Influence of changing the distance between the conductors on the total magnetic field of unshielded three-phase flat high current busduct

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Abstract **This paper shows how the shift of the axes of conductors influences on the total magnetic field of the unshielded three phase flat high current busduct. This phenomenon has been described with the formulas relevant to the relative values of the field and the parameters allowing the frequency, conductivity, and the cross-section dimensions of conductors. Into account was taken skin and proximity effects.**

Keywords **Magnetic field, tubular conductor, high current busduct.**

I. Introduction

Designing of high-current busducts for higher and higher currents and voltages generates the need of the comprehensive and precise description of electromagnetic phenomena, first of all the values of the magnetic field [1,2].

Flat high-current busducts about tubular conductors are installed among others as unshielded in extra high voltage and high voltage switching stations [3]. View of such high-current busduct is shown in figure 1.

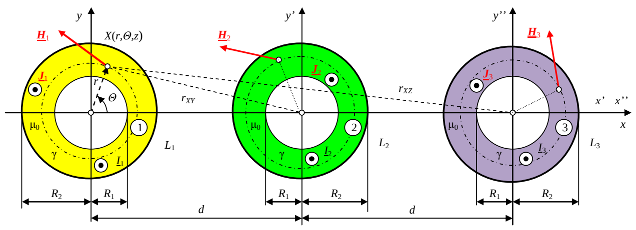

Fig. 1. Unscreened three-phase flat tubular high current busduct

Assume a symmetrical three phase currents, ie. $\underline{I}_2 = \exp[-\mathrm{j}\frac{2}{3}\pi]\,\underline{I}_1$ and $\underline{I}_3 = \exp[\mathrm{j}\frac{2}{3}\pi]\,\underline{I}_1$.

In this paper the whole total magnetic field in the different area conductors of the three-phase flat unscreened high-current busduct versus the change of the distance between the conductors axes is shown.

II. Magnetic field in the external area of conductors

The total magnetic field outside of the first conductor [4]

$$\begin{aligned}\underline{\boldsymbol{H}}_1^{ext}(r,\Theta) &= \underline{\boldsymbol{H}}_{11}^{ext}(r) + \underline{\boldsymbol{H}}_{12}^{ext}(r,\Theta) + \underline{\boldsymbol{H}}_{13}^{ext}(r,\Theta) = \\ &= \mathbf{1}_r\,\underline{H}_{1r}^{ext}(r,\Theta) + \mathbf{1}_\Theta\,\underline{H}_{1\Theta}^{ext}(r,\Theta)\end{aligned} \tag{1}$$

Magnetic field generated by current $\underline{I}_1$

$$\underline{\boldsymbol{H}}_{11}^{ext}(r) = \mathbf{1}_\Theta\,\underline{H}_{11\Theta}^{ext}(r) \tag{2}$$

where
$$\underline{H}_{11\Theta}^{ext}(r) = \frac{\underline{I}_1}{2\pi r} \tag{2a}$$

Magnetic field induced by current $\underline{I}_2$

$$\underline{\boldsymbol{H}}_{12}^{ext}(r,\Theta) = \mathbf{1}_r\,\underline{H}_{12r}^{ext}(r,\Theta) + \mathbf{1}_\Theta\,\underline{H}_{12\Theta}^{ext}(r,\Theta) \tag{3}$$

whose components are as follows

$$\underline{H}_{12r}^{ext}(r,\Theta) = -\frac{\underline{I}_2}{2\pi r}\times \\ \times\sum_{n=1}^{\infty}\left[\left(\frac{r}{d}\right)^n - \frac{1}{\underline{\Gamma}_1 R_1}\left(\frac{R_2}{r}\right)^n\left(\frac{R_2}{d}\right)^n\frac{\underline{s}_{cn}}{\underline{d}_{cn}}\right]\sin n\Theta \tag{3a}$$

and

$$\underline{H}_{12\Theta}^{ext}(r,\Theta) = -\frac{\underline{I}_2}{2\pi r}\times \\ \times\sum_{n=1}^{\infty}\left[\left(\frac{r}{d}\right)^n + \frac{1}{\underline{\Gamma}_1 R_1}\left(\frac{R_2}{r}\right)^n\left(\frac{R_2}{d}\right)^n\frac{\underline{s}_{cn}}{\underline{d}_{cn}}\right]\cos n\Theta \tag{3b}$$

