Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (16): 3330-3334, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.3330.3334

Improvement of the Best and the Worst Case Method on the Automobile Cable Bundles Dynamic Crosstalk Based on the Statistical Model

[2]Gao Yin-Han, [2]Wang Tian-Hao, [1]Yang Kai-Yu, [2]Zhang Jun-Dong, [2]Song Yu-He and [2]Jia Yan-Mei
[1]Laboratory of Automobile Simulation and Control, Jilin University, 130022, Changchun, Jilin, China
[2]College of Instrumentation and Electrical Engineering, Jilin University, 130061, Changchun, Jilin, China

Abstract: The randomness of automobile cable bundles' position brought by different installation and automobile motion, leading to cable bundles crosstalk has the dynamic range, using statistics principle to obtain the mean and deviation of dynamic cable bundles crosstalk, under the confidence level of 80% obtained the confidence interval of cable bundles dynamic crosstalk. Using this method improved the dynamic crosstalk range of the original best, worst case method. At the same time, comparing the simulation results of 273 times Random Displacement Spline Interpolation (RDSI) and the improved interval, verified the accuracy and reliability of the model. Under the condition of low frequency, the generated results of 273 times RDSI algorithm all fall in to improved the range and improved interval compared with the original interval shrank by 76%, largely improves the prediction precision, at the same time this method is simple, convenient, according to the different precision requirement, it can quickly predict dynamic crosstalk of automobile cable bundles.

Key words: Electromagnetic compatibility, automobile cable bundles, dynamic crosstalk, statistical model

INTRODUCTION

In recent years, more and more electrical and electronics equipment are applied to the vehicles to improve automobile passive safety and the main performance of the rides, etc. But at the same time, it also gives the vehicle a more complex circuit network and the electromagnetic environment. Among them, automobile cable bundles is the main body of vehicle circuit network, connecting to the electrical and electronics parts of vehicles and making it functional, but extensive automobile harness also plays an important role in the vehicle electromagnetic interference. It provides the carrier for the spread of interfering signal. Interfering signal spread along the conductor through the resistive coupling, the inductive coupling, the capacitive coupling, the impedance propagation coupling and makes the sharp decline in the vehicle electromagnetic compatibility performance. Therefore, the harness crosstalk has become the most important conductive interference in the vehicle electromagnetic interference and also become one of the first forecast targets of automobile electromagnetic compatibility design. In the cable bundles, wires in the parasitic parameters and the crosstalk of the wire are related to its geometric location of the cable bundles and influence factors such as the distance between the cable bundles and the ground. But as a result of automobile cable bundles in the process of strapping and fixed is uncertain (Bellan and Pignari, 2000; Fatou and Flavio, 2009) and there are different motions such as vibration, acceleration and deceleration in the process of the vehicle movement and it turns wire distribution into uncertain geometric arrangement. It is a low precision that through the unit length distribution parameters of the wires in the cable bundles limit geometric location calculating value of the best and worst case dynamic crosstalk. This study will use the statistical method to get the mean and the standard deviation of the crosstalk for the improvement of the best and worst case method.

Cable bundles model and unit length distribution parameters: Based on the VW vehicle cable standard of composed of 7 conducting wire harnesses of #18 specifications. In the cable bundles, conductor material is copper, insulating layer is PVC (polyvinyl chloride) that the relative dielectric constant is $\varepsilon_r = 3.0$, the conducting wire radius is R = 1 mm, the conductor radius r = 0.5 mm, insulation thickness is $\Delta r = 0.5$ mm, the length of wire is L = 2 m (electrically small), its structure is shown in Fig. 1. The wire 1 is generator line, the wire 2 is receptor line. The excitation voltage of generator wire Vs = 1V, the source impedance and the terminal impedance are divided into two cases which are the high impedance and low impedance, respectively, $Rs = R_L = R_{NE} = R_{FE} = 50\ \Omega$ and $Rs = R_L = R_{NE} = R_{FE} = 1\ k\Omega$. Because the wire conductor is the electrically small and the weak coupling, the crosstalk

Corresponding Author: Yang Kai-Yu, Laboratory of Automobile Simulation and Control, Jilin University, Changchun, Jilin, China
Tel: 0431-85095522

