Influence of the screen thickness on the total magnetic field of a double-pole bifilar high-current busduct

Dariusz Kusiak, Zygmunt Piątek, Tomasz Szczegielniak
Czestochowa University of Technology
42-200 Częstochowa, ul. Brzeźnicka 60a, e-mail:
dariuszkusiak@wp.pl, zygmunt.piatek@interia.pl, szczegielniakt@interia.pl

In the paper shown the impact of the screen thickness on the total magnetic field of a double-pole bifilar line in the screen and its immediate vicinity. The resultant magnetic field in the high-current busduct of this type has two components of different amplitudes and initial phases. As a consequence this field is elliptical. 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 screen. Into account was taken skin, internal and external proximity effects. These phenomena have a strong impact on the magnetic field in the environment of two-conductor shielded high-current busduct and should be taken into consideration also for the industrial frequency of phase currents.

KEYWORDS: tubular screen, high-current busduct, magnetic field, tubular conductor

1. Introduction

A system of two conductors in a common conductive shield (figure 1) is used as a screened bifilar transmission line [1].

In technological processes the vital value is the maximum value of magnetic field strength. The values emitted by such busducts are high even under the rated conditions [2]. For an elliptical field this value shall be adopted as the length of the longer $H_a(r,\Theta)$ semi-axis of the ellipse [3, 4]:

$$H_a(r,\Theta) = \max_{t\in(0,T)} H(r,\Theta,t) = H_1(r,\Theta) + H_2(r,\Theta) \tag{1}$$

Exceeding certain permissible values by these fields may lead to an incorrect functioning of electrical devices, excessive warming up of steel structures, degradation of the natural environment, and also may create a hazard for humans [2, 5].

In this article the image of the total magnetic field in the both external and internal area and in the screen of the two-pole bifilar high-current busduct is presented, when the thickness of the screen wall of the conductivity γ_2, internal R_3 and external R_4 radius is being changed (Fig. 1).

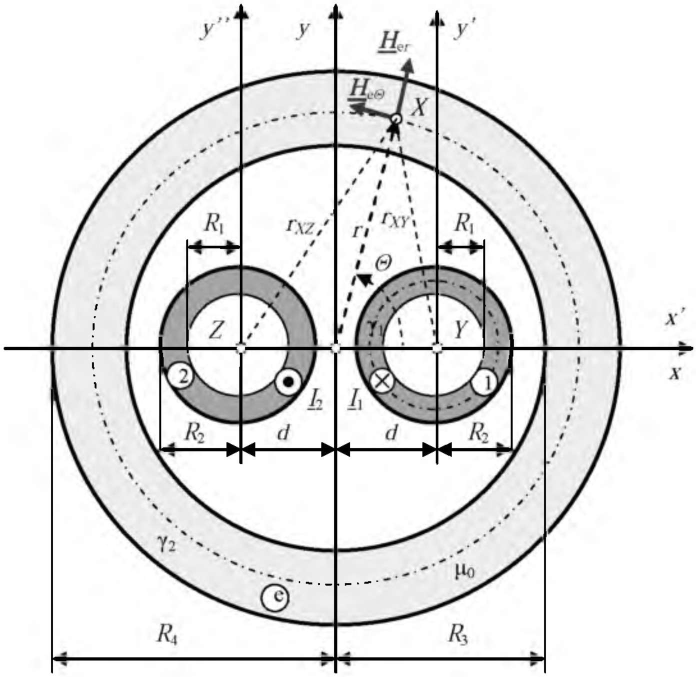

Fig. 1. Double-pole shielded high-current busduct with current $I_2 = -I_1 = -I$

2. Total magnetic field in the external area of the screen

For a screened bifilar line ($I_2 = -I_1 = -I$) with an insulated shield the magnetic field in the external area of the screen is determined by the formula [6]

$$\underline{H}^{ext}(r,\Theta) = \underline{H}_1^{ext}(r,\Theta) + \underline{H}_2^{ext}(r,\Theta) \tag{2}$$