Magnetic field generated by current $\underline{I}_3$

$$\underline{\boldsymbol{H}}_{13}^{ext}(r,\Theta) = \mathbf{1}_r\,\underline{H}_{13r}^{ext}(r,\Theta) + \mathbf{1}_\Theta\,\underline{H}_{13\Theta}^{ext}(r,\Theta) \tag{4}$$

whose components

$$\underline{H}_{13r}^{ext}(r,\Theta) = -\frac{\underline{I}_3}{2\pi r}\times \\ \times\sum_{n=1}^{\infty}\left[\left(\frac{r}{2d}\right)^n - \frac{1}{\underline{\Gamma}_1 R_1}\left(\frac{R_2}{r}\right)^n\left(\frac{R_2}{2d}\right)^n\frac{\underline{s}_{cn}}{\underline{d}_{cn}}\right]\sin n\Theta \tag{4a}$$

and

$$\underline{H}_{13\Theta}^{ext}(r,\Theta) = -\frac{\underline{I}_3}{2\pi r}\times \\ \times\sum_{n=1}^{\infty}\left[\left(\frac{r}{2d}\right)^n + \frac{1}{\underline{\Gamma}_1 R_1}\left(\frac{R_2}{r}\right)^n\left(\frac{R_2}{2d}\right)^n\frac{\underline{s}_{cn}}{\underline{d}_{cn}}\right]\cos n\Theta \tag{4b}$$

where

$\underline{d}_{cn} = I_{n-1}(\underline{\Gamma}R_2)\,K_{n+1}(\underline{\Gamma}R_1) - I_{n+1}(\underline{\Gamma}R_1)\,K_{n-1}(\underline{\Gamma}R_2)$ and

$$\begin{aligned}\underline{s}_{cn} &= -n\,\beta_c\,K_n(\underline{\Gamma}R_2)\left[I_{n-1}(\underline{\Gamma}R_1) + I_{n+1}(\underline{\Gamma}R_1)\right] + \\ &+ n\left\{\begin{matrix}2\,I_{n+1}(\underline{\Gamma}R_2)\,K_n(\underline{\Gamma}R_1) + I_n(\underline{\Gamma}R_1)\times \\ \times\left[K_{n-1}(\underline{\Gamma}R_2) + K_{n+1}(\underline{\Gamma}R_2)\right]\end{matrix}\right\} + \\ &+ \underline{\Gamma}\,R_1\left[\begin{matrix}I_{n+1}(\underline{\Gamma}R_2)\,K_{n-1}(\underline{\Gamma}R_1) - \\ -I_{n-1}(\underline{\Gamma}R_1)\,K_{n-1}(\underline{\Gamma}R_2)\end{matrix}\right]\end{aligned}$$

In the above formulas $I_n(\underline{\Gamma}R_1)$, $K_n(\underline{\Gamma}R_2)$, $I_{n-1}(\underline{\Gamma}R_1)$, $K_{n-1}(\underline{\Gamma}R_2)$, $I_{n+1}(\underline{\Gamma}R_1)$, $K_{n+1}(\underline{\Gamma}R_2)$ are modified Bessel functions of the first and second kind, respectively, of n-th, n-1 and n+1 order. Complex propagation constant of electromagnetic wave in linear conducting media $\underline{\Gamma} = \sqrt{\mathrm{j}\omega\mu_0\gamma} = \sqrt{2\mathrm{j}}\,k$, in which the attenuation constant $k = \sqrt{\dfrac{\omega\mu_0\gamma}{2}} = \dfrac{1}{\delta}$, where δ is the electrical skin depth of the electromagnetic wave in the conducting media [5], ω is an angular frequency, γ means electrical conductivity of the conductor, and permeability of the vacuum $\mu_0 = 4\pi \cdot 10^{-7}$ H·m^{-1}.