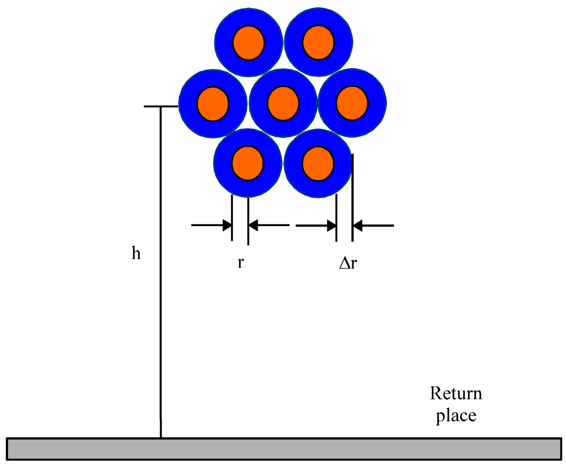

Fig. 1: 2D cross section of cable bundle

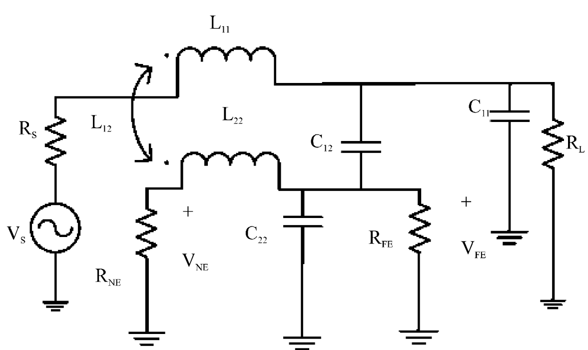

Fig. 2: Three conductor transmission line crosstalk equivalent circuit model

equivalent circuit model of three conductor transmission lines can be used to show in Fig. 2, the terminal impedance of other wires are all 50 Ω. Assuming that weak coupling and lossless, the main distribution parameter that induce wires produce crosstalk is per unit length mutual inductance and mutual capacitance, the per unit length mutual inductance can be expressed as:

$$L_{12} = \frac{\mu_0}{4\pi}\ln\left(1+4\frac{h_G h_R}{S^2}\right) \tag{1}$$

Due to the existence of the insulating layer, surrounding the conductor, the medium is inhomogeneous; the derived per unit length mutual capacitance is false. In this study, by using the theory of image method, derived and obtained parasitic per unit length capacitance matrix, such as:

$$C=\begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix}=\begin{bmatrix} c_{11}+c_{12} & -c_{12} \\ -c_{21} & c_{22}+c_{12} \end{bmatrix}=S^{-1}=$$

$$\begin{bmatrix} \frac{1}{2\pi\varepsilon_0}\left(\frac{1}{\varepsilon_r}\ln\frac{1}{r}+\varepsilon_e\ln\frac{1}{r+\Delta r}-\ln\frac{1}{2h_1}\right) & \frac{1}{4\pi\varepsilon_0}\ln\left(1+\frac{4h_1h_2}{S^2}\right) \\ \frac{1}{4\pi\varepsilon_0}\ln\left(1+\frac{4h_1h_2}{S^2}\right) & \frac{1}{2\pi\varepsilon_0}\left(\frac{1}{\varepsilon_r}\ln\frac{1}{r}+\varepsilon_e\ln\frac{1}{r+\Delta r}-\ln\frac{1}{2h_2}\right) \end{bmatrix}^{-1} \tag{2}$$

In Eq. 1, 2 r is the conductor radius, Δr is the wire insulation layer thickness, h_1,h_2 respectively presents the distance generator wire and the receptor wire between the ground, S is the distance between the generator wire and the receptor wire, effective dielectric constant $\varepsilon_e = \varepsilon_r\text{-}1/\varepsilon_r$, per unit length mutual capacitance $c_m = c_{12} = c_{21}$, can be calculated in the Eq. 2:

STATISTICAL MODEL OF CABLE BUNDLES DYNAMIC CROSSTALK STATISTICAL MODEL

When the distance between cable bundles center and the ground and the relative position inside cable bundles wires change at the same time, assuming that the probability density function of height variable of cable bundles over the ground conform to a Gaussian distribution (Li *et al*., 2010; Capraro and Paul, 1981), the variable of the distance between wire and the ground is shown in Fig. 3, it is a diagram of randomly generated in line with the Gaussian distribution of probability density.