If we introduce a relative the screen thickness

$$\beta = \frac{R_3}{R_4} \quad \text{where} \quad (0 \le \beta \le 1) \tag{3}$$

relative variable $\xi = \dfrac{r}{R_4}$ and parameter $\lambda = \dfrac{d}{R_3}$, then the formulas for the relative components of the magnetic field $\underline{H}_1^{ext}(r,\Theta)$ in the external area of the screen ($r \ge R_4$) of the double-pole shielded high current busduct are as follows [7]:

$$\underline{h}_{1r}^{ext}(\xi,\Theta) = -\sum_{n=1}^{\infty} \frac{1}{\beta} \frac{\underline{s}_n}{\underline{d}_n} \frac{\lambda^n}{\xi^{n+1}} \sin n\Theta \tag{4}$$

and

$$\underline{h}_{1\Theta}^{ext}(\xi,\Theta)=\frac{1}{\xi}+\sum_{n=1}^{\infty}\frac{1}{\beta}\frac{\underline{s}_n}{\underline{d}_n}\frac{\lambda^n}{\xi^{n+1}}\cos n\Theta \tag{5}$$

and relative components of the magnetic field $\underline{\boldsymbol{H}}_2^{ext}(r,\Theta)$ are as follows

$$\underline{h}_{2r}^{ext}(\xi,\Theta)=\sum_{n=0}^{\infty}(-1)^n\frac{1}{\beta}\frac{\underline{s}_n}{\underline{d}_n}\frac{\lambda^n}{\xi^{n+1}}\sin n\Theta \tag{6}$$

and

$$\underline{h}_{2\Theta}^{ext}(\xi,\Theta)=-\frac{1}{\xi}-\sum_{n=1}^{\infty}(-1)^n\frac{1}{\beta}\frac{\underline{s}_n}{\underline{d}_n}\frac{\lambda^n}{\xi^{n+1}}\cos n\Theta \tag{7}$$

where

$$\underline{s}_n=I_{n-1}(\sqrt{2\mathrm{j}}\alpha)\,K_{n+1}(\sqrt{2\mathrm{j}}\alpha)-I_{n+1}(\sqrt{2\mathrm{j}}\alpha\beta)\,K_{n-1}(\sqrt{2\mathrm{j}}\alpha) \tag{8}$$

and

$$\underline{d}_n=I_{n-1}(\sqrt{2\mathrm{j}}\alpha)\,K_{n+1}(\sqrt{2\mathrm{j}}\alpha\beta)-I_{n+1}(\sqrt{2\mathrm{j}}\alpha\beta)\,K_{n-1}(\sqrt{2\mathrm{j}}\alpha) \tag{9}$$

In the above formulas $I_{n-1}(\sqrt{2\mathrm{j}}\alpha)$, $K_{n-1}(\sqrt{2\mathrm{j}}\alpha)$, $I_{n+1}(\sqrt{2\mathrm{j}}\alpha\beta)$, $K_{n+1}(\sqrt{2\mathrm{j}}\alpha\beta)$ are the modified Bessel's functions of the firsts and second kind respectively, of n-1 and n+1 order, and $\alpha=kR_4$ for $k=\sqrt{\frac{\omega\mu\gamma}{2}}=\frac{1}{\delta}$ [8].

3. Impact of changing the screen thickness on the magnetic field in the external screen area

The distribution of these components magnetic field for various parameter β values is show in Figure 2, 3, 4 and 5.

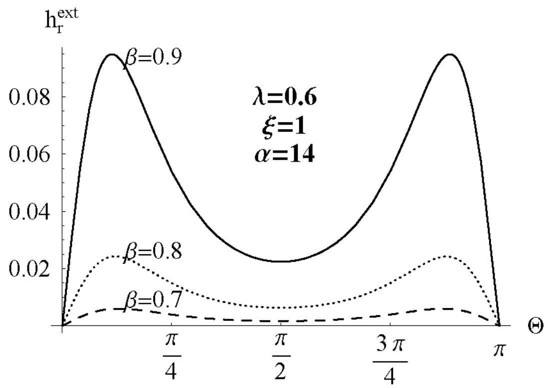

Fig. 2. Distribution of the relative radial component values of modulus of the total magnetic field in the external area of the screen of the double-pole bifilar high-current busduct

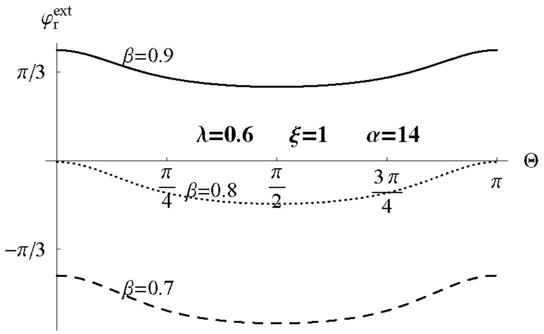

Fig. 3. Distribution of the relative radial component values of argument of the total magnetic field in the external area of the screen of the double-pole bifilar high-current busduct

