFe is not in saturation yet.

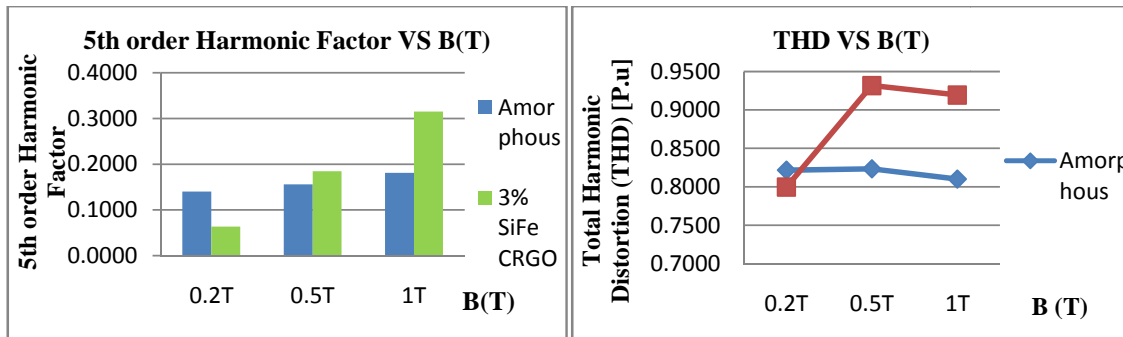


Fig. 14: Comparison of 5<sup>th</sup> order Harmonic Factor between Amorphous and 3% SiFe CRGO

Fig. 15: Comparison of THD between Amorphous and 3% SiFe CRGO

**Summary:**

Harmonic content is an important factor that influence on transformer losses. The 3<sup>rd</sup> order harmonic factor of Amorphous ribbon is lower than 3% SiFe (CRGO) about 9.2% at 0.5T. The 5<sup>th</sup> order harmonic factor of Amorphous material is lower than 3% SiFe (CRGO) about 18.3% at 0.5T. The THD of Amorphous material is lower than 3% SiFe (CRGO) about 6% at 0.5T. It does mean the harmonic effect caused by different induced current and different ingredient material.

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