Because the probability density function of the distance between wire and ground can be determined, So according to the near end crosstalk expression:

$$N_{EXT}=\left|\frac{V_{NE}}{V_S}\right|=\omega\left(M_{NE}^{IND}+M_{NE}^{CAP}\right)= \omega\frac{R_{NE}}{R_{NE}+R_{FE}}\frac{1}{R_S+R_L}1\left(L_{mn}+R_{FE}R_LC_{mn}\right) \tag{3}$$

we can deduce under different ground height of cable bundles crosstalk statistical properties. M^{IND}_{NE} and M^{CAP}_{NE}, respectively are sensibility coupling and capacitive coupling of automobile harness near-end of crosstalk, L_{mn} and C_{mn} are the per unit length mutual inductance and mutual capacitance value between generator wire and receptor wire in the cable bundles. Corresponding to different distance between cable bundles and ground height, the mean and standard deviation of cable bundles near end crosstalk can be expressed respectively as (Bellan and Pignari, 2005):

$$\mu_{NEXT}=\omega\frac{R_{NE}}{R_{NE}+R_{FE}}\frac{1}{R_s+R_L}\left(\mu_{l_{mk}}+R_{FE}R_L\mu_{c_{mk}}\right)1 \tag{4}$$

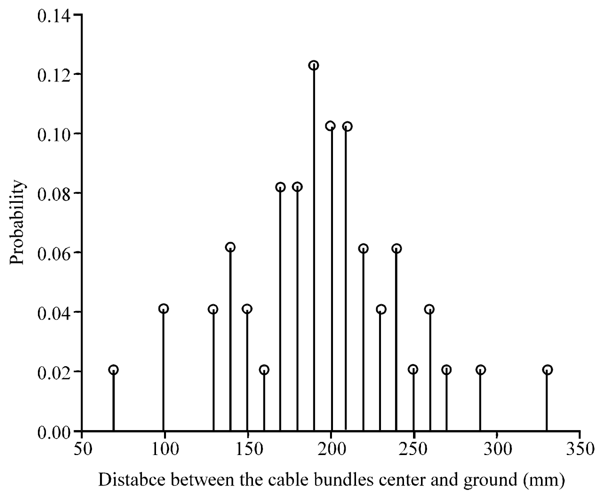

Fig. 3: Probability distribution of the distance between cable bundles and the ground

$$\sigma_{NEXT}^2 = \omega \frac{R_{NE}}{R_{NE}+R_{FE}} \frac{1}{R_S+R_L} \frac{\sigma_{l_{mk}}^2 + R_{FE}^2 R_L^2 \sigma_{c_{mk}}^2 + 2R_{FE} R_L \sigma_{l_{mk}} \sigma_{c_{mk}} \rho_{l_{mk}c_{mk}}}{N_s} 1 \quad (5)$$

μ_{lmk} and μ_{cmk} are the mean of the mutual capacitance and mutual inductance of cable bundles unit distribution parameters, σ_{lmk} and σ_{cmk} are the standard deviation of the mutual capacitance and mutual inductance of cable bundles unit distribution parameters, ρ_{lmkcmk} is the correlation coefficient between l_{mk} and C_{mk}, is the segmentation of cable bundles. Using Eq. 4 and 5, combining with the variable of cable bundles to highly probability distribution. Meanwhile considering two variables that height of automobile cable bundles and the relative position of wires, the mean expression of near end crosstalk between conductors is:

$$\mu_c = E\{C\} = \int \mu_{c/x} P(x)dx \quad (6)$$

$\mu_{c/x}$ is the mean of cable bundles crosstalk in a certain height, can be determined by Eq. 4. And considering the two variables change at the same time, the crosstalk of value expressions for the variance is:

$$\sigma_c^2 = E\left\{(C-\mu_c)^2\right\} = E\left\{C^2\right\} - \mu_c^2 \quad (7)$$

$$E\left\{C^2\right\} = \int E\left\{C^2/x\right\} P(x)dx \quad (8)$$

the variance of a fixed distance between cable bundles center and the ground can be expressed as:

$$\sigma_{c/x}^2 = E\left\{C^2/x\right\} - \mu_{c/x}^2 \quad (9)$$

So:

$$E\left\{C^2/x\right\} = \sigma_{c/x}^2 + \mu_{c/x}^2 \quad (10)$$

Put Eq. 10 into 8 and deduce:

$$E\left\{C^2\right\} = \int \left(\sigma_{c/x}^2 + \mu_{c/x}^2\right) P(x)dx \quad (11)$$

Therefore, Eq. 7 can be written:

$$\sigma_c^2 = \int \left(\sigma_{c/x}^2 + \mu_{c/x}^2\right) P(x)dx - \mu_c^2 \quad (12)$$

So, considering two variables that the distance between cable bundles center and the ground and wire harness to the relative position wire near end crosstalk statistical parameter, can be obtained from (6), (12).

BEST AND WORST CASE METHOD AND ITS IMPROVED METHOD OF AUTOMOBILE CABLE BUNDLES DYNAMIC CROSSTALK

The random distribution of wires in the cable bundles, can be in any position, but as long as get random distribution range of the wires, can estimate dynamic change of the crosstalk coupling through the maximum and minimum value of the unit length mutual inductance and mutual capacitance the of conductor A and B in the cable bundles limit geometry (Fig. 3). The worst cases of the crosstalk (Wu *et al*., 2009), two wire located in the highest position, equal height, the distance between the wires is equal to the sum of the radius of the two wires, $h_A = h_B = h_{max}$, $S = r_A+r_B$. The best cases of the crosstalk, two wire located in the lowest position, equal height, the distance between the wires is The distance between the wires is equal to the diameter of the cable bundles subtract the sum of the radius of the two wires, $h_A = h_B = h_{max}$, $S = r_A+r_B$. The equation of worst situation near-end crosstalk is:

$$NEXT_{worst} = j\omega\left(\frac{R_{NE}}{R_{NE}+R_{FE}} \frac{lL_{mworst}}{R_S+R_L} + \frac{R_{NE}R_{FE}}{R_{NE}+R_{FE}} \frac{lC_{mworst}R_L}{R_S+R_L}\right) \quad (13)$$

The best situation formula of near-end crosstalk is:

$$NEXT_{best} = j\omega\left(\frac{R_{NE}}{R_{NE}+R_{FE}} \frac{lL_{mbest}}{R_S+R_L} + \frac{R_{NE}R_{FE}}{R_{NE}+R_{FE}} \frac{lC_{mbest}R_L}{R_S+R_L}\right) \quad (14)$$