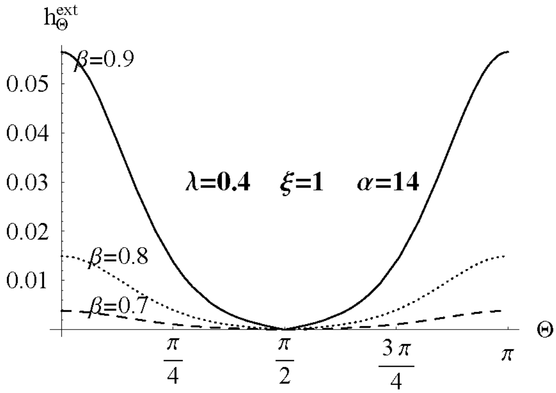

Fig. 4. Distribution of the relative tangent component values of modulus of the total magnetic field in the external area of the screen of the double-pole bifilar high-current busduct

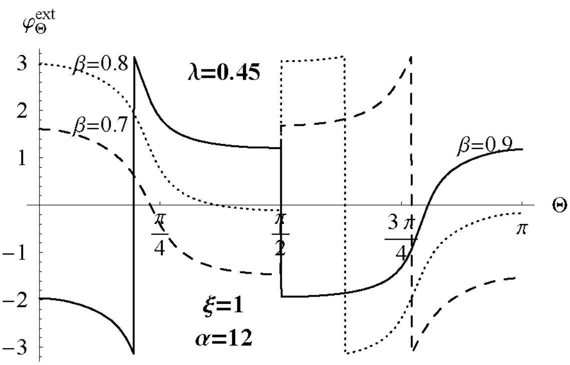

Fig. 5. Distribution of the relative tangent component values of armument of the total magnetic field in the external area of the screen of the double-pole bifilar high-current busduct

The distribution of the relative module values of the total magnetic field in the external area of the screen of the double-pole bifilar high current busduct for various β parameter values in the function of the Θ angle is shown in Figure 6.

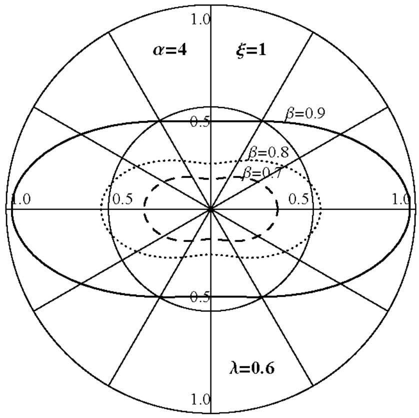

Fig. 6. Distribution of the relative value of modulus of the total magnetic field in the external area of the screen for various β parameter values

4. Impact of changing the screen thickness on the magnetic field in the screen

The total magnetic field in the screen of the double-pole bifilar line is defined by formula [9]

$$\underline{H}_e(r,\Theta) = \underline{H}_{e1}(r,\Theta) + \underline{H}_{e2}(r,\Theta) \tag{10}$$

The distribution of these components magnetic field for various parameter β values is show in Figure 7, 8, 9 and 10.

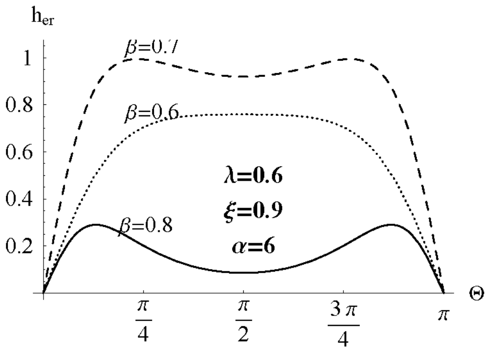

Fig. 7. Distribution of the relative radial component values of modulus of the total magnetic field in the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

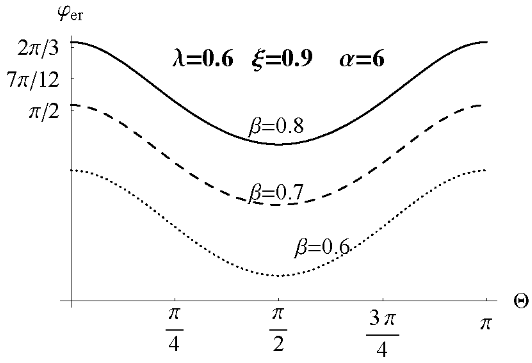

Fig. 8. Distribution of the relative radial component values of argument of the total magnetic field in the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