If we introduce a relative distance between the conductors [6]

$$\lambda_c = \frac{d}{R_2} \geq 1 \tag{5}$$

relative variable

$$\zeta = \frac{r}{R_2} \tag{6}$$

and parameter

$$\beta_c = \frac{R_1}{R_2} \quad \text{where} \quad (0 \leq \beta_c \leq 1) \tag{7}$$

and above components respect to this field $\underline{H}_0 = \dfrac{\underline{I}_1}{2\,\pi\,R_2}$, it the formulas for the relative components in the external area (for $r \geq R_2$, ie. for $\zeta \geq 1$) first conductor

$$\underline{h}_{1r}^{ext}(\zeta,\Theta) = -\frac{1}{\zeta}\sum_{n=1}^{\infty}\underline{A}_n \left[\begin{array}{l} \left(\dfrac{\zeta}{\lambda_c}\right)^n - \dfrac{1}{\sqrt{2\mathrm{j}}\,\alpha_c\beta_c\,\zeta} \\ \times\left(\dfrac{1}{\zeta}\right)^n\left(\dfrac{1}{\lambda_c}\right)^n \dfrac{\underline{s}_{cn}}{\underline{d}_{cn}} \end{array}\right] \sin n\Theta \tag{8}$$

and

$$\underline{h}_{1\Theta}^{ext}(\zeta,\Theta) =$$

$$= \frac{1}{\zeta} - \frac{1}{\zeta}\sum_{n=1}^{\infty}\underline{A}_n \left[\begin{array}{l} \left(\dfrac{\zeta}{\lambda_c}\right)^n + \dfrac{1}{\sqrt{2\mathrm{j}}\,\alpha_c\beta_c\,\zeta}\left(\dfrac{1}{\zeta}\right)^n \\ \times\left(\dfrac{1}{\lambda_c}\right)^n \dfrac{\underline{s}_{cn}}{\underline{d}_{cn}} \end{array}\right] \cos n\Theta \tag{9}$$

where the complex quantity

$$\underline{A}_n = A_n \exp[\mathrm{j}\,\varphi_n] \tag{10}$$

whose modulus

$$A_n = \sqrt{1 - 2^{-n} + 4^{-n}} \tag{10a}$$

and argument

$$\varphi_n = -\pi + \operatorname{arctg}\frac{\sqrt{3}\left(1 - 2^{-n}\right)}{1 + 2^{-n}} \tag{10b}$$

III. Influence distance between the conductors on the magnetic field in the external area

The distribution of the relative module values of the total magnetic field outside phase conductor L_1 flat high current busduct for various λ parameter values in the function of the Θ angle is shown in figure 2a. In a similar way determinated the total magnetic field outside phase conductor L_1 and L_2 (respectively figures 2b and 2c).

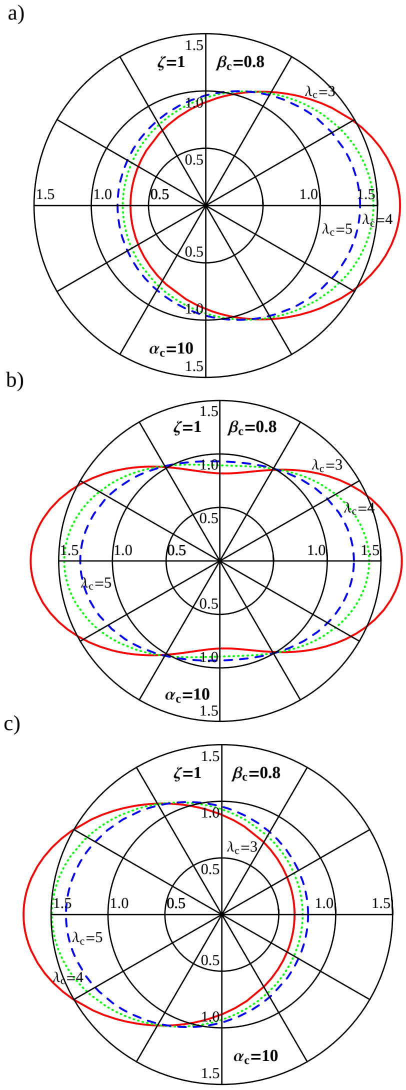

Fig. 2. The distribution of the relative module values of the total magnetic field flat high-current busduct in the external area of the phase conductor: a) L_1, b) L_2, c) L_3

IV. Conclusion

In the case of unshielded three-phase about tubular conductor flat high current busduct, distribution of magnetic field in the external area of the conductors is irregular (fig. 2), caused by the skin effect, and first of all by the proximity effect. Therefore, the mutual geometric configuration between the conductor strongly affects the total magnetic field in high-current busduct of this type.

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