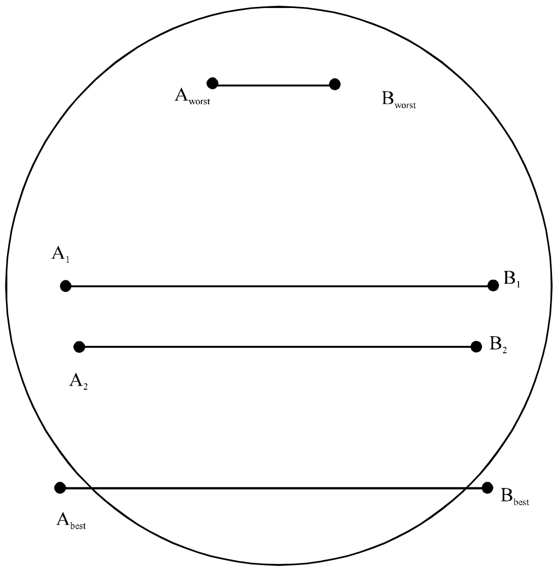

Fig. 4: Limit geometric location of conductor in the cable bundles

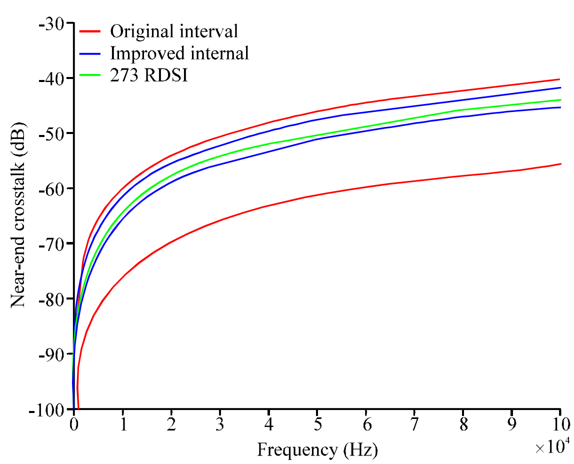

Fig. 5: Comparison between the improved version dynamic crosstalk of best and worst interval

The unit distributed parameter of four limit position in (13) and (14) can be computed by the (15-18):

$$L_{mworst}=\frac{\mu_0}{4\pi}\ln\left[1+4\left(\frac{H+R-r}{S}\right)^2\right] \quad (15)$$

$$C_{mworst}=\frac{\pi\varepsilon_0\ln\left[1+4\left(\frac{H+R-r}{S}\right)^2\right]}{\left\{\frac{1}{\varepsilon_r}\ln\frac{1}{r_a}+\varepsilon_e\ln\frac{1}{r}-\ln\left[\frac{1}{2(H+R-r)}\right]\right\}^2-\frac{1}{4}\ln^2\left[1+4\left(\frac{H+R-r}{S}\right)^2\right]} \quad (16)$$

$$L_{mbest}=\frac{\mu_0}{4\pi}\ln\left[1+\left(\frac{H-R+r}{R-r}\right)^2\right] \quad (17)$$

$$C_{mbest}=\frac{\pi\varepsilon_0\ln\left[1+\left(\frac{H-R+r}{R-r}\right)^2\right]}{\left\{\frac{1}{\varepsilon_r}\ln\frac{1}{r_a}+\varepsilon_e\ln\frac{1}{r}-\ln\left[\frac{1}{2(H-R+r)}\right]\right\}^2-\frac{1}{4}\ln^2\left[1+\left(\frac{H-R+r}{R-r}\right)^2\right]} \quad (18)$$

R is the wire radius, H is the distance between the cable bundles center and ground, R is cable bundles radius, r_a is conductor radius, S is the distance between conductor A and B, ε_e, ε_r is respectively the effective dielectric constant and relative dielectric constant. The best and worst case of dynamic cable bundles crosstalk can be calculated by (13-18), By (6) and (12), in order to ensure rationality of the forecast of the best and worst dynamic crosstalk case, the confidence level selected is 80%. Eighty percent of the cable bundle dynamic crosstalk value is in range between μ_c-1.25 σ_c and μ_c-1.25 σ_c, that is improved version of the best and worst case, which can narrow the prediction interval range. Use the model of cable bundles based in Fig. 4. The mean of the distance between cable bundles and the land is 400 mm, the standard deviation is 300 mm, obtained the original and improved interval of he dynamic near end crosstalk of the cable bundles, as shown in Fig. 5.

CONCLUSION

When the vehicle move, the distance of the wires within the cable bundles and the distance between the cable bundle and the ground is always changing, putting forward the improved model based on the statistical model of cables bundles dynamic crosstalk and coupling the best and worst case of prediction model. Under the condition of low frequency, we can observe numerical simulation results of 273 Random Displacement Spline Interpolation (RDSI) were on the improved dynamic crosstalk range of the best and worst case through Fig. 5 (Salio *et al*., 1999, 2000; Sun *et al*., 2007), verified accuracy and reliability of the proposed algorithm. At the same time, the original dynamic crosstalk interval of the best and worst case is 15.0 dB, the range of he improved interval is 3.7 dB, the interval of the improved model reduced 76%. Thus, the improved model is simple and convenient and it can greatly improves the precision, quickly predicts the variation of crosstalk of wiring, provide the basis for vehicle electromagnetic compatibility design, has very important practical significance.

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