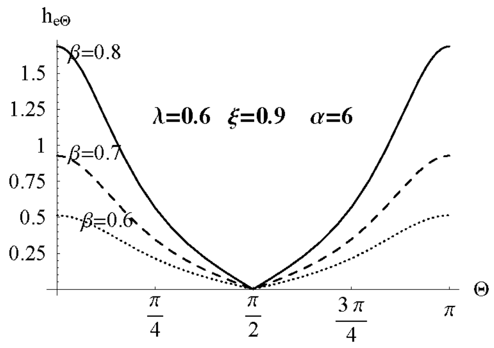

Fig. 9. Distribution of the relative tangent component values of modulus of the total magnetic field in the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

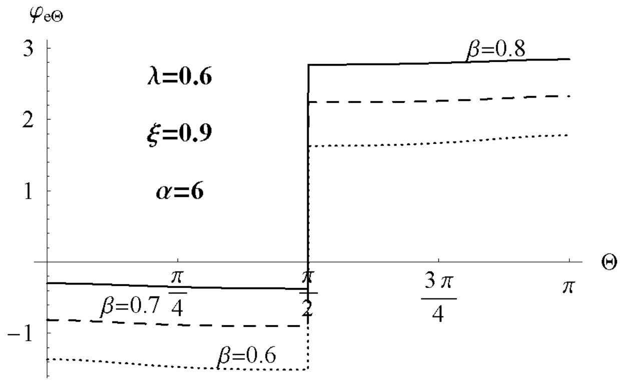

Fig. 10. Distribution of the relative tangent component values of argument of the total magnetic field in the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

The distribution of the relative module values of the total magnetic field in the screen of the double-pole bifilar high current busduct for various β parameter values in the function of the Θ angle is shown in Figure 11.

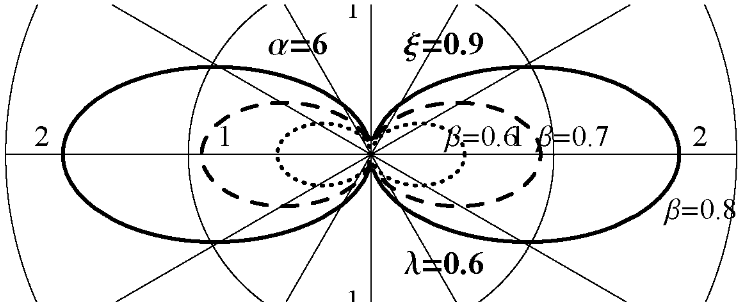

Fig. 11. Distribution of the relative value of modulus of the total magnetic field in the screen for various β parameter values

5. Impact of changing the screen thickness on the magnetic field in the internal screen area

For a screened bifilar line ($I_2 = -I_1 = -I$) with an insulated shield the magnetic field in the internal area of the screen is determined by the formula [10, 11]

$$\underline{H}^{\text{int}}(r,\Theta) = \underline{H}_1^{\text{int}}(r,\Theta) + \underline{H}_2^{\text{int}}(r,\Theta) \tag{11}$$

The distribution of these components magnetic field for various parameter β values is show in Figure 12, 13, 14 and 15.

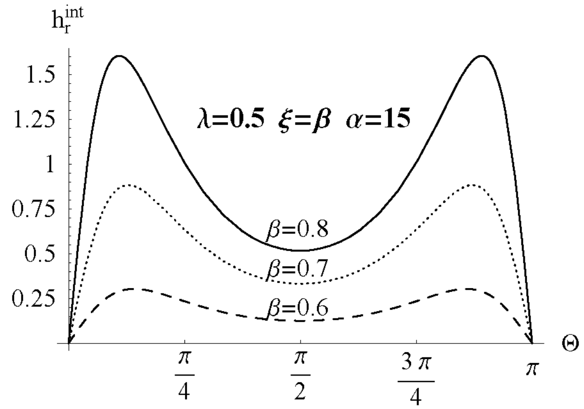

Fig. 12. Distribution of the relative radial component values of modulus of the total magnetic field in the internal area of the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

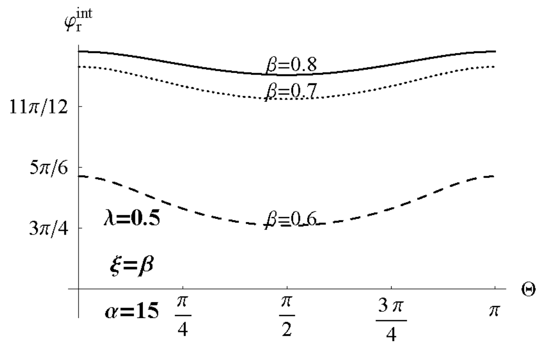

Fig. 13. Distribution of the relative radial component values of argument of the total magnetic field in the internal area of the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

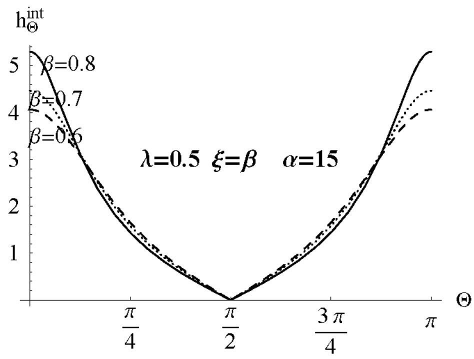

Fig. 14. Distribution of the relative tangent component values of modulus of the total magnetic field in the internal area of the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

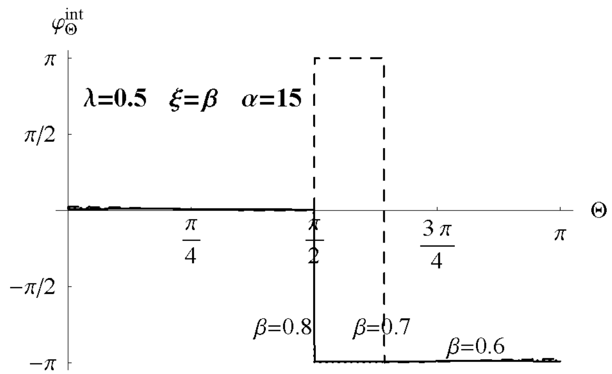

Fig. 15. Distribution of the relative tangent component values of argument of the total magnetic field in the internal area of the screen of the double-pole bifilar line ($I_2 = -I_1 = -I$) for variable β parameter

The distribution of the relative module values of the total magnetic field in the internal area of the screen of the double-pole bifilar high current busduct for various β parameter values in the function of the Θ angle is shown in Figure 16.

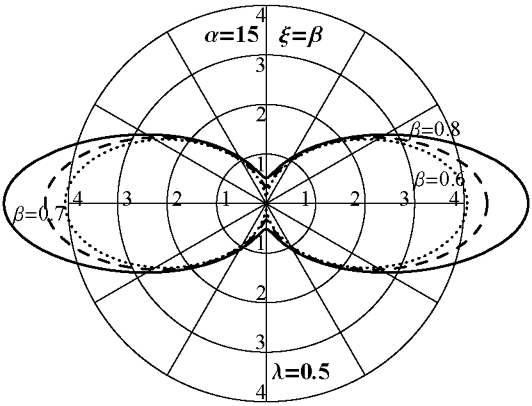

Fig. 16. Distribution of the relative value of modulus of the total magnetic field in the internal area of the screen for various β parameter values

6. Conclusions

Introduction of relative variable β and parameters α, ξ and λ for the screen allows to show derived formulas as complex components and modules of magnetic field strength of the double-pole bifilar high-current busduct in general forms, independent of the specific values of conductivity, transverse dimensions and relative positions of the conductors and shield, and the frequency of phase currents. This also allows for a general analysis and visualisation of the modules and the arguments of this field in the form of plots as the functions of relative variables of the angle Θ or the parameters mentioned above for the set values of the variable or the set values of applicable parameters (Figures 2-5, 7-10 and 12-15).

The obtained solutions are expressed in the form of series with modified Bessel functions and they take into account the skin effect as well as the internal and external proximity phenomena. They are valid in the frequency range allowing to neglect the displacement currents.

For a double-pole bifilar line the distribution of the magnetic field in the screen and in its internal and external area is irregular, and this is caused by the skin effect but first of all by the proximity phenomenon. It is also dependent on the direction sense of the current in conductors.

The presented distributions of the total magnetic field in a double-pole shielded high-current busduct as well as the analysis of the obtained formulas and numerical calculations show that with the increase of the screen wall thickness (lover value of the β parameter) the magnetic field becomes more and more irregular (Fig. 6, 11 and 16). Besides, if the direction senses are opposite we observe a characteristic phenomenon of pulling the magnetic field into the centre of the two-conductor system.

The mutual geometric configuration between the internal R_3 and external R_4 radiuses of the screen strongly affects the total magnetic field in the high-current busducts of this type.

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